Factors Affecting the Use of Precast Concrete Systems in the United States

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Abstract: The use of precast concrete systems offers several advantages such as speedy erection, higher quality, lower project cost, better sustainability, and enhanced occupational health and safety. In spite of these advantages, the share of precast concrete systems in the U.S. building construction market is very low. The factors behind this low market share are discussed in several studies. This study aims to identify the current factors that affect the use of precast concrete systems, compare them with the ones that prevailed in 1995, and figure out what has changed through the last 11 years in the American precast concrete industry. The findings of an extensive survey indicate that most of the dominating barriers to the extensive use of precast concrete systems in 1995 are either eliminated or drastically reduced, while some of them still prevail. Practitioners should be well informed about the factors that affect the use of precast concrete systems if these systems are to be used more extensively.

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Introduction

Precast concrete technology is recognized worldwide as offering significant advantages including easier and quicker erection of the building structure, lower project cost, achieving tighter control over quality, enhanced durability, less material waste, high levels of design flexibility, better sustainability, enhanced occupational health and safety, better architectural appearance, and improved standardization and modularization of reinforced concrete components compared to on-site produced components (Pheng and Chuan 2001; Chan and Hu 2002; Eastman et al. 2003; Sacks et al. 2004; Hamill et al. 2006; VanGeem 2006; Kale and Arditi 2006; Manrique et al. 2007).

Despite these significant advantages, precast concrete systems' share of the overall building construction market in the United States is still very low (approximately 1.2%) (Eastman et al. 2003; Sacks et al. 2004). According to Sacks et al. (2004), many factors influence the market share of precast concrete systems such as labor costs, climate, and the relative costs of alternative construction methods. The most comprehensive study addressing the main reasons why precast concrete systems are not extensively used in the United States was published by Arditi et al. (2000). The findings of the Arditi et al. (2000) study were based on a survey, which had been carried out in 1995, of 100 contractors, 100 designers, 100 precast concrete manufacturers, and 100 labor unions (Ergin 1995). Arditi et al. (2000) found that lack of expertise in precast concrete design and contractors' unawareness of significant cost savings that may likely be achieved when using precast concrete systems were two of the main factors preventing the extensive use of these systems in the U.S. building construction market in 1995.

Since the construction industry is subject to drastic and quick changes due to its dynamic nature and its complex relations with other industries, the 11 years between 1995 and 2006 is a long period of time to expect the very same business environment to prevail. The main objective of this research was to determine the current factors that affect the use of precast concrete systems in the United States, to compare them to the ones dominating 11 years ago, to find out what has changed since 1995, and to make recommendations to overcome the obstacles to the extensive deployment of these systems.

Research Methodology

This study is a replication of the research conducted by Arditi et al. (2000) in 1995. The reasons why precast concrete systems are not extensively used in the U.S. building construction market were investigated through four mail surveys administered to contractors, designers, precast concrete manufacturers, and labor unions. Although most of the questions in the four questionnaires are common, some were designed specifically with the recipient in mind. The questions are meant to explore the factors affecting the use of precast concrete systems in the United States.

The questionnaires were sent to 100 contractors, 100 designers, 100 precast concrete manufacturers, and 100 labor unions. *Engineering News Record*'s (*ENR*'s) list of "Top 400 contractors" (*Directory of Contractors* 2006) was used to select 100 contractors. The *ENR*'s list of "Top 400 contractors" (*Directory of Contractors* 2006) ranks the 400 largest general contractors by their revenue in 2005. Each contractor's workload in general building contracts was calculated by multiplying the value of total contracts by the percent of general building contracts. The values of general building contracts so obtained were sorted in descending

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order. The addresses of the top 100 contractors in this list were obtained from *ENR*'s *Directory of Contractors* (2006). These 100 firms ranked between second and 387th positions in the *ENR*'s list of "Top 400 contractors."

A similar procedure was followed in selecting the 100 design firms to which the questionnaires were mailed. Since the questionnaire included both engineering and architecture-related questions, only the firms classified as architect engineer (AE), engineer architect (EA), and planner (P) were considered for selection. The final selection was made after multiplying the firms' calculated billings with their percentage of general building activity; hence, the firms were sorted in descending order of their general building billings. Their addresses were obtained from the *ENR*'s *Directory of Design Firms* (2006). These firms ranked between second and 498th positions in *ENR*'s list of "Top 500 design firms."

To select the precast concrete manufacturers to which questionnaires were mailed, the manufacturers in the United States had to be identified and classified according to the product they offer. There are 246 plants in the United States that are certified by the Precast/Prestressed Concrete Institute (PCI) (*Membership Directory* 2006). The questionnaire was mailed to 100 of the 246 PCI certified plants selected at random. The addresses of 100 PCI certified precast concrete manufacturers were obtained from the PCI's *Membership Directory* (2006) by picking any manufacturers that produce architectural precast units, beams, columns, joists, and hollow slabs were selected for the survey. The selection was not based on the volume of production, as related data were not available.

There are three main participants in the precast concrete supply chains, which include designers, manufacturers, and contractors that take part in the design, production, and assembly of precast concrete systems, respectively. Although on-site labor is not crucial in precast concrete supply chains, labor unions may play a significant role in their utilization by contractors (Ergin 1995; Arditi et al. 2000). The fourth type of questionnaire was prepared to investigate whether labor unions have any impact on the use of precast concrete systems in the U.S. building construction market.

The mailing addresses of 25 locals of the International Union of Bricklayers and Allied Craftsmen, 25 locals of the Operative Plasterers' and Cement Masons' International Association of the United States and Canada, 25 locals of the Laborers' International Union of North America, and 25 locals of the United Brotherhood of Carpenters and Joiners of America were obtained from their official Web sites www.bacweb.org, www.opcmia.org, www.liuna.org, and www.carpenters.org, respectively, through random sampling.

The building officials may also play a role in the utilization of precast concrete systems in the U.S. building construction market as the approval of precast concrete systems may sometimes be problematic, particularly in earthquake zones. However, the building officials were excluded from this survey because the research methodology employed by Arditi et al. (2000) that was adopted in this study left them out of the survey.

In order to see whether there is a significant difference between the current factors that affect the use of precast concrete systems in the United States and the ones dominating in 1995, the one-sample Wilcoxon signed-rank and one-sample binomial tests were conducted by using the statistical package SPSS (SPSS Inc., Chicago). These nonparametric tests were appropriate, since the ordinal data (i.e., four-point scale, where 0=not important, 1=fairly important, 2=important, 3=very important) was used to rate the perceptions of the respondents (Field 2005). The one-sample Wilcoxon signed-rank test is used to test whether a sample median differs significantly from a hypothesized value (Currell and Dowman 2005), and the one-sample binomial test was used to test the statistical significance of deviations from a theoretically expected distribution of observations into two categories based on a specified probability parameter (Green and Salkind 2004). The results of both tests were assessed at 95% confidence level.

Table 1. Response Rates of Surveys

Type of recipient	Number of questionnaires			Rate of response (%)
	Mailed	Wrong address	Answered	
Contractors	100	0	14	14
Design firms	100	0	14	14
Manufacturers	100	3	19	19
Labor unions	100	3	12	12
Total	400	6	59	15

Discussion of Findings

Of the 400 questionnaires that were mailed, 59 were returned duly filled out and six were returned unopened (wrong address). The response rates by type of respondent are presented in Table 1. Of the respondents, only 1 of the 14 designers (7%) indicated that they did not use precast concrete systems in their building projects. Apparently, the large majority of the designers and all of the contractors used precast concrete systems in their building projects. This result is encouraging, as it shows that more designers and contractors have been using these systems compared to the findings in the 1995 survey by Arditi et al. (2000).

As it was the case in 1995, the highest rate of response (19%) was achieved in the survey of precast concrete manufacturers. The main reason behind this relatively high response rate may likely be that precast concrete manufacturers see the survey as an opportunity to promote their products, express their ideas about the systems they produce, and proclaim the problems they probably experience in their business environment.

Level of Standardization

Achieving standardization and modularization of reinforced concrete components is the major advantage that precast concrete systems promise. However, severe compatibility problems may be experienced when more than one manufacturer are involved in a project. Indeed, the overall success of industrialized systems is subject to a nationwide standardization, well-defined set of policies for modularization, and quality control (Arditi et al. 2000).

PCI was established to promote greater understanding of the design and use of precast and prestressed concrete and to represent the industry in 1954. It sets rules for the standardization of production and quality control of precast concrete components. In order to achieve these goals, PCI provides its professional members with substantial materials on product innovation, new technology adaptation, design methods development, training, and quality assurance. Today, there are about 150 PCI Producer member companies with 246 certified plants in the United States. It should be kept in mind that PCI certification is not a must for

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Table 2. How Adequate Is Education in Precast Concrete Systems?

Type of recipient	Structural aspects		Architectural aspects		Managerial aspects	
	Adequate (%)	Inadequate (%)	Adequate (%)	Inadequate (%)	Adequate (%)	Inadequate (%)
Contractors	25	75	8	92	17	83
Design firms	54	46	46	54	18	82
Manufacturers	6	94	0	100	17	83

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precast concrete plants in the United States; the number of noncertified plants is over 300 (Arditi et al. 2000). Although PCI-certified manufacturers' operations including both engineering practices and management commitment are regularly audited by PCI, there is no assurance that noncertified plants have any quality commitments or controls in place.

The questions about standardization were meant to determine whether contractors and designers preferred using the products of PCI-certified manufacturers and to establish the level of product compatibility problems encountered by contactors, design firms, and manufacturers. It was found that contractors and designers "usually" prefer the products of PCI-certified manufacturers. On a scale of 0–4 (where 0=never, 1=rarely, 2=sometimes, 3=usually, and 4=always) both the contractors and designers scored on the average 3.29, a little higher than the scores of 3.09 and 3.10 for contractors and designers, respectively, in the 1995 survey conducted by Arditi et al. (2000). Although the survey results reveal that there is a slightly stronger preference on the part of contractors and designers to work with PCI-certified manufacturers today compared to in 1995, the one-sample Wilcoxon signed-rank test indicates no significant difference at 95% confidence level.

It was also found on a scale of 0–2 (where 0=never, 1=sometimes, and 2=often) that contractors, designers, and manufacturers scored an average of 0.78, below "sometimes," when they were asked about the frequency of compatibility problems. Although this finding seems encouraging as the average score was 0.85 in 1995 (Arditi et al. 2000), the one-sample Wilcoxon signed-rank test indicates that the average scores are not significantly different from each other at 95% confidence level. Similarly, when they were asked about the severity of compatibility problems, on a scale of 0–2 (where 0=not severe, 1=severe, and 2=very severe), the same respondents scored on average 0.08, which is a little over "not severe." This score is lower than the score of 0.10 found in the 1995 survey conducted by Arditi et al. (2000). The one-sample Wilcoxon signed-rank test constitutes a reasonable proof at 95% confidence level that compatibility problems of precast concrete components are less significant today than they were in 1995. This may result from the accumulated experience and the higher preference of designers and contractors for PCI-certified manufacturers.

Expertise

According to Arditi et al. (2000), lack of expertise in precast concrete systems is one of the main factors that prevents the extensive use of these systems, since lack of expertise in these systems may lead to poor design, poor plant management and production, and poor erection practices.

One of the major advantages of precast concrete systems is that they shield both production and erection processes from uncertainties, hence allowing the generation of more predictable schedules. However, lack of expertise in precast concrete systems may eliminate such an advantage. Indeed, lack of expertise in concrete design may create severe conflicts between manufacturers and designers; lack of competence on the part of the manufacturer can cause failures in the production stage that may in turn cause delays in the flow of delivery to the construction site; lack of competence on the part of the contractor can bring about delays in the erection schedule, even if components are delivered to the site on time, and prevent the contractor from gaining the expected cost savings through speedy erection (Arditi et al. 2000).

To explore the level of expertise in precast concrete systems currently available in design offices, designers were asked if they employed structural engineers who are specialists in these systems. Thirty-one percent of the design firms employed such specialists on their staff, whereas this rate was 40% in 1995 (Arditi et al. 2000). Although the one-sample binomial test does not indicate a significant difference between these rates at 95% confidence level, the difference cannot be ignored. Today's lower rate may result from the deficient engineering and architecture curricula that do not provide adequate education about precast concrete systems. In order to figure out the level of such education in U.S. universities, the contractors, designers, and manufacturers were asked if they believed the academic curricula in universities provided adequate education about precast concrete systems from the structural, architectural, and managerial standpoints. Table 2 indicates that the majority of contractors, designers, and manufacturers believed that the academic curricula in universities do not provide adequate education about precast concrete systems today as it was in 1995 (Arditi et al. 2000). It looks like expertise in these systems is not available. Indeed, only a few universities in the United States offer precast concrete at the undergraduate and graduate levels (*Industry News* 2005).

Prospective engineers' knowledge about these systems can be provided via architecture/engineering curricula in universities. However, it looks like teaching the know how of industrialized building systems is not at the top of educational institutions' priority list when they design their academic curricula. This problem may likely be overcome by developing new courses in civil engineering and architecture programs and specialty training in master's programs to teach the structural, architectural, and managerial aspects of precast concrete systems. On the other hand, active professionals' familiarity with these systems may be disseminated via company-wide training programs, continuing education courses, or more extensive endeavors, such as education/training programs provided by PCI. Undoubtedly, awareness of both prospective and active professionals about the nature of precast/prestressed concrete, its capabilities, and its wide range of applications would help in disseminating the use of precast concrete systems.

The endeavors of PCI in endowing both prospective and active engineers with adequate knowledge about precast concrete systems are noteworthy. PCI provides handbooks and textbooks to architecture students, supports workshops for professional educa-

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tors who teach in the schools of architecture, and offers active professionals continuing-education courses (Endicott 1997).

Design Issues

Architectural design and structural analysis of precast concrete components may not be much different from those of cast-in-place reinforced concrete systems. However, there are some issues that need to be particularly addressed during the architectural design and structural analysis of precast concrete systems. In the architectural design context, architects should particularly pay attention to avoid not only repetitiveness that may cause monotony, but also incompetent designs that may ultimately bring about poor production quality, e.g., cracks, moisture penetration, poor thermal insulation, and joint failures. Despite these issues, there is no consensus on how the use of precast concrete in building projects actually influences the architectural performance of those buildings. While some architects believe that most of the complex patterns that cannot be produced by using conventional methods can easily be obtained by using precast methods, some others claim that their architectural creativity suffers when using precast concrete systems because of the constrained modularity of these systems. Some architects believe that precast concrete structures tend to be excessively repetitive because producing a large variety of precast components may cost much more than producing them in situ, whereas others insist that precast concrete systems encourage the use of flexible designs.

Contractors, designers, and manufacturers were asked whether architectural creativity suffers when precast concrete systems are used. Fig. 1 shows that while the large majority of manufacturers (90%) believed that architectural creativity is enhanced when precast concrete systems are used, the majority of contractors (71%) and designers (62%) thought that the architects' creativity suffers "somewhat" from these systems. The one-sample binomial tests indicate that the perceptions of contractors, designers, and manufacturers concerning the impacts of precast concrete on the architectural creativity are not significantly different from what they were in the Arditi et al. (2000) study conducted in 1995.

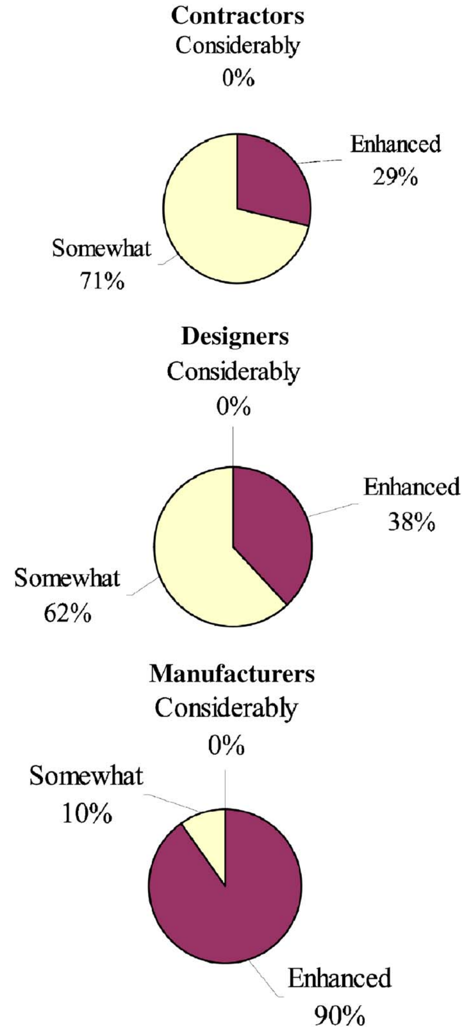

Fig. 1. Does architectural creativity suffer when precast concrete systems are used?

As seen in Fig. 1, there are differences between the answers of manufacturers and the other two groups of respondents. There may be two reasons behind this marked difference. One is that while the manufacturers might have seen this survey as an opportunity to promote their products by means of proclaiming precast concrete's technical capabilities, the designers and contractors may have experienced difficulties in meeting architectural requirements of the projects in which precast concrete was used. The second is that the manufacturers are definitely more aware of the extent to which precast concrete can meet architectural requirements than designers and contractors. Lack of awareness of the designers and contractors about the capabilities of precast concrete systems may result from the aforementioned deficient formal education in U.S. universities and/or lack of prior experience in using precast concrete systems.

From the structural analysis standpoint, the most important handicap is the performance of precast concrete systems under high seismic loads. According to Priestley and Tao (1993), the use of precast concrete buildings in seismic regions of the United States has been limited due to the uncertainty about their performance in earthquakes. Indeed, while precast concrete structures performed remarkably well in the 1995 Kobe earthquake (Muguruma et al. 1995), their performance was much worse than cast-in-place concrete buildings in the 1992, 1995, and 1999 earthquakes that occurred in Turkey (Celep and Kumbasar 2004). Precast concrete buildings in Turkey showed enormous deformations and underwent severe failures due to distress in the connections. On the other hand, the frame structures studied by Camba and Meli (1993) showed no sign of distress in the connections or elsewhere during the 1985 Mexico earthquake. In the 1994 Northridge earthquake, while most of the precast structures close to the epicenter showed very small deformations, some of them that were not so close underwent severe failures (Iverson and Hawkins 1994). These unexpected and volatile performances of precast concrete structures in recent earthquakes supports the Arditi et al. (2000) contention that an adequate safety level could be obtained for even the most severe seismic conditions if stricter building codes for that type of structure were followed.

In recent years, several research and development programs were conducted, mostly through the support of PCI and the National Science Foundation (NSF), to develop a more comprehensive seismic design methodology for precast/prestressed concrete structures. Based on the findings of these research studies, building codes became tighter. For instance, several major changes were made in the 2005 edition of the American Concrete Institute Building Code Requirements for Structural Concrete (ACI 318-05) since the publication of the previous edition of the ACI code (ACI 318-02). The impacts of those changes on the seismic de-

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sign of precast concrete structures were thoroughly discussed in several studies (Ghosh 2004, 2005). Moreover, the Sixth Edition of the *PCI Design Handbook*, published in 2004, has been considerably upgraded to reflect the numerous building code changes.

Designers and manufacturers were asked to categorize the performance of precast concrete systems in earthquakes as "perfect," "good," "poor," or "inconsistent." All of the manufacturers thought that precast concrete systems performed "good" and 82% of the designers shared the same view. None of the designers answered "poor" to this question. Only 18% of the designers claimed that the use of precast concrete is "inconsistent." There is a slight difference in the answers of manufacturers and designers to this question, which may likely result from the lack of objectivity of manufacturers. Afterall, the manufacturers are profit-seeking organizations, and it is very reasonable that they do not want to criticize the products in which they invested. On the other hand, both manufacturers' and designers' answers to this question are very promising for the safety of precast concrete structures under critical loads compared with those in 1995.

In 1995, 85% of the manufacturers claimed that precast concrete structures performed "good," and 15% rated their products' performance as "inconsistent." In contrast, 40% of the designers stated in 1995 that the performance of precast concrete structures was "good," whereas 32% disagreed with this view and rated the performance as "poor" (Arditi et al. 2000). The one-sample binomial tests constitute reasonable proof that the perceptions of both manufacturers and designers about the performance of precast concrete structures under high seismic loads have significantly changed in the positive direction, and they now believe that this type of building performs better in earthquakes. This positive change may be the result of the aforementioned changes recently made in building codes. It seems that those efforts drastically helped in both improving the performance of precast concrete systems under seismic loads and easing designers' concerns about the probable damages that may occur in precast concrete structures during earthquakes.

Transportation

The transportation cost of precast components is directly proportional to the number of truckloads used in the delivery process and the unit cost of delivery. The number of truckloads is mainly affected by the weight and size of the precast concrete components to be transported and the capacity of the trucks used for delivery, whereas the unit cost of delivery is directly influenced by the distance between the manufacturer's plant and the construction site. Another constraint related to transportation is the allowable weight and size of loads that are limited by the carrying capacity of bridges and pavements and by the horizontal and vertical clearances in tunnels and underpasses (Arditi et al. 2000). Moreover, traffic congestion at the worksite may bring about a problem for the contractor (Pheng and Chuan 2001). Since precast concrete components are bulky and heavy materials, the transportation cost of those components is very high. The weight/size limitations specified by highway agencies might constrain designers' creativity by compelling them to keep the component sizes within limits when designing precast concrete structures.

Designers were asked if transportation-related constraints have had any adverse effect on their precast concrete designs. Only 8% of the designers thought that the adverse effect is "considerable," while 61% believed that transportation-related restrictions "somewhat" adversely affected their designs, and 31% thought that these limitations do not have any impact on their precast concrete designs. Based on the answers to this question, 69% of the designers said that transportation-related restrictions somehow adversely affect their precast concrete designs today, whereas only 52% thought so in 1995 (Arditi et al. 2000). The one-sample binomial test indicates that the designers' perceptions do not significantly differ from what they were in 1995. It is possible that this slight difference may have been caused by owners' mounting demands for more functional and aesthetic buildings (e.g., high-rise buildings with large spans) in which large amounts of bulky and heavy components need to be used. While earlier applications of precast concrete were mainly low-rise industrial buildings, today precast concrete systems are used in multistory buildings and larger structures. For instance, the largest municipal departments in the Aurora Municipal Center project required a 56,000 ft^2 floor plate with spans of 70 ft in many areas (Todd et al. 2004). Most of the precast concrete pieces were very large and some weighed upwards of 28 tons, hence, the trucks carried only an average of 1.4 pieces per trip (Todd et al. 2004). Given that kind of demand on the part of owners, designers may feel the pressure of transportation constraints now more than ever. However, as seen in the Aurora project reported by Todd et al. (2004), if the logistics are thoroughly planned, all of the obstacles resulting from transportation constraints can be overcome.

Manufacturers were asked if transportation costs play a role in their decision to participate in a project. Nine of the 19 manufacturers (47%) indicated that they did as opposed to 71% in 1995 (Arditi et al. 2000), whereas the remaining 53% claimed that transportation costs had nothing to do with this decision. The one-sample binomial test indicates at 95% confidence level that the transportation cost does not play a significant role in manufacturers' decision to participate in a project today as it did in 1995.

Union Politics

Union politics may not play a central role in precast concrete supply chains. However, they should be considered as a factor that may prevent the extensive use of precast concrete structures in the U.S. building construction market. Since the use of precast concrete components in building projects drastically reduces the amount of work on site, labor unions may tend to protect their workers by including prefabrication clauses in their collective bargaining agreements with contractors (Arditi et al. 2000).

Contractors were asked whether labor unions have a negative attitude when contractors use precast concrete components in their building projects. As many as 85% of the contractors indicated that labor unions "rarely" or "never" react against their projects where precast concrete systems are used, whereas the remaining 15% said "sometimes." No contractor marked "usually" or "always." This finding is consistent with the conclusion of the former study conducted by Arditi et al. (2000) in 1995.

Labor unions were asked if they put some restrictions on the use of prefabricated components on construction sites. Eleven of the 12 union officials (92%) checked the "never" choice in this question, whereas the remaining one union official said "rarely." When they were asked whether prefabrication restrictions in labor contracts protect their members from possible future dismissals, all of the 11 union officials who responded to this question, checked "no." This finding is also very similar to the one found in 1995 (Arditi et al. 2000). It can be concluded that the labor unions in the construction industry do not create any barriers against the use of precast concrete systems today, as was the case in 1995.

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Table 3. Do Designers Consult Manufacturers in Design Stage?

Respondents	Never (%)	Rarely (%)	Sometimes (%)	Usually (%)	Always (%)
Contractors	0	43	21	36	0
Designers	0	8	15	46	31
Manufacturers	0	21	48	26	5

Communication among Parties

Speedy erection and low project cost are two of the major advantages that precast concrete systems promise. However, severe delays in production and erection schedules, substantial cost overruns, and constructability problems may be encountered unless good communication and coordination is achieved among all the key parties involved in a project. The role of precast concrete manufacturers is crucial in the success of a project, as they are expected to produce the precast concrete components in agreement with designers' drawings and specifications, and deliver them to the construction site on schedule (Arditi et al. 2000). Any inefficiency in this information flow may necessitate reworks that may at times be excessive. To avoid such occurrences, manufacturers are often consulted by designers in the early stages of design. Therefore, manufacturers mostly have to confront difficulties in the implementation of design instructions, which in turn affects both the production and erection schedules. The contractor's good communication with the designer and the manufacturer also plays a key role in the success of the project in terms of meeting schedule and budget constraints in the erection stage.

The respondents were asked questions about their efforts in communicating with the other parties at different stages of the project. The questions related to communication in the design stage were directed to designers and manufacturers. Good communication between the manufacturer and the designer in the design stage definitely helps in reducing the possible problems that are likely to occur in the production and erection stages. Manufacturers were asked how often they encountered problems in the production stage due to uncertainties in design. On a scale of 0–4 (where 0=never, 1=rarely, 2=sometimes, 3=often, and 4=very often), manufacturers scored on average 2.58, higher than "sometimes" and close to "often." The responses indicate that the existence of design problems cannot be ignored because the average frequency is close to "often." Although this finding is slightly discouraging, because the average score was 2.37 (which is higher than "sometimes") in 1995 (Arditi et al. 2000), the one-sample Wilcoxon signed-rank test indicates no significant difference at 95% confidence level.

Designers were asked to categorize how frequently they were consulted by manufacturers regarding design instructions. Sixty-seven percent of the designers claimed that they were consulted by manufacturers "often" or "very often," whereas this rate was only 30% in 1995 (Arditi et al. 2000). This finding is very promising as manufacturers appear to consult designers more often than they did in 1995. This difference is supported by the one-sample binomial test at 95% confidence level.

The problems encountered during the production stage may be partly overcome by good communication between the designer and the manufacturers in the design stage. The question related to this issue was asked of the contractors, designers, and manufacturers in different forms. Table 3 shows the beliefs of these parties about how much designers consult manufacturers during the design stage. On a scale of 0–4 (where 0=never, 1=rarely, 2=sometimes, 3=usually, and 4=always), the designers scored on average 3.00, which is "usually," whereas contractors and manufacturers scored 1.92 and 2.16, respectively, which are more or less close to "sometimes." In other words, while designers claim that they "usually" consult manufacturers during the design stage, contractors and manufacturers believe that designers consult manufacturers only "sometimes." The corresponding scores were 2.90, 2.39, and 2.42 in 1995, respectively. The one-sample Wilcoxon signed-rank test indicates that the respondents' perceptions on this issue today are not significantly different from what they were in 1995 at 95% confidence level. It appears that manufacturers and contactors find designers' efforts of consulting manufacturers not to be quite adequate. Design defects, which cause production problems, can easily be avoided if designers request more input from producers during the design stage.

Designers were asked whether contractors procure precast concrete components from manufacturers that they consulted in the design stage. Fifty-eight percent of responding designers reported that contractors "usually" work with manufacturers that they consulted in the design stage, the remaining 42% marking "sometimes." This finding is encouraging, since only 31% of designers had marked "usually" in 1995 (Arditi et al. 2000). The one-sample binomial test constitutes a reasonable proof that contractors prefer to work with a manufacturer that was consulted by the designer in the design stage today significantly more than they did in 1995. Procuring precast concrete components from manufacturers that were consulted by the designer in the design stage is likely to reduce the number of defective components the contractor receives, which in turn allows the contractor to complete the project on schedule and within budget.

The coordination of the activities of the parties during the construction stage is as important as coordinating the activities in the design stage. One means of achieving a good level of communication between the contractor and the other key project participants is holding periodic meetings during the construction process. A question related to this issue was asked of the contractors. Table 4 shows the three parts of the question and the corresponding responses. The responses to this question reveal that the parties communicate efficiently in the construction phase. This finding is very similar to the one found in 1995 (Arditi et al. 2000). It is obvious that contractors are aware of the importance of a good level of communication during the construction phase.

In some cases, a contractor procures precast concrete components from more than one manufacturer. Manufacturers were asked if they held periodic meetings with other manufacturers in jobs where they work in consortia. Of the 19 respondents, seven

Table 4. Periodic Meetings of Contractors with Designers and Manufacturers

Meetings	Yes	No
Separately with designer	10	4
Separately with manufacturer	10	4
Jointly with designer and manufacturer	13	1

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stated that they did not work in consortia with other manufacturers. While 11 of the remaining 12 (92%) organized such meetings, 1 (8%) did not. It is obvious from these findings that manufacturers communicate efficiently with other manufacturers. The one-sample binomial test constitutes reasonable proof that manufacturers recognize the importance of communication with other manufacturers working in the same project significantly more than they did in 1995, as only 63% of manufacturers reported holding periodic meetings then (Arditi et al. 2000). The enhanced level of communication helps to reduce the number of problems caused by compatibility problems in the construction phase. Indeed, as mentioned in the standardization section, contractors, designers, and manufacturers experienced fewer compatibility problems now compared to 1995.

The responses to the questions that aim to determine the level of communication among the project participants at different stages of the project indicated that communication in the construction stage is considered to be adequate by the respondents, whereas the consultation process between designers and manufacturers in the design stage could be improved.

Cost Savings

It is commonly acknowledged that the use of precast concrete systems in a project enables lowering the overall project cost. In order to assess contractors' perceptions of the accuracy of this statement, contractors were asked if they believe that the cost of construction goes down when precast concrete systems are used. Ninety-three percent of the contractors said that they achieved cost savings when they used precast concrete systems, whereas only 7% stated that they did not. The responses to this question revealed that today contractors are quite aware that they can achieve cost savings when they use precast concrete systems. This finding is promising, because Arditi et al. (2000) found in their 1995 study that only 42% of contractors declared cost savings in projects where they used precast concrete systems. The difference between the two surveys is statistically significant, as evidenced by the one-sample binomial test. There may be three major reasons for this positive change in contractors' perceptions. One may be that better communication achieved in the design and construction stages brings about better project performance in terms of less delay in production and erection, as discussed in the previous section. Second, it may be that manufacturers have become more professional because they have been using recent advances in information technologies (Chan and Hu 2002; Sacks et al. 2003; Eastman et al. 2003; Sacks et al. 2004, 2005), which certainly improve the overall production process and schedules. The final reason may be related to the lower cost of precast concrete components caused by fierce competition between the increasing number of manufacturers. It should be noted that if the level of expertise improves and a good level of communication is achieved, then using these systems can become more economical for contractors.

User Satisfaction

The satisfaction of end users plays a significant role in the decision to use precast concrete systems in building projects. The respondents were asked to categorize the overall satisfaction of the occupants of precast concrete buildings. Table 5 shows that all of the 18 manufacturers who responded to this question said that

Table 5. How Satisfied Are Occupants of Precast Concrete Buildings?

Respondents	Not satisfied (%)	Somewhat satisfied (%)	Very satisfied (%)
Contractors	0	29	71
Design firms	0	50	50
Manufacturers	0	0	100

the occupants were "very satisfied" with precast concrete buildings in which they live and work. However, the perceptions of contractors and designers were that users were less satisfied than what the manufacturers claimed. On a scale of 0–2 (where 0 = not satisfied, 1 = somewhat satisfied, and 2 = very satisfied), the contractors and designers scored on the average 1.71 and 1.50, respectively, higher than "somewhat satisfied" and close to "very satisfied." These scores are slightly higher than the ones found by Arditi et al. (2000). None of the respondents checked "not satisfied" in this question in 2006 or in 1995. The reason why nearly all of the manufacturers checked "very satisfied" both today and in 1995 may be because of manufacturers' eagerness to promote their products and their possible tendency to protect themselves against any criticism against their products.

Future

The last question in all four questionnaires was the same and aimed to identify the respondents' perceptions on how the use of precast concrete systems will change in the next ten years. As seen in Fig. 2, none of the respondents said that they expected a considerable decrease in the use of precast concrete systems in the United States in the next 10 years. Only 8% of the designers and 9% of the labor unions marked "small decrease." It was not surprising to see that the majority of the manufacturers (94%) stated that they were expecting a considerable increase in the use of precast concrete systems in the next 10 years, while the remaining 6% checked on "small increase." In 1995, the respondents also claimed that they were expecting an increase in the use of precast concrete systems in the United States in the next 10 years.

Summary of Findings

The Main Findings of the Research Are Presented Below:

- Most designers and contractors claimed that they prefer to work with PCI-certified manufacturers. This preference is slightly stronger today than in 1995.
- Compatibility problems of precast concrete components are not perceived as significant by contractors or designers. Such problems are encountered significantly less frequently today than they were in 1995. This may have been achieved by the higher preference of designers and contractors for working with PCI-certified manufacturers.
- Education in precast concrete systems is still deficient in U.S. universities to the same extent as it was in 1995. Most of the respondents reported that the academic programs in the structural, architectural, and managerial aspects of precast concrete systems are not satisfactory.
- Inadequate education in the structural and architectural aspects

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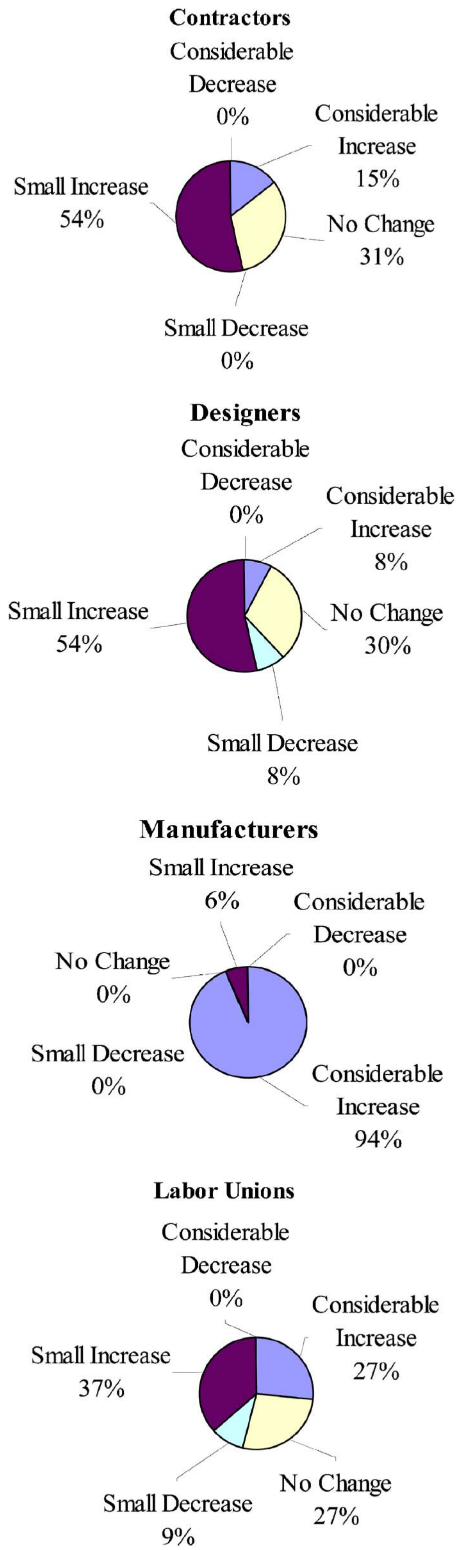

Fig. 2. Future of use of precast concrete systems

of precast concrete systems results in a shortfall in the number of specialized designers. Only 31% of the design firms stated that they employed professionals who can claim to be specialized in precast concrete systems, whereas this rate was 40% in 1995.

- The majority of contractors and designers think that architectural creativity suffers when precast concrete systems are used, but not considerably. On the other hand, most manufacturers believe that architectural creativity is enhanced with the use of precast concrete systems. However, their objectivity is doubtful. These findings are more or less the same as the ones in 1995.
- Poor or inconsistent performance of precast concrete buildings in earthquakes is not a concern of designers today, whereas it was in 1995. Most designers now believe that this type of building performs well in earthquakes. This positive change is probably caused by the drastic changes recently made in building codes with the efforts of PCI.
- Size/weight restrictions on truck loads have a slightly more significant impact on the design of precast concrete systems than they did in 1995. This slight difference may be the result of owners' mounting demands for longer spans and larger and heavier components.
- The labor unions in the construction industry do not create any barriers against the use of precast concrete systems today as was the case in 1995. Both labor unions and contractors stated that they do not have any arguments about using precast concrete components in construction sites.
- The level of communication among the project participants in the construction stage is considered to be adequate by the respondents, whereas the consultation process between designers and manufacturers in the design stage could be improved. This finding is consistent with the one in 1995.
- Ninety-three percent of contractors said that they achieved cost savings when they used precast concrete systems, a higher percentage than in 1995. This positive change in contractors' perceptions may have been caused by better communication achieved in the design and construction stages, manufacturers that take advantage of advances in information technologies, and the lower cost of precast concrete components.
- The respondents stated that the occupants of precast concrete buildings are somewhat satisfied with the constructed facilities. Thus, satisfaction of the occupants with precast concrete buildings does not seem to have an adverse effect on the extent to which precast concrete systems are used; neither did it in 1995.
- An increase in the use of precast concrete systems in the United States in the near future is expected by the large majority of respondents.

Conclusions

Although the use of precast concrete systems offers significant advantages, these systems' share of the overall building construction market is very low. This study aimed to investigate the current factors that affect the use of precast concrete systems in the U.S. building construction market, and to identify those factors that have changed through the last 11 years. The same questionnaires used by Arditi et al. (2000) in a 1995 survey were sent to contractors, designers, manufacturers, and labor unions, and the findings were compared with the ones obtained in 1995.

The findings mentioned in the previous section reveal that most of the prerequisite conditions favorable for the extensive use of precast concrete systems, which already existed in 1995, either prevail or have changed for the better in the last 11 years. For example, there is a slightly stronger preference on contractors' and designers' part for working with PCI-certified manufacturers; fewer product compatibility problems are encountered; the PCI's efforts to standardize the industry are ongoing; architectural and

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aesthetic limitations are not considered to be major problems; union politics do not appear to be a major deterrent; and the occupants of precast concrete buildings are satisfied with the premises in which they work and live. Moreover, some of the barriers to the extensive use of precast concrete systems in 1995 have been either eliminated or drastically reduced. Namely, poor or inconsistent performance of precast concrete buildings in earthquakes is not one of the concerns of designers anymore, and contractors are aware of the cost saving advantage that can be achieved with the use of precast concrete systems today more than in 1995. On the other hand, some of the factors that were identified to prevent the extensive use of precast concrete systems in 1995 still exist today. For instance, there is a major shortage of expert personnel that can design and manage building construction that makes use of precast concrete components. The main reason behind this general lack of expertise appears to be the deficient engineering and architecture curricula currently in effect in U.S. universities and colleges. The lack of expert engineers and architects brings about ambiguities in design, which in turn may cause problems at the production stage where manufacturers encounter more problems now than they encountered in 1995. Furthermore, size/weight restrictions on truck loads have a slightly more significant impact on the design of precast concrete systems than they did in 1995 (the difference is not significant, but it cannot be ignored).

Awareness of both prospective and active professionals about precast concrete systems would help in disseminating the use of these systems. Adequate knowledge can be provided to prospective engineers about precast concrete systems by developing new courses that cover the structural, architectural, and managerial aspects of precast concrete systems, by providing practical experience as well as theoretical knowledge, and by making sure that these courses become an integral part of undergraduate and graduate curricula in architecture and civil engineering programs (Polat and Damci 2007). Three main activities can be carried out within the context of these courses: (1) Educational trips: Educators may organize trips to precast concrete production plants and construction sites so that the students can observe not only the technical features and production process of precast concrete components, but also their capabilities, the wide range of application, and the management of the supply chain of precast concrete components; (2) Case studies: The case study method has been proven to be a very useful learning tool and it can be further enhanced with the use of multimedia and the World Wide Web. Case studies may create an educational tool that brings into the classroom a "real-life" design and construction problem, including the construction field, operation of equipment, and details of construction methods. This enables students to better understand the details of the planning, design, and construction of a complicated precast concrete building project (Golias et al. 2005); and (3) Assignments: After the educational trips and case studies, giving students an assignment on designing a complicated precast concrete building project would play a significant role in providing adequate knowledge about precast concrete systems. Active professionals' familiarity with these systems may be fostered via companywide training programs, continuing education courses, or more extensive endeavors, i.e., a variety of useful resources provided by PCI. It looks like precast concrete systems are here to stay. It is expected that their use will increase in the future.

This study is of benefit to the participants of the precast concrete industry, because it helps them to understand the main reasons that prevent the use of precast concrete systems, it makes them aware of the problems the other parties encounter, and it guides them in eliminating the barriers to the deployment and dissemination of these systems.

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