Scientia Iranica A (2016) 23(4), 1578–1593

Sharif University of Technology
Scientia Iranica
Transactions A: Civil Engineering
www.scientiairanica.com

Review Article

New construction for resilient cities: The argument for sustainable low damage precast/prestressed concrete building structures in the 21st century

R.B. Fleischman[a,*] and P.E. Kim Seeber[b]

a. *Department of Civil Engineering & Engineering Mechanics, University of Arizona, Tucson AZ, USA.*
b. *Seaboard Services of Virginia Inc., Taylors SC, USA.*

Received 27 December 2015; accepted 21 June 2016

KEYWORDS
Precast-prestressed concrete structures;
Resilient construction;
Sustainable construction;
seismic-resistant structures;
Low-damage systems.

Abstract. Thoughtfully chosen, properly designed new construction can significantly improve both the resilience to natural and man-induced disasters and the long-term sustainability of modern urban environments in the 21st century. In particular, precast/prestressed concrete construction has the ability to provide low-damage buildings at similar costs to traditional construction while also providing a more sustainable construction form, in terms of higher energy efficiency and lower embodied energy. In this paper, low-damage sustainable precast concrete seismic systems are described. Prestressing leads to less material required and hence less embodied energy; piece erection leads to cleaner, quieter construction sites; and insulation and architectural finish can be integrated directly into the precast unit, increasing energy efficiency, and consolidating construction operations. With respect to resilience, earthquake damage is avoided by taking advantage of the inherent jointed nature of precast concrete construction, thereby promoting opening of gaps between precast units rather than cracking of the concrete itself, and using unbonded post-tensioning concepts to restore the structure to its original position. The potential use of precast concrete in developing countries, where no precast industry exists, is considered in the context of global sustainability. The performance of precast concrete in recent earthquakes is presented as an example of a resilient construction.

1. Introduction

Community resilience for sustainable urban environments involves the ability for the sustaining urban community to rapidly regain its regular function, in terms of habitation, commerce, public services, local culture; and way of life, after a sudden and disruptive natural or manmade event [1]. Figure 1 shows a schematic of this process, indicating the difference between resilience and sustainability. As seen, the factors that influence community resilience can be divided in two groups: (1) those that pertain to the actions the community can take prior to an event to lessen the immediate impact of the event on loss of function (i.e. increase robustness), termed ex-ante mitigation; and (2) those that pertain to the actions the community can take in response to the event (rapidity of recovery), termed ex post actions. This process can be applied to natural and man-made hazards in general, and thus while the paper focuses on earthquake resilience, many of the points are applicable generally to multi-hazard resilience.

For earthquake resilience, ex-ante mitigation primarily refers to hardening of infrastructure, for in-

*. *Corresponding author.*
E-mail addresses: rfleisch@email.arizona.edu (R.B. Fleischman); kseeber@seaboardservices.com (P.E. Kim Seeber)

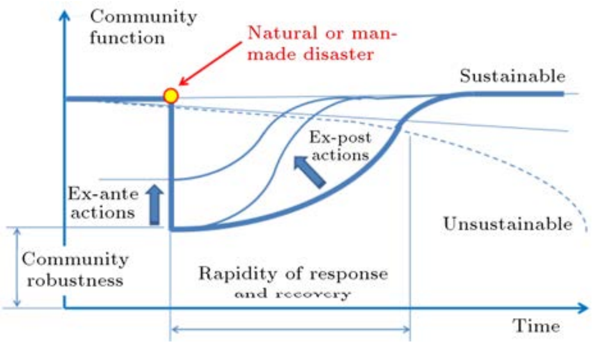


Figure 1. Loss triangle: actions influencing resilience.

stance retrofitting (or demolition) of vulnerable structures and promoting new construction that is more resistant to earthquake hazards [2]; the ex-post actions refer to the preparedness of the community [3]: in the immediate aftermath emergency responders and critical care facilities, and government leaders, decision makers, and public service broadcasters; and in the longer term, inspectors and engineers, city planners, urban and public policy makers, community organizers, insurance companies, etc. Note that though the expost actions occur after the event, effective preparedness to execute these actions requires significant planning, coordination, and preparation prior to the event.

It may be claimed that, historically, governing bodies have tended to be more reactive than proactive to natural disasters with a focus on post-event response. In recent years, however, great advances in assessing the vulnerability of individual infrastructure assets and communities have provided unparalleled opportunities, including the use of geospatial information, remote sensor data, analytics, and visualization to interpret and gain knowledge for the purpose of planning for responding to, and recovering from, disaster events [4]. A key step for community earthquake resilience is to inventory existing or planned infrastructure in terms of vulnerability and consequence and relate it to anticipated seismic hazard [5]. However, as urban communities have become more complex, where the lifelines (power grids, utilities, communication, transportation networks, etc.) are intertwined with coupled integrated systems that provide normal business and daily life; and infrastructure may be aging while the population remains dense; the interactions of these failing critical lifelines can have cascading effects on a community and surrounding regions [6]. Business interruption, dislocation of the populace, and loss of normal activities can have severe negative societal, cultural, and economic effects locally, regionally, or nationally, leading to natural disastrous events that overwhelm even the most carefully planned response [7]. Thus, the importance of building inherent robustness into the community infrastructure has risen relatively [8], and comprehensive ex-ante mitigation strategies have been found to be effective [9].

Community resilience efforts have to be considered in the context of sustainability [10]. Sustainability refers to the ability of a system or process to endure (or thrive) over its intended duration. In the context of modern urban environments, sustainability pertains to ecological impact, durability, energy and resource consumption relative to supply, and economic viability for continued functionality based on operational requirements, long term deterioration, and changes in the surrounding environment [11]. Thus, while community resilience might be viewed as the ability to restore functionality after a singular event, sustainability is the ability to maintain functionality over the expected life-cycle (Refer to Figure 1). Community resilience often poses competing requirements to the parallel requirements for sustainability; at a minimum, policies for these critical aspects are fighting for the same scarce resources [12].

This paper will focus on ex-ante mitigation of building structures, and in particular, new sustainable construction for developed or developing countries that is more resilient to earthquake hazards. The discussion focuses on precast/prestressed concrete; a construction form with characteristics that lead to advantages in resilience and sustainability.

2. Sustainability issues for building structures

Sustainability for buildings focuses on environmental effects and energy use through the construction, operation, and demolition of the structure, including those associated with the raw materials used in the process. These factors are often evaluated in a Building Life Cycle Assessment (LCA) covering construction and operation [13].

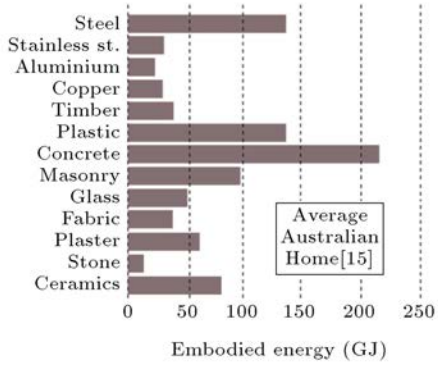
2.1. Concrete building construction: Embodied energy and CO_2 emissions

Key aspects of sustainability for concrete include embodied energy and carbon emissions in its construction: About 6% of all energy consumed is used to manufacture and transport building materials [14]. The Process Energy is the measure of energy directly related to manufacture of the material (raw material extraction, transportation to plant, product manufacturing costs) and is more commonly reported than a total embodied energy (business overhead costs, etc.) [15]. The structure, envelope, and finishes comprise over 60% of the "cradle-to-gate" embodied energy in an office building, including non-trivial amounts of energy required to transport materials to a project site [16]. Thus, while embodied energy depends on material and building techniques, it can be reduced significantly when local materials are used for building construction [17]. Fig-

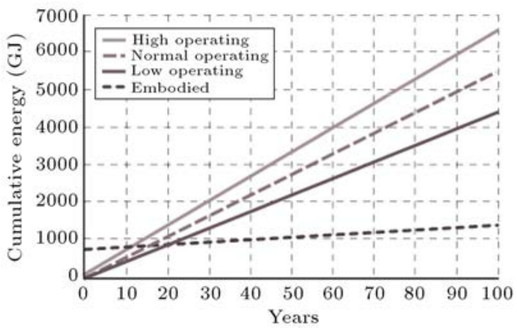
Material	Watt-Hr./Kg
Straw bale	67
Adobe block	117
Rammed earth	117
Local stone	219
Concrete	361
Plasterboard	1694
Portland cement	2167
Plywood	2889
Fiberglass insulation	8416

Embodied energy in building materials [18]

(a)



(b)



(c)

Figure 2. Embodied Energy: (a) Material density [18]; (b) typical home construction [15]; and (c) operational energy [22].

ure 2(a) shows the embodied energy density inherent in different construction materials [18]. Though not possessing the highest density, the significant percentage by weight of concrete used in structures tends to render it as the most significant contributor in construction (e.g., Figure 2(b) [15]).

Typical concrete contains approximately 10-12% cement by volume. Significant CO_2 emissions occur in cement production due to both fuel use (combustion-generated, 1/3rd) and heating of the calcium carbonate (calcination, 2/3rd) [19]. Since the 1970's, the U.S. cement industry has reduced CO_2 emissions and energy usage per ton of cement by approximately one third [20]. The global cement industry has reduced its specific net CO_2 emissions per ton of product by 17% since 1990. However, overall cement production has increased by 74% in the same time, leading to an absolute CO_2 emissions increase of 44%. Today, cement production still accounts for approximately 5% of global CO_2 emissions, one of the more significant contributors outside electric generation and transportation [21].

2.2. Building operation

Worldwide, approximately 70% of generated electricity is being consumed by buildings. Buildings employ 40% of raw materials (3 billion tons annually) for construction and operation worldwide [21]. In the U.S., buildings consume 65% of the electricity generated and more than 36% of the primary energy (such as natural gas); they produce 30% of the national output of greenhouse gas emissions; and they use 12% of the potable water [22].

Many developing nations have increased energy demands due to increased manufacturing and urbanization. For instance, in China (see Section 3.5), energy demand has increased dramatically as it has become one of the major manufacturing centers of the world with demand expected to exceed current supply [23]. A major contributor to reducing demand would be more energy-efficient buildings, which can lower operating costs by a factor of two [22].

It is important to holistically view embodied energy in the context of the buildings, overall life-cycle [24], as tradeoffs exist between initial versus operational energy costs. For instance, providing good thermal mass for energy efficiency (see Section 3.3) may be associated with a higher embodied energy; as buildings consume less energy in operations, the energy embodied in the building's materials will become increasingly important as a percentage of a building's total energy footprint [16]. However, if an infrastructure asset is durable (see Section 3.1) and thus can remain in service longer, the operational energy efficiency can become more significant than the one-time embedded energy demands (see Figure 2(c)), even if the thermal mass is high in embodied energy, leading to net savings [25].

2.3. Measures for improving concrete sustainability

In concert with targets for overall CO_2 emissions [26], plans call for reduction in the cement industry by the year 2020 to 10% below a 1990 baseline through investments in equipment, improvements in formulations, and new techniques for cement and concrete that improve energy efficiency and durability [21]. These targets count on several advances with the potential to improve the carbon footprint of concrete construction, in conjunction with measures to lower the energy required in cement production [20]. The advances, in different stages of development (research, demonstration, pilot, semi-commercial), include emerging grinding and kiln technologies, alternative raw materials and cement products, carbon capture technologies, and nanotechnology [27].

One key advance is the use of Supplementary Cementitious Materials (SCMs) as pozzolan replacements in the manufacture of cement. SCMs are by-products of other industrial processes and include fly ash (coal-burning electric power plants), slag (iron blast-furnaces in steel mills), silica fume (electric arc furnaces), and calcined clays. These post-industrial recyclable materials are plentiful ($\sim$60 million tons of fly ash were produced in the U.S. in 2007) and would otherwise occupy valuable landfill space. The amount of cement used in concrete may be reduced by up to 60% through SCM substitution, leading to a reduction in greenhouse gas emissions per cubic yard of concrete of 45% [21]. SCM can also modify concrete properties, e.g. fly ash reduces concrete permeability and heat of hydration, and increases strength and durability [28]. Fly ash also slows the time of set which may be offset by chemical accelerating admixtures (other admixtures can reduce water demand or intentionally entrain air). Light colored SCMs, such as white silica fume or metakaolin can be used for architectural face mixes. As industrial by-products, some SCMs may not be part of an ideal future due to lower material availability as sustainable development extends to other industries. In the meantime, SCMs offer a low-cost solution with beneficial sustainability effects on multiple industries.

More exploratory technologies exist such as carbon storage methods. For instance, Accelerated Concrete Carbonation Curing (ACC) attempts CO_2 sequestration. This method accelerates the curing process, improves physical properties while storing carbon dioxide [29], and claims a potential to reduce global CO_2 emissions by as much as 1% [30].

3. Precast concrete construction

3.1. Precast concrete

Precast concrete is "prefabricated" at a plant and brought to the job site (see Figure 3). It is typically prestressed at the plant using high-strength steel tendons that place the concrete in compression (often placed lower in the cross-section to counteract the effects of gravity load, i.e. camber the beam upward so that gravity loads bring it back to the "zero" balance point) and thereby make the units more effective in transferring gravity loads. Prestressing provides two distinct benefits:

Figure 3. Precast concrete [31].

1. It increases stiffness because the cross-section acts as uncracked concrete;
2. It increases durability since reinforcing steel is not exposed to corrosion introduced by moisture penetrating cracks in the concrete.

The primary advantages of precast/prestressed construction include [31]:

1. *Speed of Construction*: Precast unit production occurs in parallel while site work progresses; the structure is erected rapidly by lifting units off the back of a truck; and all weather construction (cold weather does not stop construction);
2. *Better Quality Control*: Precast units are produced in controlled environment (ideal humidity, temperature, etc.) using standardized modular forms by skilled, experienced workers, and are easily inspected;
3. *Light Long spans*: Greater span-to-depth ratios are achieved for prestressed members;
4. *Durability*: The higher quality control inherent in precast concrete production, combined with the low permeability, low water-to-cement ratio and higher material strengths possible in the process, together with the uncracked nature of prestressed elements leads to a highly durable produce.

Precast/prestressed construction finds widespread use for exposed long-span structures such as stadiums, parking structures, and highway bridges. In recent years, the technique has found increasing use for a wide variety of architecture, including hotels; schools; and medical, governmental, and office buildings [31].

3.2. Precast concrete sustainability advantages

Precast concrete has several aspects that make it attractive as a sustainable building material [32], including those that directly address Leadership in Energy and Environmental Design (LEED^{TM}) Environmental Quality Credits [22]. These aspects pertain to its production, construction, and in-service qualities [33]:

1. *Less material:* The greater span-to-depth ratio possible for prestressed members leads to more slender precast members, and thus significant material savings (cement, gravel, and sand), and less water use in precast construction. The lighter members lead to a lower total structure dead weight, translating into smaller foundations. These material savings all translate directly to less use of natural resources, and less embodied energy and emissions associated with mining, processing, and transporting of raw material, and manufacturing and transporting of finished product;
2. *Less waste:* Raw materials, including water, are used more efficiently than normal construction because of precise mixture proportions and tighter achievable tolerances. Precast concrete generates low amounts of (low toxicity) waste (about 2% of concrete at a precast plant is waste, of which nearly 95% can be recaptured to produce new panels [32]);
3. *Efficient production:* Precast concrete is made in a factory with much more efficient use of energy than in-situ construction, leading to less energy used to build precast. Most U.S. precast plants are within 300 km of a building site with raw materials obtained or extracted from sources within 300 km of the plant. The primary raw materials used to make cement and concrete are abundant all over the world. Precast concrete elements are usually shipped efficiently because of their large, repetitive sizes and the ability to preplan shipments during the normal course of a project [33];
4. *Ease of recycling:* Waste materials are more likely to be recycled in plant concrete production. For example, gray water is often recycled into future mixes; about 5% to 20% of aggregate in precast concrete can be made of recycled concrete [33]; sand and acids for finishing surfaces are reused; and steel forms and other materials are reused;
5. *Durability:* The controlled environment and lower water-cement ratio (0.36-0.38) possible at the precast plant produces higher-quality concrete, which leads to a highly-durable, longer-lasting structure. The prestressing of units prevents or re-closes cracks, making the structure resistant to rain penetration and repeated freeze-thaw cycles, thereby mitigating reinforcement corrosion issues. Reinforcement is placed with higher-quality control in the plant than in-situ construction, greatly reducing the likelihood of inadequate cover, a common reason for surface deterioration. The longer service life for precast structures means less resources required for maintenance, repair, and replacement;
6. *Clean construction:* Precast construction is cleaner with less noise, dust, and particulates created at the jobsite as the major task is unloading precast units from the truck, ideal for urban areas with neighbors in close proximity to the site. Little waste or debris is created at the construction site (e.g. no formwork) [33]. Fewer trucks and less time are required because the concrete is made off-site, particularly beneficial in urban areas where minimal traffic disruption is critical. Precast units are large components, so greater portions of the building are completed with each activity;
7. *Low end-of-service life impacts:* Precast concrete can be readily "de-constructed", i.e. disassembled rather than demolished, avoiding dust pollution, noise, debris, and potentially dangerous demolition stages. Units from demolished structures can be reused in other applications, e.g. to protect shorelines [32]. A precast concrete shell can be left in place when the building interior is renovated;
8. *Down-cycleable:* Precast concrete is readily "down-cycled" (building materials broken down and reused) with a minimum amount of energy. Examples include using crushed precast concrete units as aggregate in new concrete or as base materials for roads, sidewalks, and tiles (see Figure 4).

Table 1 shows a comparison between typical precast and cast-in-place floors [34]. Note these benefits must be interpreted in conjunction with the material advances occurring in the wider concrete industry described in Section 2.3.

3.3. Advantages of total precast

Using a "total precast solution", which is a building totally made of precast elements, provides further advantages for sustainability. In this case, the structural precast members (columns, beams, and floor units) are supplemented by architectural precast elements (wall panels, cladding). Architectural precast has many attractive qualities [35] including thermal efficiency, excellent acoustic properties, and the ability to be built integrally with structural members (see Figure 5(a)) to integrate and optimize insulation levels, glazing, shading, thermal mass, air leakage control, surface

(a) (b) (c)

Figure 4. Precast down-cycling: (a) Planters [32]; (b) decks [65]; and (c) pavers [64].

(a) (b) (c) (d)

Figure 5. Precast Panels: (a) Integral cladding [36]; (b) sandwich panel; (c) insulation; and (d) heat lag [42].

Table 1. Embodied energy comparison [34].

Energy shown per m^2 of floor.	Hollowcore	Cast-in-situ
Concrete (kg)	263.7	423.0
Reinforcement (kg)	3.2	6.1
Total mass (kg)	266.9	429.1
Eutrophication (kg P04-3 eq.)	0.0356	0.0410
Exhaustion (x 10-12)	0.0468	0.0707
Ecotoxicity (x $l0^3$ m^3)	2.78	5.81
Greenhouse effect (kg CO_2 eq.)	55.2	53.4
Acidification (kg SO_2 eq.)	0.252	0.306
Summer smog (kg C_2H_4 eq.)	0.0297	0.0460
Human toxicity (kg)	0.318	0.411
Use of primary energy (MJ)	461	643
Solid waste (kg)	36.3	58.8

color, and texture. In particular, precast concrete can be used in a "sandwich panel" configuration for high efficiency in which a layer of insulation is sandwiched between the two wythes of the concrete panel (see Figure 5(b) and (c)).

1. *Integrated design:* Precast units can be left exposed with natural finishes of a wide range of profile, texture, and color options that require no additional treatment to achieve function and aesthetics. Polished concrete floors do not require carpeting; exposed concrete walls or ceilings do not require finish materials. This reduces the need for production, installation, and maintenance of finish materials, and eliminates products that could otherwise degrade indoor air quality, e.g. Volatile Organic Compounds (VOCs) in interior finishings that can release gases or combine with other chemicals in the air to form ground-level ozone. Concrete itself contains low to negligible VOCs, both in lower concentrations and emission rates [33];

2. *Specified exterior finish:* Precast exterior panels can be produced to provide reflective white surfaces to minimize urban heat island effects, and can be self-cleaning or change color [35]. Precast concrete's controlled production allows for replication of color for all panels for a project using pigments that will not fade due to sunlight [33]. Many urban areas are 2-4°C warmer than surrounding areas due to the heat island effect and are warming [36]. This has an impact on air quality as temperature is a major contributor to smog. A key measure is albedos; the amount of solar radiation reflected from a surface measured from non- to fully-reflective (0-1.0) [37]. Materials with higher albedos will reduce the heat

island effect, thereby saving energy and improving air quality [33]. Traditional Portland cement concrete has an albedo near 0.4, but raw material ratios can be adjusted to create white Portland cement with an albedo of 0.7-0.8, and the surface emittance (ability to release absorbed heat [38]) of most concrete surfaces is in the range of 0.85-0.95.

3. *Efficient building envelope:* Precast panels provide good fire resistance; significantly reduce sound penetration; and are impervious to rot, termite and vermin. Properly sealed precast panels (typically large with minimal joints) have low air infiltration and are resistant to wind-driven rain, and in conjunction with continuous, edge-to-edge insulation between precast concrete layers prevent moisture intrusion in hot and humid climates [32]. Exterior precast sandwich panels directly integrate optimal insulation that can save up to 25% on heating and cooling costs [33]. The thermal mass associated with concrete walls can significantly reduce energy demands by storing heat and delay the time it takes for a surface to heat up or cool off [22]. This thermal lag moderates daily temperature to reduce peak heating and cooling energy loads, or shift major energy usage to off-peak times (see Figure 5(d)). Nighttime ventilation can cool thermal mass warmed during the day [33]. Combined with insulated wall panels, the precast unit can produce high R factors and lower energy needs. These attributes can help earn LEEDTM Optimize Energy Performance credits [22] and translate into lower first costs for mechanical equipment due to smaller capacity requirements.

Autoclaved Aerated Concrete (AAC) is a highly thermally insulating concrete-based material used in precast panels. The better thermal efficiency of AAC makes it suitable for use in areas with extreme temperature as it eliminates need for separate materials for construction and insulation leading to faster construction and savings. Installation is quick and easy because the material can be routed, sanded, or cut to size on-site using standard carbon steel power tools. Due to its lower density, buildings constructed using AAC require smaller structural members and foundations. Improved thermal efficiency lowers heating and cooling loads in buildings; the porous AAC structure provides good fire resistance. The AAC industry is growing in Asia due to strong demand in housing and commercial space, with China, Central Asia, India, and the Middle-East the biggest markets for AAC manufacturing and consumption [38].

3.4. Future/ongoing precast concrete industry initiatives for sustainability

Recognizing that a 2% increase in construction costs will result in a savings of 10 times the initial investment in operating costs for utilities (energy, water, and waste) in the first 20 years of a building's life [39], the Precast/Prestressed Concrete Institute (PCI) is pursuing industry-wide sustainability initiatives including [32]: Tying member certification to meeting federal, state, and local green ordinances; increased use of local aggregate resources in mixtures; water reclamation; use of admixtures such as hardening accelerators to eliminate applied heat in curing; wider use of Self-Consolidating Concrete (SCC) for quicker placement, no vibration, and less surface defects; use of environmentally-friendly thin brick laminates in place of conventional brick; carbon-fiber reinforcement that allows lighter, larger concrete sections with less embedded energy and no corrosion; increased use of SCMs to reduce cement consumption (given the easier accommodation of the increased curing time associated with SCMs in a precast plant than on the jobsite [28]); Enclosed sandblasting facilities with 100% process-waste and dust control; standardizing wood form parts for multiple (∼40) reuses [32]; converting discarded forms into mulch or fuel; and recycling scrap steel and reinforcement. Note both the ACC and AAC techniques are more easily introduced in precast concrete's controlled production environment. In addition, PCI recognizes and awards precast projects that exhibit excellence in sustainability (see Figure 6).

3.5. Sustainable precast construction case study: China

As an example of the potential for the use of precast concrete in the developing world, consider recent developments in China. The modern precast industry

Figure 6. Award-winning green precast projects [32].

Table 2. Global cement production [40].

Main world producers - the G-20 group							
Country	**Cement production (million tonnes)**						
	2000	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
China	597.0	1068.8	1236.8	1361.2	1388.4	1650.0	1868.0
India	102.5	142.7	159.0	170.5	183.3	186.92	10.0
European Union	229.9	248.0	264.8	271.0	251.7	201.5	190.4
USA	87.8	99.3	98.2	95.5	86.36	3.9	65.5
Turkey	36.0	42.8	47.4	49.3	51.4	54.0	62.7
Brazil	39.8	38.7	41.4	45.9	51.6	51.4	58.9
Japan	83.3	68.7	69.9	67.8	63.0	54.9	51.7
Russian Federation	32.4	48.7	54.7	59.9	53.5	44.3	50.4
Korea, Rep. of	51.3	47.2	49.2	52.2	51.7	50.1	47.2
Saudia Arabia	18.2	26.1	27.03	0.3	37.4	37.8	41.0
Mexico	32.3	36.0	38.8	39.5	38.3	37.1	38.9
Indonesia	27.8	33.9	33.0	35.0	38.5	36.9	37.8
Italy	38.9	46.4	47.8	47.4	43.0	36.3	-
Germany	35.4	31.2	32.9	32.3	32.5	30.0	-
France	19.2	20.9	22.0	22.1	21.2	18.3	-
Canada	12.8	13.5	14.3	15.1	13.7	11.0	12.4
South Africa	8.2	12.1	13.1	13.7	13.4	12.0	12.0
Argentina	6.1	7.6	8.9	9.6	9.7	9.4	10.4
Australia	7.5	9.1	9.2	9.6	9.7	8.7	9.3
United Kingdom	12.5	11.6	12.1	12.6	10.5	7.8	-

in China was essentially nonexistent due to earlier poor seismic performance (see Section 4.1). However, the significant increase in China's cement production in the 21st century [40] (see Table 2) has led to a renewed interest in precast concrete. Starting around 2007, Chinese engineers, academia, contractors and developers began taking measures including inviting U.S. representatives to share knowledge on precast concrete in the form of presentations and discussions [41]. At the time, there was no widespread use of precast concrete other than bridges (a notable exception is the Dalian Xiwang Tower, a 43-story office tower employing precast/prestressed concrete beams, slab, and façade cladding system, constructed in record time in 1999, ~2 floors/week [42]). The resulting increased awareness of technical advances in precast technology over the past 30 years, in particular seismic resistant construction, has led to a rebirth in the Chinese precast industry with the potential for economic savings and lessening the environmental impact of the massive China construction boom.

Within the last half-decade, more than 50 new precast manufacturing factories have been built, including joint ventures with established European companies to establish a large mainland precast technology presence [43]. Builders, including the largest developer in China, have started actively promoting precast concrete for use in their projects, introducing technology from the Japanese precast industry and physical testing of ~$500M USD [44]. Several major precast concrete housing projects have been constructed (see Figure 7) [44]. An additional driving factor is the cost of labor in China, which has increased dramatically over the past 5 years and will continue to increase. The labor cost per cubic meter of precast concrete is less than that of cast in-situ concrete construction because of the efficient labor use in precast concrete [41].

Figure 7. China precast projects [45].

On the basis of these developments, the China Ministry of Construction instructed the China Institute of Building Standard Design and Research and Academy of Building Research to develop a new precast code for all of China [41]. The precast concrete structures technical specifications [45] are to become effective October 2014 with design aids being developed to accompany the code. In parallel, energy codes [46] are being enacted that mandate staged energy savings over time that enforce insulation requirements, and thus should further promote the use of precast concrete, in particular the insulated precast wall panels that are becoming popular to meet these requirements [41].

4. Earthquake resistant design

4.1. Past seismic performance of precast concrete

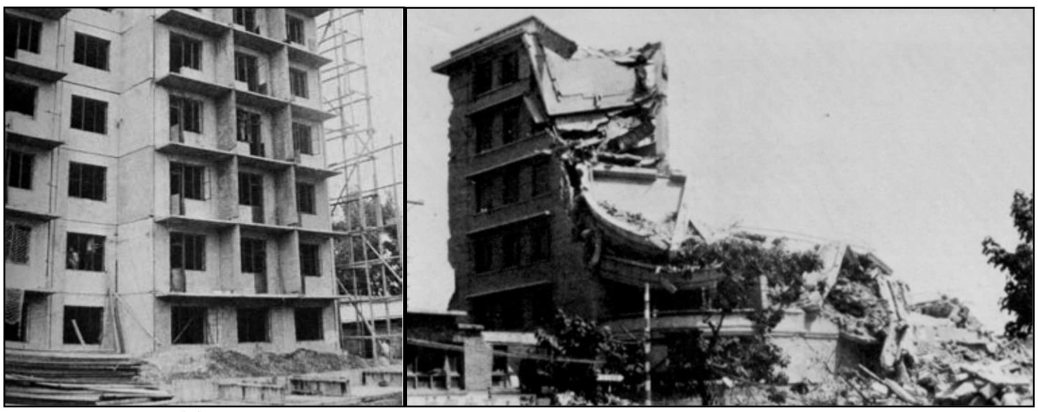
Precast concrete construction has been shown to be one of the most efficient, durable and economical construction techniques. However, its widespread use has been hampered by its past performance in earthquakes. Figure 8 shows several significant failures of precast structures in the past including: (a) collapse of a precast parking structure in the 2010 Baha Mexico earthquake [47]; (b) collapse of a precast parking structure in the 1994 Northridge earthquake [48]; (c) collapse of industrial buildings in the 2012 Emilio-Romagna earthquake [49]; and (d) out-of-plane failure of precast wall panels in the 2010 Chile earthquake [50]. Other than the first, where the building was under construction [48], the vulnerability of these structures is related to inadequate consideration of the panelized nature of precast structure and the needed characteristics of the connections details that unite them. As an example, consider precast construction in 1970s China.

Figure 8. Precast concrete failures in past earthquakes.

Figure 9(a) shows a typical apartment building under construction consisting of: precast exterior walls, precast floors, cast-in-place concrete interior shear walls, and brick partitions [51]. Many of these multi-family residential structures were built using a "Russian" system of flat slabs supported by load bearing panels [52] with few and brittle connections between precast units. In the M7.8 Great Tangshan Earthquake of July 28, 1976, approximately 85% of buildings in the region collapsed (see Figure 9(b)) leading to approximately one-half million fatalities [51].

4.2. Intent of the seismic design codes and guidelines

It is typically understood that it is not practical, reliable, or economical to "out-strength" an earthquake. Thus, modern seismic codes have adopted the approach of designing building structures for strengths significantly lower than those required for elastic response to the design earthquake, but requiring special detailing of the structure so that after it reaches its strength, certain key selected regions will serve as "structural fuses", yielding in ductile fashion, that is without fracturing or losing strength, thereby dissipating the energy of the earthquake. Typically, using the concept of "capacity design", other portions of the structure are designed to be sufficiently stronger than the fuses to keep them elastic, and thus not requiring expensive special detailing. The measures, in conjunction with



(a) (b)

Figure 9. Chinese construction circa 1970: (a) Precast construction; and (b) earthquake damage [52].

rules to avoid configurations that would be susceptible to a global collapse mechanism, form the basis of the code intent.

Existing building structures can be broadly divided into those that are properly configured, proportioned, designed, and detailed for good seismic performance and those that are not. The modern earthquake engineering code was not established until the 1970's, and important lessons have been learned in decades since. The built infrastructure may have service lives of 50-100 years, thus many existing older structures predate the modern seismic codes and thus do not conform to the best practices. Further, recent improved understanding of the geological seismic hazard worldwide has led to a reevaluation of the seismic risk for certain urban environments where strict seismic detailing has not been historically required. Buildings that do not conform to accepted seismic rules are termed "non-ductile". Most of the precast failures (see Section 4.1) are due to non-ductile details or components (e.g. floor systems).

However, it is important to note that, depending on the level of detailing and energy dissipation provided, a conforming structure may be designed for forces to nearly 10 times lower than would be required for elastic response. Thus, a properly designed and detailed structure is intended to incur damage to itself in the design earthquake (the energy is dissipated by yielding of the structure itself). This damage, while not leading to failure, may require repair or replacement; or may produce a structure that is not adequate for an aftershock or future earthquakes. The nonstructural elements (cladding, partitions, windows, etc.) have to undergo compatible displacements with the structure and can also incur damage. Likewise, the structure may not return to its original position, instead possessing residual drifts that may incur inoperability of elevators, doors or lead to penetrations in insulation or waterproof seals.

In recent years, the concept of Performance Based Earthquake Engineering (PBEE) has emerged. In this approach, an engineered asset is designed not just for adequate strength, but also to respond to the diverse needs of owner and users under common and extreme loads [53]. In parallel with advancements in PBEE, there is a recognition that minimizing or eliminating damage is an important performance requirement for seismic resilient urban communities due to an ongoing debate on the societal expectations of building performance in rare but devastating earthquakes [54].

5. Two design philosophies: Emulative versus Jointed precast concrete systems

The concept of accumulating versus avoiding damage can be clearly illustrated in the two seismic design philosophies applied to precast concrete construction, so-called "emulative" and "jointed" systems. These design approaches prevent the poor detailing or construction issues that led to precast failures in previous earthquakes. Though in use in many countries, New Zealand construction practice will be highlighted since its performance was tested recently.

5.1. Emulative precast concrete systems

The concept of emulative precast construction is to proportion the precast concrete structure to possess strong joints (relative to the elements), thereby forcing the inelastic response to the earthquake within the precast elements themselves, and to provide these precast elements with the special detailing associated with traditional seismic design of (cast-in-place) Reinforced Concrete (RC). Precast emulative systems are expected to perform similarly to properly designed ("conforming") cast-in-place construction under earthquake shaking [55], or even better since the special detailing involves accurate placement of the steel reinforcement, which is better suited to the precast plant than the jobsite (refer to Section 3.2). In a properly detailed RC moment frame, for instance, nonductile actions such as shear failure are precluded and the capacity design approach requires a strong-column/weak-beam design that protects against a concentration of lateral deformation termed a story mechanism. For emulative designs, the precast units are provided with: (1) ductile beam end region detailing; (2) sufficient transverse reinforcement to preclude shear failures and provide adequate confinement in plastic hinge zones; (3) proper detailing in joints to avoid anchorage, bond, or splice failures; and (4) overstrength in the column and joint to keep these regions elastic. In New Zealand, most emulative precast moment frames systems employ small cast-in place closure pours in splice regions located between the precast units [56]. The closure pour can occur at beam mid-span (see Figure 10) where the precast unit is erected by passing column longitudinal reinforcing through ducts. These closure joints are typically completed with pouring of the floor topping slab, including beam top reinforcing steel and diaphragm anchorage.

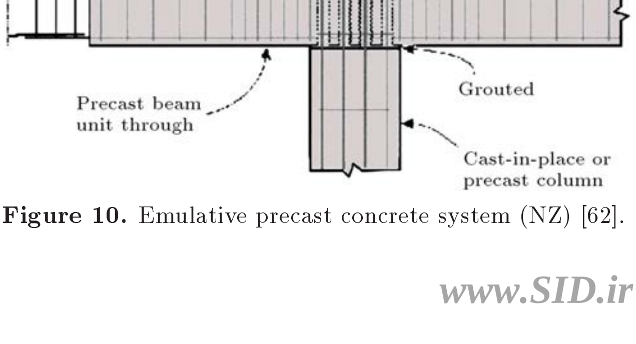


Figure 10. Emulative precast concrete system (NZ) [62].

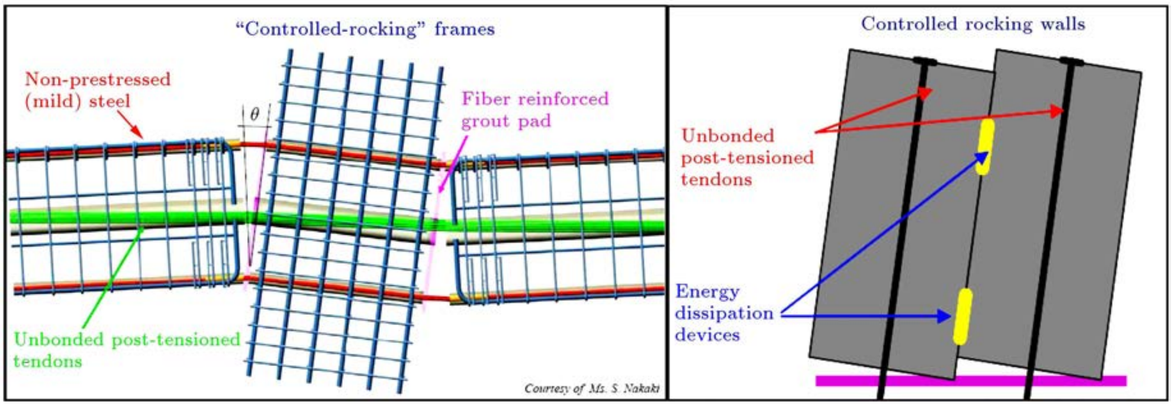


Figure 11. Jointed precast systems: (a) Hybrid frame; and (b) hybrid wall [58].

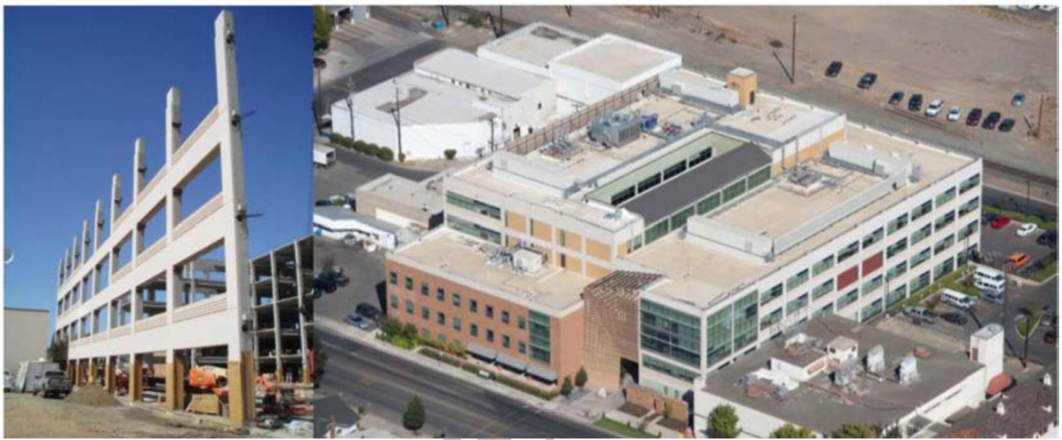


Figure 12. Recently constructed hybrid precast frame [60].

5.2. Jointed precast concrete systems

A more recent precast construction practice is jointed ductile construction, in which nonlinear deformation occurs not in distributed plastic hinge regions within precast units, but instead in specially detailed joints between precast units. The precast units are made stronger than the connections between the units, and the joints provide the ductile seismic "fuses" [57]. The most developed among jointed systems are PRESSS moment frames and coupled rocking walls [58,59] (see Figure 11). Both systems use unbonded post-tensioning through precast elements to achieve self-centering behavior. The structural elements are maintained in the elastic range, and energy dissipation can be provided by internally grouted mild steel or replaceable external dissipators. Because of the self-centering behavior and the use of reversible joint opening (rather than the cracking and yielding of plastic hinges), such systems are referred to as low-damage or damage-control systems. The systems can be considered to provide cost-efficient alternatives to seismic design options of base-isolation and supplemental damping devices.

These systems have begun to be built in the U.S. and elsewhere, including a recent LEEDTM silver design [60] (see Figure 12), which take full advantage of the thermal mass of the concrete exposing it to the interior as well as the exterior to maximize its benefits. The design team's mechanical engineer estimated that the energy savings from using the thermal mass of concrete was approximately 15% [60].

6. Case study: precast concrete performance in the 2011 New Zealand earthquake

6.1. The 2011 New Zealand earthquake

The 2011 Christchurch earthquake was roughly equivalent to the Maximum Considered Earthquake for Los Angeles, for a region with a design seismicity roughly equivalent to Portland [61]. Several reinforced concrete buildings collapsed or were damaged beyond repair, leading to nearly 200 fatalities. The strict seismic code and the well measured earthquake permitted a unique opportunity to evaluation building performance under strong ground shaking.

6.2. Performance of emulative precast systems

Figure 13(a) shows a 20-story Christchurch office tower built in 1988 using the system shown in Figure 10. Note that Figure 13(a) is post-earthquake. The moment

Figure 13. Precast emulative tower [62]: (a) Exterior; (b) construction; (c) typical seismic damage; and (d) demolition.

frame possessed specially-detailed interior and corner precast beam units installed on cast-in-place columns. Figure 13(b) shows a 1988 photo of one of the precast corner units being erected. Figure 13(c) shows the typical damage endured by one of those units, indicating the ductile damage expected of a specially detailed RC frame, and little damage in the column, indicating that the emulative design met its intended behavior [62]. Nevertheless, the damage incurred by this frame, which protected the building, led to the tower being torn down (see Figure 13(d)). Note that this demolition was performed using piece "deconstruction" as described in Section 3.2.

6.3. Performance of jointed precast systems

Contrast the above performance to a jointed precast structure, also located in the region of strong shaking. Figure 14(a) shows the structure, a 3-story medical office building, again shown after the earthquake. The structure employed hybrid frames (i.e. Figure 11(a)) in one direction and hybrid rocking walls (Figure 11(b)) in the other [63]. Figure 14(b) shows the extent of the damage incurred in this structure, which was limited to some drywall rubbing on the staircase. Figure 14(c) shows the precast hybrid moment frame, indicating no damage and a re-centered structure [62]. Figure 14(d) shows the post-earthquake state of the buildings, indicating an immediate operational state, as needed in a critical care facility.

6.4. Discussion of performance

The emulative structure performed exactly as intended under an earthquake significantly stronger than its design earthquake. The design placed joints in the precast structure at non-critical locations and detailed the precast unit to safely dissipate the energy of the

Figure 14. Precast hybrid structure [62]: (a) Exterior; (b) seismic damage; (c) frame; and (d) post-EQ operational.

earthquake without structural distress. But the damage incurred to the structure was deemed unacceptable for repair and the structure was demolished. This indicates a difference in the expectation of the design professional/code and that of the general public [62]. Contrast this with the performance of the hybrid structure which survived the earthquake essentially damage free and immediately operational. This difference points out the benefits of using such low-damage structures for resilient communities.

7. Conclusions

Precast concrete construction possesses inherent characteristics that may be competitive in modern construction where an increased emphasis is placed on sustainability and earthquake resilience. The high quality control and prestressing of precast concrete lead to less material required and hence less embodied energy; the piece erection lead to cleaner, quieter construction sites; and the insulation and architectural finish can be integrated directly into the precast unit, increasing energy efficiency and consolidating construction operations. The seismic performance of precast concrete, historically a liability due to nonductile details acting at critical joints, can actually outperform other construction forms in the modern world where damage accumulation is less tolerated by taking advantage of the jointed nature to eliminate structure damage and the use of unbonded post-tensioning to provide a re-centered structure after the earthquake. The safe, effective, and efficient use of precast concrete involves an investment in technology, infrastructure, and transfer of knowledge from those countries with extensive experience, but in the longer term has the potential for economic savings, less adverse environmental impact, and improved urban resilience.

Acknowledgements

The post-earthquake reconnaissance trip to Christchurch New Zealand was supported by funds from the Precast/Prestressed Concrete Institute (PCI). The participation and contributions of PCI reconnaissance team members, Stefano Pampanin, Jose Restrepo, Joe Maffei, and Franz Zahn, in addition to the co-authors are acknowledged. Any findings or conclusions do not necessarily reflect the views of PCI.

References

1. National Academies, *Disaster Resilience: A National Imperative*, Joint Report, Cmte. on National Resilience to Hazards & Disasters; Cmte. on Sci., Eng., & Public Policy, Wash. DC: The National Academies Press (2012).
2. FEMA, *Mitigation Ideas: A Resource for Reducing Risk to Natural Hazards*, Federal Emergency Management Agency, Risk Analysis Division (January 2013)
3. National Research Council "National earthquake resilience: Research, implementation, and outreach", Report by the Committee on National Earthquake Resilience, Washington, DC: The National Academies Press (2011).
4. Bevington, J., Huyck, C., Dell'Acqua, F., Wieland, M., Jordan, C., Eguchi, R. and Adams, B. "Remote sensing for building inventory generation", *9th Intl. Workshop on Remote Sensing for Disaster Response*, Stanford, CA (Sept 2011).
5. Chang, S.E., Gregorian, M., Pathman, K., Yumagulova, L. and Tse. W. "Urban growth and long-term changes in natural hazard risk", *Environment and Planning A*, **44**, pp. 989-1008 (2012).
6. O'Rourke, T.D. "Critical infrastructure, interdependencies, and resilience", *Engineering for the Threat of Natural Disasters*, Washington, DC: The National Academies Press (2007).
7. Rose, A. "Economic resilience to disasters", Report to Comm./Reg. Resilience Inst., Oak Ridge TN (Nov. 2009).
8. National Research Council, "Grand challenges in earthquake engineering research", A Community Workshop Report. Washington, D.C.: The National Academies Press (2011).
9. NIBS "Natural hazard mitigation saves: An independent study to assess the future savings from mitigation activities", *National Institute of Building Sciences* (2005).
10. Moddemeyer, S. "Resilience as a framework for sustainability", *Cities of the Future, Resilience and Sustainability*, CollinsWoerman, OneSF Presentation, San Francisco (2010).
11. Cleveland, J., *Moving Best Practices Forward for Sustainable Communities*, Innovation Network for Communities, Presentation, National Academy of Sciences (May 29, 2013).
12. Johnson, L., Hueste, M.B., Olshansky, R.B. and Zhang, Y. "Perspectives on modeling seismic mitigation strategies", *Risk Assessment, Modeling and Decision Support*, Springer-Verlag, pp. 247-260 (2008).
13. Bribián, I.Z., Usón, A.A. and Scarpellini, S. "Life cycle assessment in buildings: State-of-the-art LCA methodology as a complement for building certification", *Bldg. & Environment*, **44**(12), pp. 2510-2520 (Dec. 2009).
14. EIA, Energy Information Administration, *Annual Energy Review*, U.S. Department of Energy, Wash. DC (2009).
15. Milne, G. and Reardon, C., *Your Home Material Use: Embodied Energy*, Commonwealth Scientific and Industrial Research Organisation (CSIRO), Australia National Science Agency (2013).
16. Cannon Design, *Material Life: Embodied Energy of Building Materials* (2013).

17. Mishra, S. and Usmani, J.A. "Comparison of embodied energy in different masonry wall materials", *International Journal of Advanced Engineering Technology*, pp. 90-92 (Oct-Dec. 2013).

18. Baird, G., Alcorn, A. and Haslam, P. "The energy embodied in building materials - updated New Zealand coefficients and their significance", *IPENZ Transactions*, **24**, No. 1/CE, NZ ERDC (1997).

19. Gibbs, M.J., Soyka P. and Conneely, D. "CO_2 emissions from cement production, IPCC background document: Good practice guidance and uncertainty management in national greenhouse gas inventories", *Intergovernmental Panel on Climate Change* (1997). http://www.ipcc.ch/

20. Portland Cement Association, 1998 U.S. and Canadian LaborEnergy Input Survey, Skokie, IL (1998), www.cement.org.

21. "Cement sustainability initiative", 2012 Progress Report, World Business Council for Sustainable Development (2012).

22. U.S. Green Building Council, "An introduction to the U.S. green building council and the LEED green building rating system," (October 2005), www.usgbc.org.

23. Energy Information Administration, China Energy Analysis Brief, U.S. D.O.E., Washington DC (February 2014).

24. Hegner, S. "Embodied energy for energy efficiency measures: An assessment of embodied energy's relevance for energy saving in the Swiss residential building sector", *Diploma Thesis*, ETH Zurich (Sept. 2007).

25. Adams, E., Connor, J. and Ochsendorf, J. "Embodied energy and operating energy for buildings: cumulative energy over time. Design for sustainability", *Civil and Environmental Engineering, MIT*, Cambridge, MA (2006).

26. UNEP 2014, The Emissions Gap Report: 2014, A UNEP Synthesis Report, Published by the United Nations Environment Programme (UNEP), Nairobi (November 2014).

27. Hasanbeigi, A., Price, L. and Lin, E., *Emerging Energy-Efficiency and CO_2 Emission-Reduction Technologie for Cement and Concrete Production, China Energy Group*, Energy Analysis and Environmental Impacts Department Environmental Energy Technologies Division, Lawrence Berkeley National Laboratory (2012).

28. Zachar, J. "Sustainable and economical precast and prestressed concrete using fly ash as a cement replacement", *J. Mater. Civ. Eng.*, **23**(6), pp. 789-792 (2011).

29. Bridgette Meinhold, http://inhabitat.com; Canadian environmental consultants, Carbon Sense Solutions

30. Kashef-Haghighi, S. and Ghoshal, S. "CO_2 sequestration in concrete through accelerated carbonation curing in a flow-through reactor", *Ind. Eng. Chem. Res.*, **49**, pp. 1143-1149 (2010).

31. Precast/Prestressed Concrete Institution, *PCI Design Handbook*, Sixth Edition, Chicago IL (2004).

32. PCI Sustainability FAQ, Precast/Prestressed Concrete Institute (2013). www.pci.org

33. Van Geem, M. "Achieving sustainability with precast concrete", *PCI Journal*, pp. 42-61 (Jan.-Feb. 2006).

34. "Environmental issues in prefabrication. Environmental issues in prefabrication", fib State-of-Art report N°21, International Federation Beton, 56 pages, ISBN 978-2-88394-061-1 (March 2003).

35. *The Little Green Book of Concrete: Precast Concrete for Sustainable Construction*, National Precast Concrete Association (NPCA) in conjunction with British Precast (2008).

36. Heat Island Group, Environmental Energy Technologies Division, Lawrence Livermore National Laboratory, http://eetd.lbl.gov/Publications

37. American Society for Testing and Materials, ASTM E 1918, *Standard Test Method for Measuring Solar Reflectance of Horizontal and Low Sloped Surfaces in the Field*, West Conshohocken, PA (1918).

38. AAC India, http://www.aac-india.com/speech-indian-aac-industry-today-tomorrow/

39. "Green value, green buildings growing assets", www.rics.org/greenvalue

40. Clarke, M. "British precast", *The Great Works of Prefabrication, Presentation*, **15**, WCEE 2012, Lisbon (24-28 Sept. 2012).

41. Seeber, K. "The future use of PC in China", *Technical Presentation*, China Academy of Building Research (2014).

42. http://precastdesign.com/projects/high-rise/dalian_xiwang_gallery.php#13_dalian_xiwang/Xiwang_01.jpg

43. Chu, K., and Hendrickx, J., Finland Country Discovery Report, South China Post Topics (02 July 2013), http://www.scmp.com/article/1273870/team-finla nd-raises-level-co-operation-mainland-firms

44. Xu, X. and Zhao, Y. "Some economic facts of the prefabricated housing", *Dept. of Supply Chain Management & Marketing Sciences Seminar*, Rutgers Univ. (January 2010), http://zhao.rutgers.edu/Xu-Zhao-10-01-12.pdf

45. *National Standard of the People's Republic of China: Code for Design of Concrete Structures*, GB 50010-2010, Ministry of Housing and Urban-Rural Development, China Architect and Building Press, 2010, 2014.

46. *The Emerging Chinese Market for Building Energy Efficiency*, U.S. Department of Energy Webinar (Oct 29, 2014), http://www.globalchange.umd.edu/data/seminars/2014-10-29-China_Bldg_EE_Opportunities.pdf

47. "The El Mayor cucapah, Baja California earthquake", An EERI Learning from Earthquakes Reconnaissance Report, Jorge Meneses, Editor, Earthquake Engineering Research Institute (April 4, 2010).

48. Iverson, J.K. and Hawkins, N.M. "Performance of precast/prestressed concrete building structures during Northridge earthquake", *PCI Journal*, **39**(2), pp. 38-55 (1994).

49. "The 29th May 2012 Emilia Romagna earthquake", EPICentre Field Observation Report, No. EPI-FO-290512, 21/06/2012, UCL EPICentre, University College London (June 2012).

50. Ghosh, S.K. and Cleland, N.M. "Performance of precast concrete building structures", *Earthquake Spectra: June 2012*, **28**(S1), pp. S349-S384 (2012).

51. *The Great Tangshan Earthquake of 1976*, Overview Volume, Earthquake Engineering Laboratory, California Institute of Technology Pasadena, CA 2002, Eds. L. Huixian (Chinese) G. Housner and H. Duxin (English) (1976).

52. Khare, R.K., Maniyar, M.M., Uma, S.R. and Bidwai, V.B. "Seismic performance and design of precast concrete building structures: an overview", *Journal of Structural Engineering*, **38**(3), pp. 272-284 (Aug-Sept. 2011).

53. Krawinkler, H., *Advancing Performance-Based Earthquake Engineering, Selected Papers in Earthquake Engineering*, NISEE Earthquake Engineering Library, PEER Center, UC-Berkeley (2000).

54. Pampanin, S. "Reality-check and renewed challenges in earthquake engineering: Implementing low-damage structural systems", *Bulletin of NZSEE*, **24**(4), pp. 137-160 (December 2012).

55. CAE, 1991, *Guidelines for the Use of Precast Concrete in Buildings*, Centre for Advanced Engineering, University of Canterbury, Christchurch, New Zealand, 1st edition (2nd edition 1999).

56. Park, R. "Seismic design and construction of precast concrete buildings in New Zealand", *PCI Journal*, **47**(5), September-October, pp. 60-75 (2002).

57. fib, Fédération Internationale du Béton, *Seismic Design of Precast Concrete Building Structures*, State of the Art Report. Bulletin No. 27, Lausanne, Switzerland p. 254 (2003)

58. Priestley, N., Sritharan, S., Conley, J. and Pampanin, S. "Preliminary results and conclusions from the PRESSS five-story precast concrete test building", *PCI Journal*, **44**(6), pp. 42-67 (1999).

59. Ghosh, S. and Hawkins, N. "Codification of precast seismic structural systems", *PCI Journal*, **51**(3), May-June, pp. 2-5 (2006).

60. Ibrahim, F. PE, SE, LEED AP, Director of Preconstruction Services, Clark Pacific, "Total precast case study: Caltrans district office building 3", Presentation PCI Committee Days (April 2012).

61. EERI, "Learning from earthquakes: The M 6.3 Christchurch, New Zealand, earthquake of February 22, 2011", Special Earthquake Report, Earthquake Engineering Research Institute, May (2011).

62. Fleischman, R., Restrepo, J., Pampanin, S., Maffei, J., Seeber, K. and Zahn, F. *Damage Evaluations of Precast Concrete Structures in the 2010-2011 Canterbury Earthquake Sequence*, EQ Spectra: Feb 2014, **30**(1), pp. 277-306 (2014).

63. Cattanach, A. and Pampanin, S., "21st century precast: The detailing and manufacture of NZ's first multi-story PRESSS-building", in *Proceedings NZ Concrete Industry Conference*, Rotorua, NZ (October 2-4 2008).

64. Stepstone, Inc., Precast Solutions (1983). Retrieved from http://www.stepstoneinc.com/profile_popup.htm?script=large-scale-narrow-modular-pavers.js&section=0&ind=14

65. Cathy Schwabe Architecture. Retrieved from http://www.houzz.com/ideabooks/2383952/list/precast-concrete

Biographies

Robert Bernard Fleischman, PhD, is a Professor, and formerly the Delbert R. Lewis Associate Professor, in the Civil Engineering and Engineering Mechanics Department at the University of Arizona. Dr. Fleischman's research area is seismic resistant design and resilience of precast/prestressed concrete and steel structures with recent projects including the development of new low-damage seismic-resistant building systems, evaluation of water pipe systems, and developing a new design methodology for precast concrete floor diaphragms. The latter work will included in new design provisions approved for inclusion in the ASCE 7-16 Load Standards and Part 3 of the 2015 National Earthquake Hazards Reduction Program (NEHRP) Recommended Provisions for Seismic Design for New Buildings. Dr. Fleischman has industry experience at Turner Construction (NYC), Thornton-Tomasetti (Chicago) and Rutherford & Chekene (San Francisco). He has won several national awards for his research including the 2016 American Society of Civil Engineers (ASCE) Charles Pankow Award for Innovation, the National Science Foundation (NSF) 2014 NEES Outstanding Contributor Award, and the Precast/Prestressed Concrete Institute (PCI) 2014 Leslie D. Martin Award of Merit, the 2009 and 2004 Martin P. Korn Awards, the 2006 Charles C. Zollman Award, and 2004 George D. Nasser Award. Dr. Fleischman has led earthquake reconnaissance teams to Haiti and New Zealand. Dr. Fleischman has also won teaching awards at the University of Arizona six times in the past decade.

Kim Seeber, P.E., FPCI, is a senior vice president at Seaboard Services of Virginia Inc. in Taylors, S.C. Mr. Seeber received his B.S. and his M.S. degrees from The University of Illinois at Urbana-Champaign. He has served on several key committees of the Precast/Prestressed Concrete Institute (PCI) including as Chairman of the 35-member PCI Industry Handbook Committee, responsible for the publication of the PCI Design Handbook, the industry standard for precast/prestressed construction. In recent years, Mr. Seeber has focused on the development of a sustainable precast concrete industry in China, having served on an international delegation meeting with Chinese government officials, industry practitioners and university faculty. In this capacity, Mr. Seeber has made several key international presentations. He was part of the four-man team sent to New Zealand in 2011 to investigate the performance of precast concrete systems in the 2011 Christchurch Earthquake. Mr. Seeber was elected a Fellow of the Precast/Prestressed Concrete Institute in 2000.