LadderBlock System

Seismic Performance

8436 Spicewood Springs Road
Austin, TX 78759
Tel. +1-512-250-5200
info@LadderBlock.com
www.LadderBlock.com

LadderBlock™ Seismic Performance

State of the Art in Precast Seismic Design

In many regions of the world that are prone to earthquakes, reinforced concrete is the preferred construction system. Concrete structures can offer the strength to resist the ground motions of an earthquake, but in many cases they are so stiff that they suffer severe damage during the event. The resulting damage can render a building uninhabitable, but the worst outcome is a collapse that endangers the lives of those in or near the structure. Unless concrete members and their internal reinforcing steel are properly detailed, vital structural members can shear or be reduced to rubble, and the resulting loss of integrity of critical members can lead to collapse.

The engineering of structures to resist seismic activity improves with the knowledge gained in every earthquake, and with continuing engineering research conducted in labs across the globe. Engineers today are better informed regarding the detailing and features that improve the seismic performance of structures, and this knowledge is supplemented by the development of tools such as base isolation and improvements in methods for designing ductility into structural systems. Base isolation systems seek to minimize and damp the effects of ground motion that are felt by a structure, and ductility is the feature of a structural system that allows it to dissipate the energy of an earthquake, often by directing damage to locations that are not critical to the survival of the structure.

In the design of precast concrete structures to resist seismic forces, the objective has long been to design and build a precast structure to emulate the behavior of a cast-in-place structure. Precast connections that normally consist of welded or bolted embed plates can tend to produce localized failures and brittle behavior, so trends have been toward building structural systems that use cast-in-place concrete joints to connect precast elements. This approach can successfully emulate the seismic behavior of cast-in-place concrete. The seismic design of cast-in-place concrete generally seeks to achieve ductility, or the energy absorbing behavior that can allow a structure to ride the ground motion and survive, by accepting damage in non-critical members away from joints. Although these methods can achieve the goal of a structure that survives without collapse, the result is often a building that is permanently deformed and unusable. Current research is therefore directed at reducing structural damage.

Recent thinking in the engineering community has moved away from emulating the behavior of cast-in-place concrete and toward designing precast systems that behave very differently. In research conducted as part of the Precast Seismic Structural Systems (PRESSS) Program undertaken jointly by the U.S. and Japan, a variety of details have been developed and tested with the goal of building ductility at the joints that occur between precast elements. Details evaluated include a variety of post-tensioned beam, column, and shear wall systems that allow rotations to occur at joints with little or no damage. Encouraging results were achieved using internal post-tensioning cables with sections that were unbonded at joints. The increase in ductility that resulted from these details allowed the structure to return to its original position after undergoing deformations that were much greater than would be expected in even a severe earthquake. In essence, the energy of the earthquake motions were absorbed in the stretching and rebound of post-tensioning cables, rather than through permanent yielding of reinforcement as would occur in a cracked cast-in-place structure.

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Although the benefits of post-tensioning cables can be included in a LadderBlock assembly (see "LadderBlock Multi-Story Considerations"), basic LadderBlock features described below can offer many of the benefits of a post-tensioned system, but without the cost and complexity normally associated with those systems. And while a LadderBlock structure could easily incorporate a base isolation system, features that are inherent in the LadderBlock system can provide similar damping of and cushioning against ground movements.

LadderBlock Seismic Engineering

The engineering of a LadderBlock structure to resist earthquake forces enjoys the same advantages that are found in its gravity and wind load design; the work is greatly simplified by the modularity of the building system. Although Frame Blocks, Spacer Blocks, and Sculpted Floor Blocks™ can be combined in an infinite number of ways to construct buildings of different sizes and shapes, the basic building block geometry and connectivity are constant. This allows the design engineer to gain a deep understanding of the structural behavior of each building block, and of the interface between blocks. Once this understanding is translated into analytical modules, these modules can be replicated and combined to build an analytical model of a proposed assembly with speed and ease. The design process can therefore be accelerated beyond conventional practice; and for the same reasons that a LadderBlock structure can be erected in a fraction of the time required for conventional construction.

LadderBlock structures that are designed in conformance with the International Building Code (IBC) are subject to the provisions of the American Concrete Institute (ACI) Building Code Requirements for Structural Concrete, ACI 318. Chapter 21 of ACI 318 includes prescriptive requirements that apply to both cast-in-place and precast concrete moment frames, but the commentary to Section 21.6.3 states that "Precast frame systems not satisfying the prescriptive requirements of Chapter 21 have been demonstrated in experimental studies to provide satisfactory seismic performance characteristics". ACI Section 21.6.3 specifies that such precast special moment frames satisfy the requirements of ACI T1.1, "Acceptance Criteria for Moment Frames Based on Structural Testing" (most recent revision adopted as ACI 374.1-05). ACI T1.1 defines a protocol for establishing a design procedure that is validated by analysis and laboratory tests, and is the vehicle by which LadderBlock seismic design procedures and validation are being established. Although ACI T1.1 generally allows the testing of discrete beam/column joints that may be of reduced scale, the testing and validation of LadderBlock assemblies will include the evaluation of full-scale multi-level assemblages. This testing will deliver data that is more complete and accurate than could be obtained from more limited testing.

Static load and displacement testing methods to simulate seismic activity are well established. Full-scale testing of LadderBlock can be performed in a number of structural laboratories that offer shear wall or other loading systems that can apply large lateral forces at heights above a reaction floor. Because of the speed and ease with which LadderBlock structures can be erected, it is also feasible to perform lateral load testing by erecting two multi-story assemblies side-by-side and then pushing the two apart or pulling them together in a controlled and instrumented procedure. Such tests could in fact yield simultaneous pairs of load and test data for the two loaded structures. A more limited number of facilities in the U.S. and abroad also

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offer dynamic testing for seismic response using large-scale shake tables. Combining static load / displacement testing of the LadderBlock system with dynamic testing on a shake table will provide an even more comprehensive understanding of the response of LadderBlock during a seismic event. The information gathered from these tests will enable the refinement of design methods, and the modular extrapolation of these methods will enable the design of larger and taller structures in conformance with the International Building Code.

Beneficial LadderBlock Features

At the most general level, LadderBlock offers significant advantages in structural performance by virtue of the inherent precision, quality control, and reliability of the structure as compared to cast-in-place construction. But there are also specific features of the LadderBlock system that greatly enhance its seismic performance potential.

Two such features that are unique to LadderBlock are the use of long threaded rod connectors and the incorporation of compressible bearing pads at block interfaces.

In normal bolted construction, the bolts are generally short and can only stretch a small amount before permanent yielding and tensile fracture of the bolt will occur. Threaded rod connectors in a LadderBlock structure are unusually long; a threaded rod that passes through an 8” thick Frame Block column and a 16” Spacer Block column can stretch along its 24” length; and the accumulation of such movements can offer elasticity to allow the movement that is needed for a structure to respond to an earthquake with little or no permanent damage. The threaded rod connectors inherent in a LadderBlock assembly can dissipate the energy of a seismic shaking and return a structure to its original position in much the same way that unbonded post-tensioning tendons can. It is of added benefit that the energy dissipation afforded by the long bolts occurs away from critical beam-column joints.

Another unique aspect of the LadderBlock system is the presence of continuous bearing pads, or gaskets, between both horizontal and vertical interfaces of the precast members. The thickness of the pads can be adjusted to provide additional flexibility where needed, or to tune the stiffness of a structure during design. In much the same way that some base isolation systems utilize thicknesses of reinforced neoprene bearing pads at the base of a structure to isolate it from ground movements, the bearing pads that are built into every level of a LadderBlock structure can provide damping and ductility in the structural response to an earthquake. Because this energy dissipation occurs at member interfaces, the moment connections inherent within each LadderBlock element are available to act as a secondary energy dissipation system and to provide a high level of structural redundancy and safety.

When designing a structure to resist gravity loads or wind loads, the engineer is generally confident that the actual forces are smaller than the design forces that will be experienced by the structure. The same is not true in seismic design. Actual forces experienced in a strong earthquake may be much larger than the calculated design forces, so that the potential for unexpected damage always exists. In a cast-in-place concrete structure, significant damage to portions of the load resisting system may require that the entire structure be demolished. Another unique attribute of LadderBlock lies in its proven replacement part capability. Because block geometry is standardized and manufactured with extraordinary precision, it is possible to remove and replace one or several damaged threaded rod connectors, bearing pads, or blocks in

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a LadderBlock structure. Because standard replacement blocks can be quickly reproduced or even taken from inventory, the repair of a damaged LadderBlock structure to “like new” condition can be accomplished in a fraction of the time required to execute a lesser repair on a conventional structure.

When the unique features of a LadderBlock seismic structure are combined to build a well-engineered building, the system offers the potential for a building to exceed performance expectations, and to survive where conventional construction fails.

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