LadderBlock Wall System - Strength to Protect against Progressive Collapse

The LadderBlock Wall System (patents pending) offers a precision precast building solution that makes safer and more economical work of repetitively building anything from villas to multistory towers, while building at a speed that is not possible using conventional construction techniques. LadderBlock is engineered for speed. But it is engineered first for strength.

Joint Strength

Conventional precast wall to wall connections rely on two or three welded joints between steel plates that are embedded at each end of each wall; these connections cause stress concentrations and are prone to corrosion.

LadderBlock wall joints interlap reinforced precast fingers (Fig. 1) to weave the structure together at every joint, and then those joints are pinned and grouted solid to lock them together. Each LadderBlock project is designed to meet or exceed the requirements of the International Building Code, or local codes as applicable, and each building is engineered and detailed on the basis of an analytical model that is specific to the geometry and loading conditions of the project.

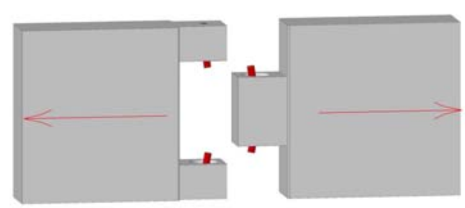


Fig. 3

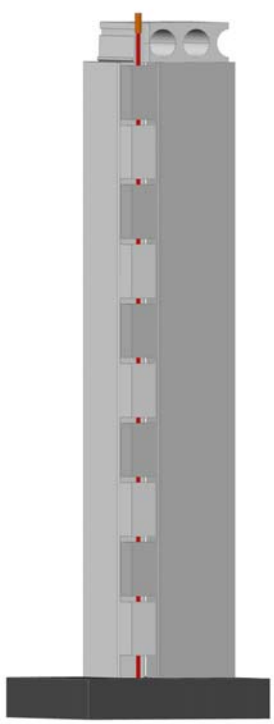


Fig. 1

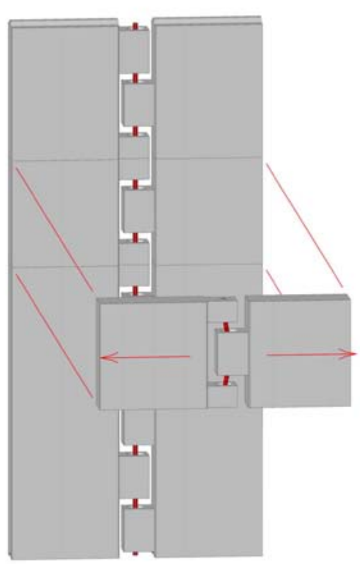


Fig. 2

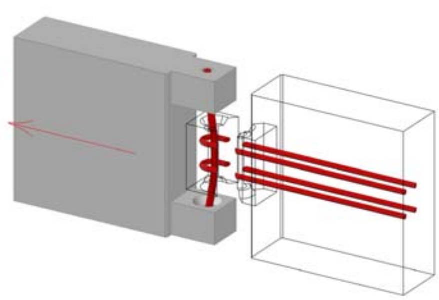


Fig. 4

Consider the work required to break apart a LadderBlock wall finger joint such as that shown in Figure 1. Before anything else could happen, the grout that fills the joint would have to crack or crush between every finger, while concurrently engaging the vertical reinforcing steel pin (shown red) that passes through every joint. The size and material strength of the joint pin is based on engineering requirements for each project. The pin may consist of anything from a small diameter reinforcing steel bar to a large diameter high strength bar or strand that might be post-tensioned, so that a great range of joint and system strengths are available to the design engineer.

As an earthquake or other destructive force tries to tear a LadderBlock wall joint apart, consider the action within a single finger of this joint (Fig. 2). The forces required to pull this one finger out of the joint would have to be large enough to fail the grout and shear the joint pin across not one but two planes (Fig. 3). The only other way to pull this finger out of the joint is to fracture the precast concrete finger itself (Fig. 4), along with the reinforcing steel hairpins bars that wrap around the pin sleeve inside every finger. Both finger failure modes would require a very large force, especially by comparison to the force required to tear apart a conventional precast joint that consists of field-welded embed plates. LadderBlock's large finger capacity is multiplied by every finger that enters the joint to provide extraordinary joint strength. The individual fingers that extend into a joint from any given wall are generally separated by large distances, or moment arms, so a LadderBlock wall joint offers large lateral load resistance and the stability that comes with moment resistive connections. That high joint strength is multiplied by every joint in the structure, at every wall intersection, to provide a completed building that offers uncommon performance and strength.

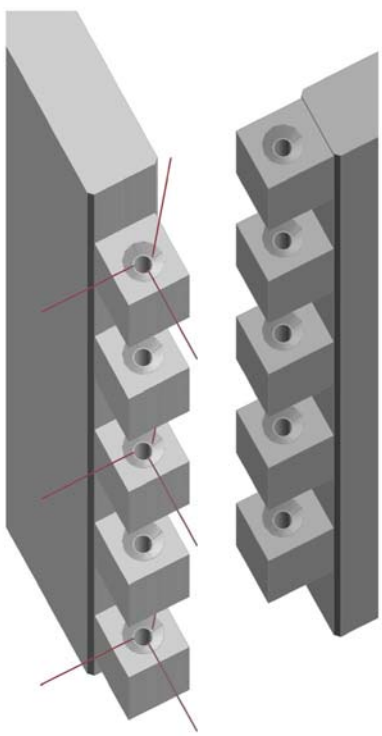


Fig. 5

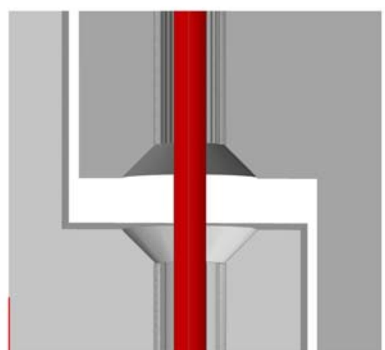


Fig. 6

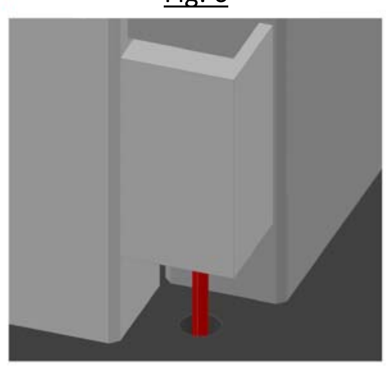


Fig. 7

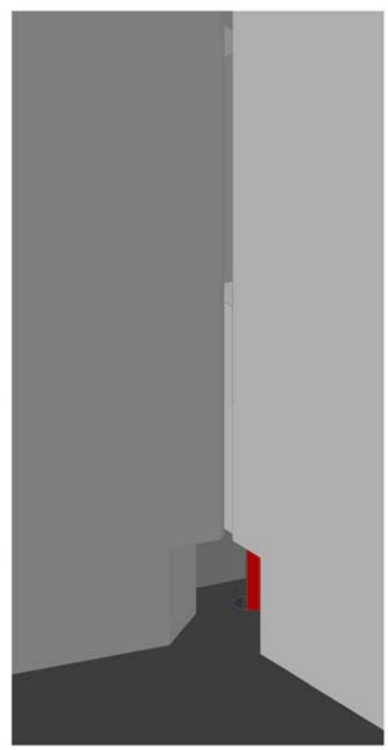


Fig. 8

LadderBlock wall joints are manufactured with features like form tie wires (Fig. 5) that facilitate the grouting operation and help ensure the strength of the finished joint. The grout locks the joint together as the first line of strength, and also serves to protect the vertical joint pin. LadderBlock connections leave no steel exposed to potential corrosion, but always encase the steel in a protective layer of grout. Vertical joint pins extend into oversized holes in the slab (Fig. 7), and wall block bases are detailed and cast to provide access to these joints (Fig. 8) for subsequent grouting operations. The grout ties each continuous vertical pin to the foundation and locks it into the height of the joint.

Steel vertical pins in each joint extend to about the level of the next precast floor or roof deck above. They are joined with standard bar couplers (Figs. 9 and 10) to the corresponding pin of the wall above. Couplers develop the strength of the pin and provide continuous vertical reinforcement at every stacked joint in the building.

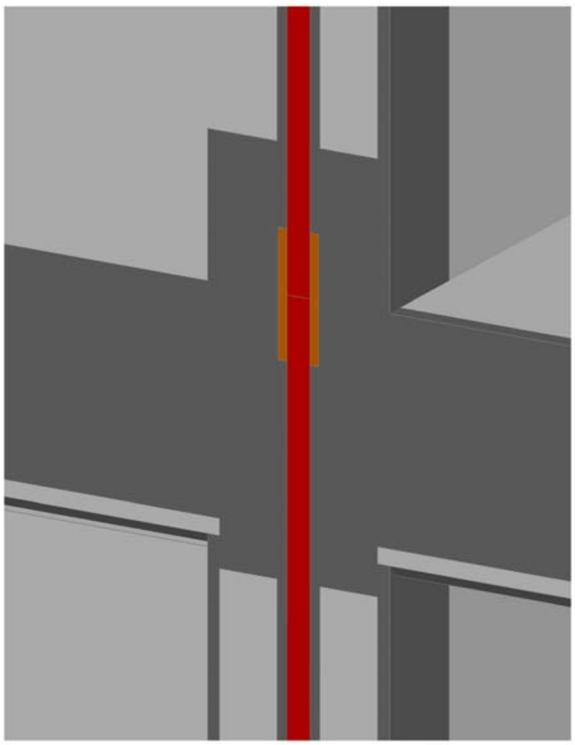


Fig. 9

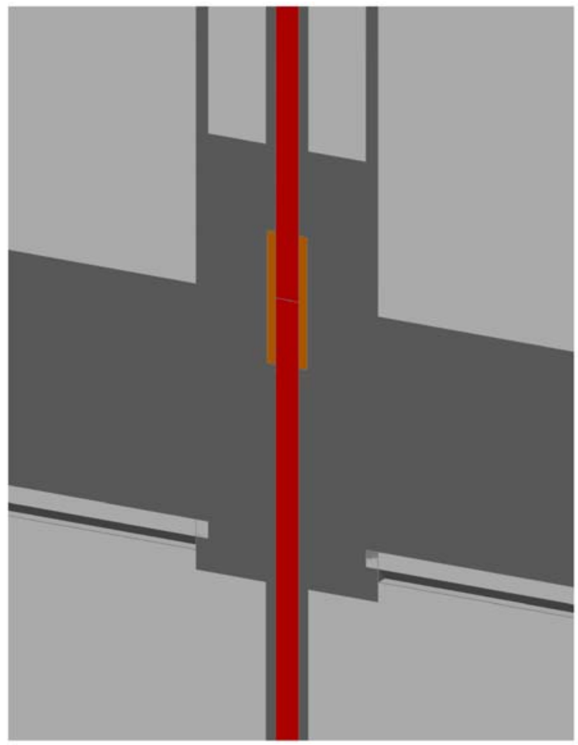


Fig. 10

Wall System Lateral Strength

LadderBlock structures are detailed to place the horizontal joint of perimeter walls (Fig. 11) and continuous stair and core walls (Fig. 12) at the mid-depth of the hollow core plank floor system. The resulting shear key between levels combines with every grouted joint core (Figs. 9 and 10), each of which acts as its own shear key reinforced with continuous vertical steel, to interlock stacked levels of LadderBlock wall structure across each floor. Interior walls generally stack to sandwich the hollow core panels, and finger joints interlock all walls so they respond to loads as a cohesive structure.

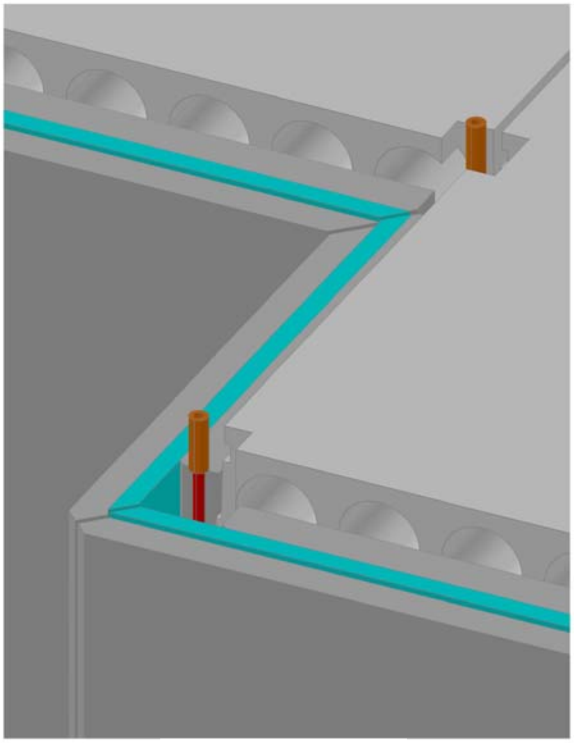


Fig. 11

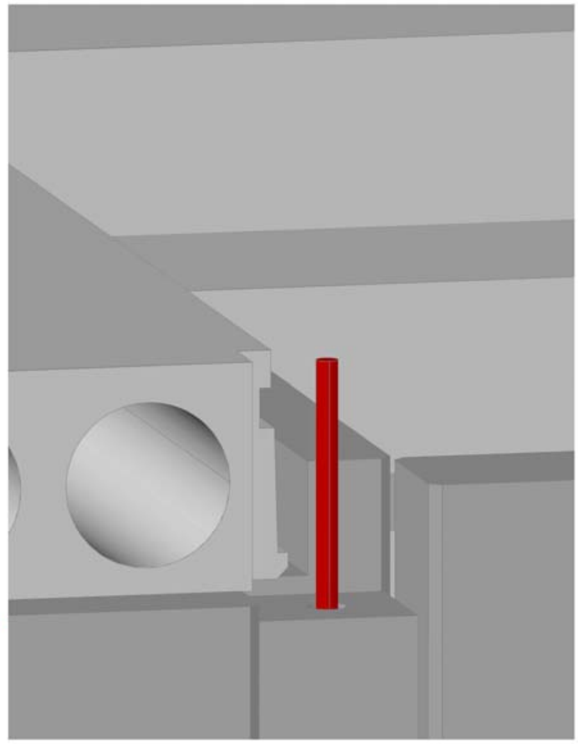


Fig. 12

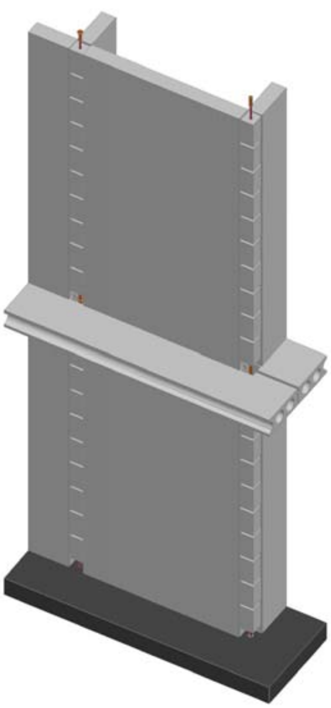


Fig. 13

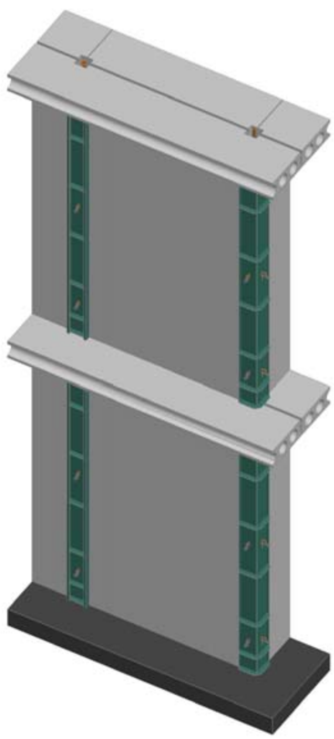


Fig. 14

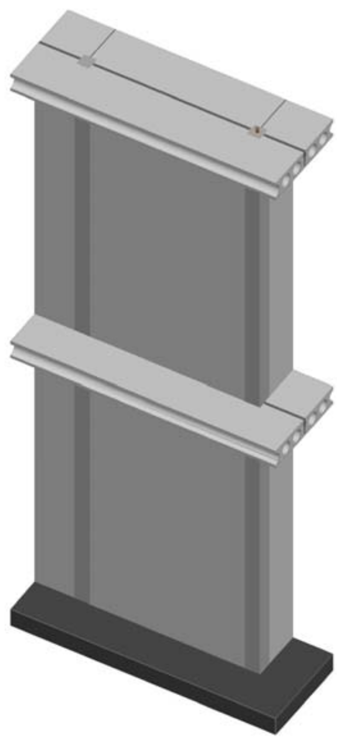


Fig. 15

The two story stack of walls shown in Figure 13 is a section of a building that is assembled quickly and safely; the joints are then encased by prefabricated grout forms (Fig. 14) and filled. Grout can be engineered to be stronger than the wall concrete, or it can be engineered as "soft" grout to facilitate future disassembly or reconfiguration. Strength is designed to meet the requirements of the job. Once the installed grout (Fig. 15) has hardened, the resulting joint behavior is much closer to cast-in-situ construction than it is to conventional precast.

Uplift that might be generated by lateral loads is resisted by the continuous vertical pins, which are tied to the foundation and grouted into the wall joints (Fig. 16). Pins are embedded into the foundation to whatever depth is required by design (Fig. 17), and they are coupled to provide continuous vertical reinforcement across levels (Fig. 18).

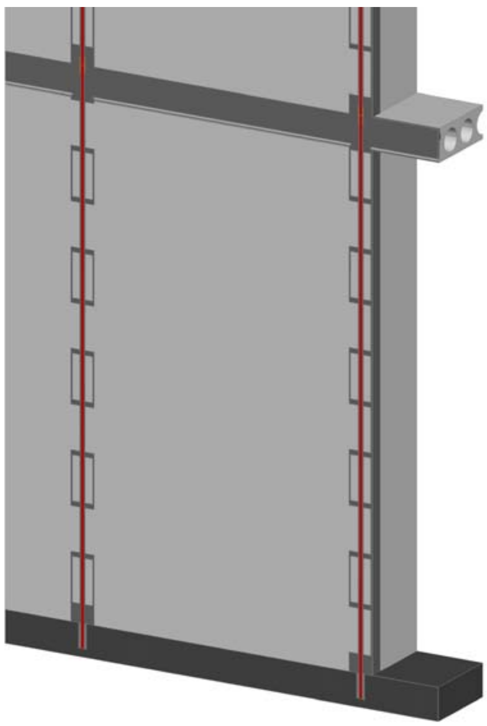


Fig. 16

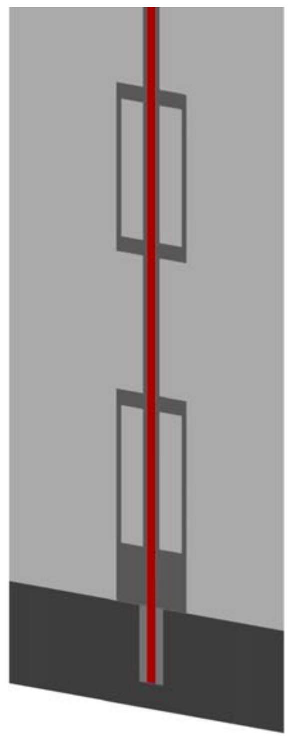


Fig. 17

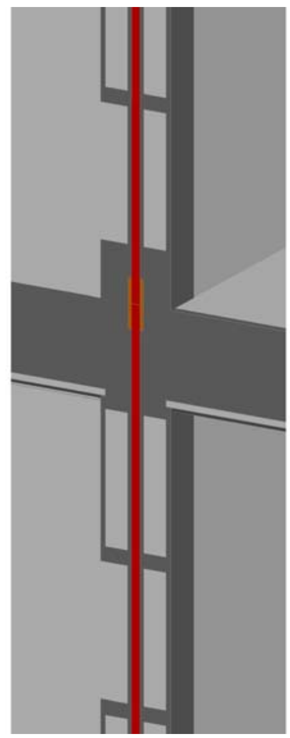


Fig. 18

In a typical bay of a low rise building, these pins occur at every wall intersection (Fig. 19). If required for a given design, for example a multistory building in an area of high seismic risk, walls can be detailed and manufactured with supplemental vertical bars (Figs. 20 and 21). Again, these bars could be replaced with high strength bars or strand and then post tensioned. Such measures provide even higher levels of strength and performance that can justify their cost. In either case, supplemental vertical bars are detailed to provide continuity down to the foundation (Fig. 22), so that the wall panel structure behaves cohesively to resist all loads specified by the Code.

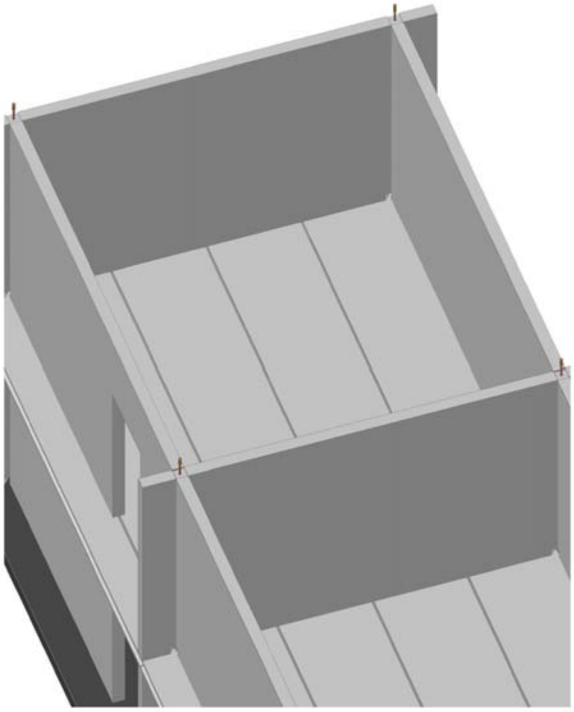


Fig. 19

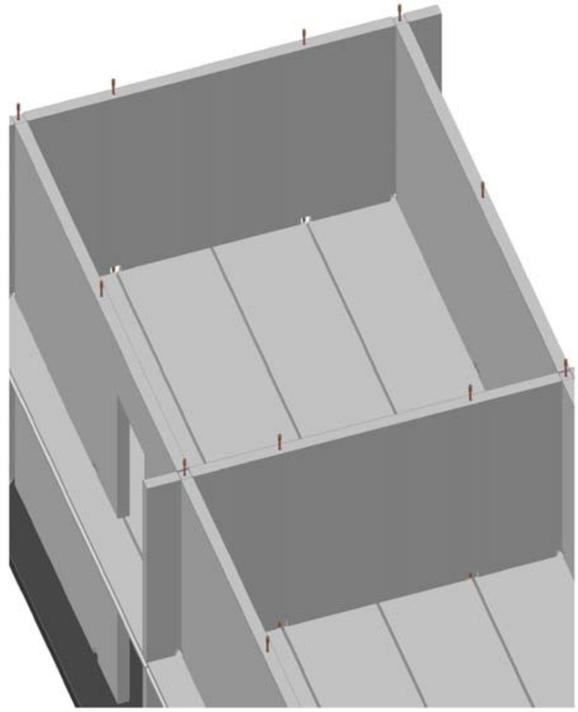
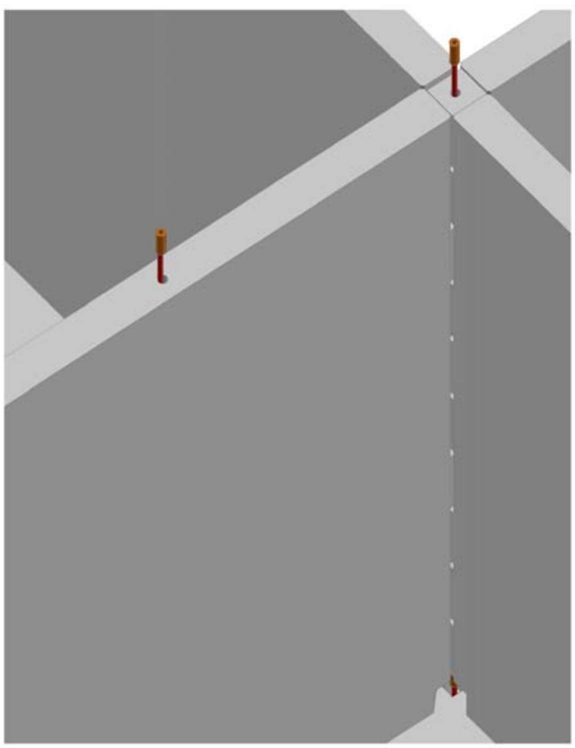


Fig. 20



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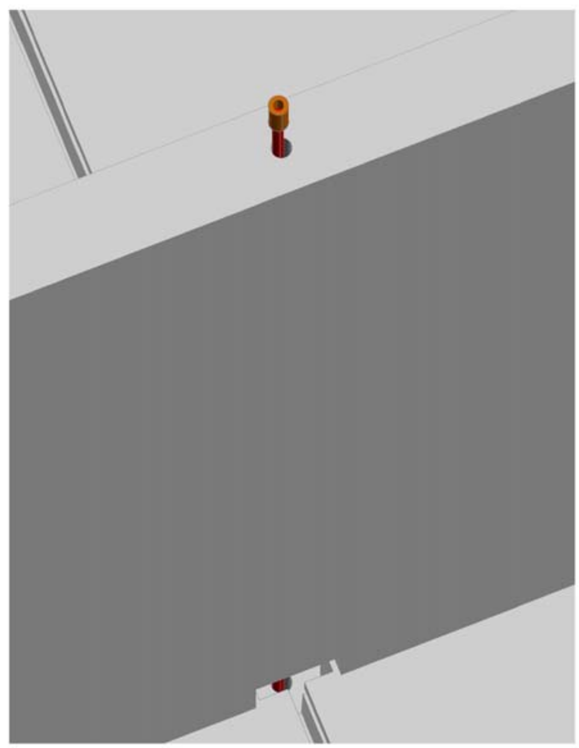


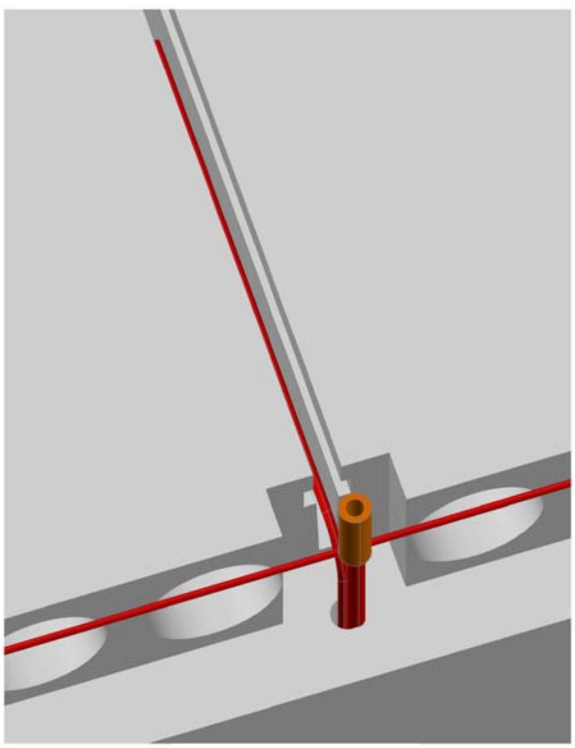
Fig. 22

Strength to Protect against Progressive Collapse

LadderBlock is designed and built with vertical and horizontal integrity reinforcement that is required by the American Concrete Institute (ACI) specifically to protect against progressive collapse. The Code provisions were developed in response to a small number of high profile collapses. These incidents pointed to the need for details that establish structural continuity and protect against progressive collapse in the event of an unanticipated overload such as an explosion.

For buildings using the wall system and taller than 3 stories, in addition to the minimum requirements of ACI 16.5.1, LadderBlock buildings integrate the structural integrity reinforcement specified in ACI 16.5.2. This reinforcement consists of longitudinal and transverse ties in the floor system (Figs. 23 and 24), perimeter ties along the floor edge (Fig. 23) and vertical ties in walls continuous over the height of the building (Fig. 22). All reinforcement is encased when hollow core plank joints and vertical wall joints are filled with structural grout. The grout both engages the reinforcement to provide structural integrity and protects the steel from corrosion.

The integration of structural integrity reinforcement and additional vertical reinforcement into an example interior bay (Fig. 25), shown cut out of a larger assembly, is demonstrated by a 3D view of that reinforcement (Fig. 26) shown for the same bay, where the walls and floor planks are hidden from view. These reinforcing elements are grouted into the structural joints to result in a structure with the continuity and redundancy needed to survive an unexpected overload that includes some loss of support; to localize damage and guard against progressive collapse.



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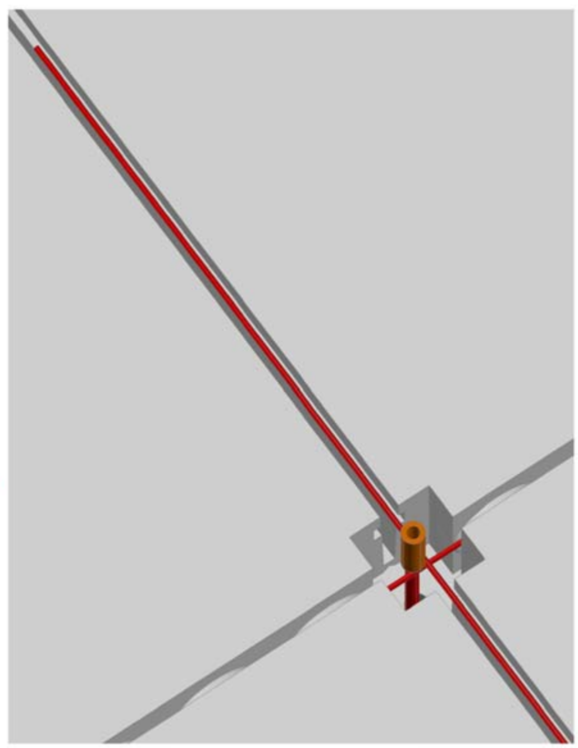

Fig. 24

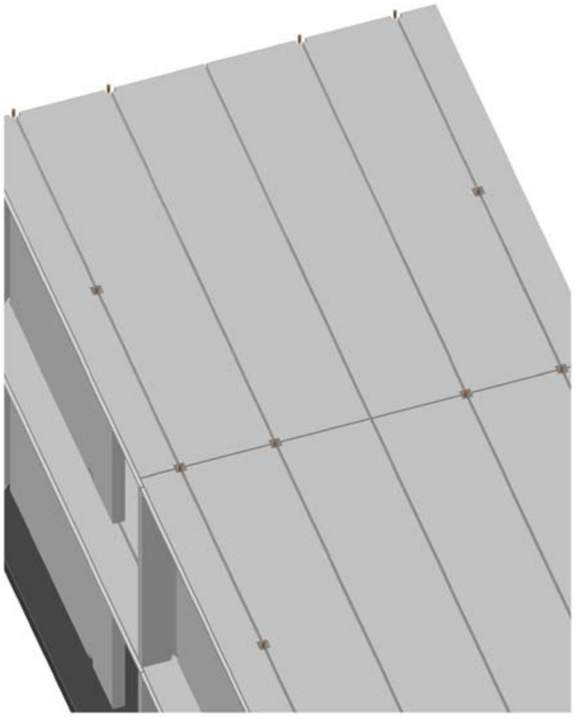

Fig. 25

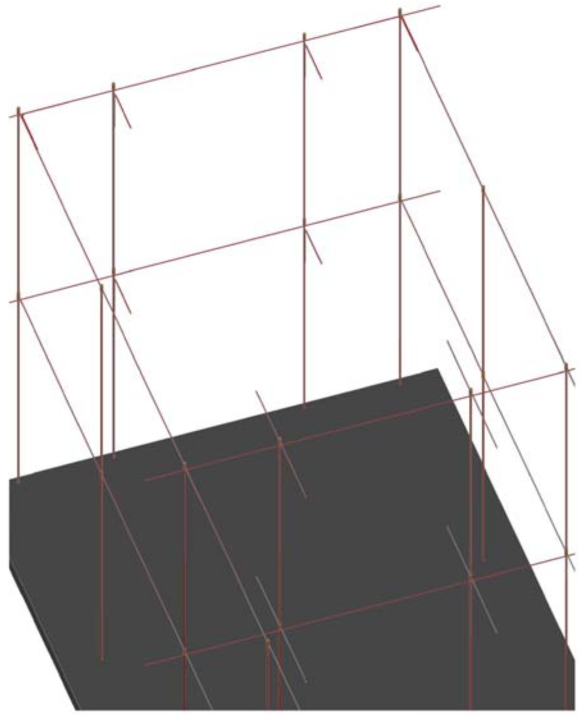

Fig. 26

Seismic Strength

Additional reinforcement and detailing may be necessary for the seismic design of a given project. For seismic loading, the International Building Code refers to ASCE 7; that document contains different seismic design categories (SDC), from A to F. SDC classifications indicate a range of increasing seismic hazard, and the actual SDC classification for a given structure is not only based on local seismicity but also on type of soil and building occupancy. For seismic design, IBC refers to ACI Chapter 21.

The seismic force resisting system of a Ladderblock precast wall structure classifies as a Bearing Wall System. Bearing wall systems permitted by ASCE 7 include ordinary precast shear walls and intermediate precast shear walls. ACI Chapter 21 includes specific requirements for these two types of walls. In general, these requirements are related to connection details between wall panels and between panels and foundations to provide enough ductility. On the basis of the specific demands of each project, connection details are and special reinforcing elements are incorporated as required to ensure that each LadderBlock structure complies with the Code and performs well under load.

In addition to complying with the prescriptive provisions listed above, a structural model of each building is developed. The Ladderblock precast wall system can be considered a variation of the well known large-panel precast concrete building system, which has been used successfully around the world in seismic areas. Shear and overturning forces are evaluated for each panel and reinforcement is provided accordingly. Out of plane stability of panels is checked. Behavior is of the LadderBlock assembly is analyzed, and performance is designed and detailed in.

Screed or No Screed

Certain conditions, such as a floor plate with particularly long spans or one subjected to high gravity or diaphragm loads, may make it cost effective to incorporate structural screed into a design. But the LadderBlock system can generally establish a competent structure that satisfies Code requirements without the need for structural screed.

Where a screed is to be incorporated for the purpose of concealing plumbing and electrical runs within a floor, LadderBlock's lack of dependence on the screed means it can be non-structural, so that screed material can be less costly and installation details do not interfere with progress in completing the structure; they are off the critical path.   This is just one more advantage LadderBlock brings to the overall cost efficiency and progress of the project.

Strength and Integrity

LadderBlock integrates state of the art engineering with solid detailing and precision manufacturing. The result is construction of unequaled quality, safety, and speed; structure that performs with strength and integrity even under severe loads.