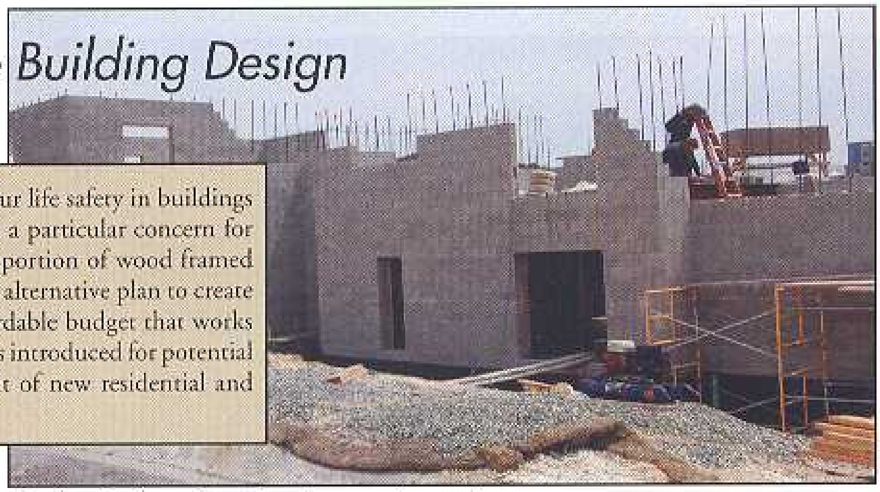
The New Fire Safe Building Design

By Dilip Khatri, Ph.D., S.E., and Gina Keil Cruz, P.E.



Exterior elevation with reinforced masonry shear wall system.

As we are all aware, the threat of fire to our life safety in buildings is all too common. The United States has a particular concern for this type of threat because of its large proportion of wood framed facilities. This article presents a reasonable alternative plan to create a fire safe building design, within an affordable budget that works for builders. A proposed fire safe building is introduced for potential long term application in the development of new residential and commercial buildings.

Creating a Fire Protective Building Envelope

Wood frame Type V construction has been the focus of our construction market since the end of World War II, and has remained the cost effective solution for the typical home builder. The unfortunate reality is that wood frame houses are susceptible to fire damage, loss, and pose a significant life safety threat to its occupants. California residents know this fact all too well, given the large exposure to wild fire threats across the state.

The key parameter in developing a fire safe building design is to utilize materials that are fire resistant. Concrete and masonry have the best fire rating performance with a minimum 4-hour protection rating. Steel is subject to melting and phase change at 800°F and can easily warp and deform, resulting in structural damage to a building. Wood collapses under heavy fire exposure. The challenge is to create a cost effective fire safe building envelope that can withstand the effects of temperature, heat, fire, and long term exposure to natural elements.

A building envelope utilizing perimeter masonry shear walls creates a 4-hour resistance to an exterior fire event. Masonry is commonly used in fire stations and is a long proven, accepted fire wall material. Utilizing reinforced, fully grouted masonry further adds to the seismic resistance of the shear wall system.

The horizontal diaphragms are designed using precast concrete (such as Spancrete) panels. Spancrete is a proprietary rigid diaphragm system developed by the Spancrete corporation and available nationally. It is approved by the International Code Council Evaluation Service (ICC-ER # 2151).

The roof is designed with prefabricated metal/steel truss system, which is further fire-proofed using an ICC approved fire proof material. Roof sheathing is conventional wood plywood, but this is covered with a Class A roof tile to insulate the plywood from fire exposure.

Wood walls are utilized on the interior or non-structural portions as partition elements. No structural loads are carried by any of the wood walls, so these elements are inside of the 4-hour fire protective envelope.

Structural System

A building envelope is created that provides a rigid diaphragm with rigid masonry shear walls. The structure is a boxed structure with stiff walls and overall structural period less than 0.5 seconds. Reinforced masonry shear walls deliver a "minimum" in plane shear value of 50 psi, which equates to 50psi x 7.63 inches x 12 inches = 4,578#/foot for an 8-inch block wall. With reinforced steel that complies with IBC 2006 criterion for high seismic zones, this may be increased to 75 psi maximum:

For,

8-inch block: $V_{in\text{-}plane}$ = 75psi x 7.63 x 12 = 6,867#/foot = 6.8 Kips/foot

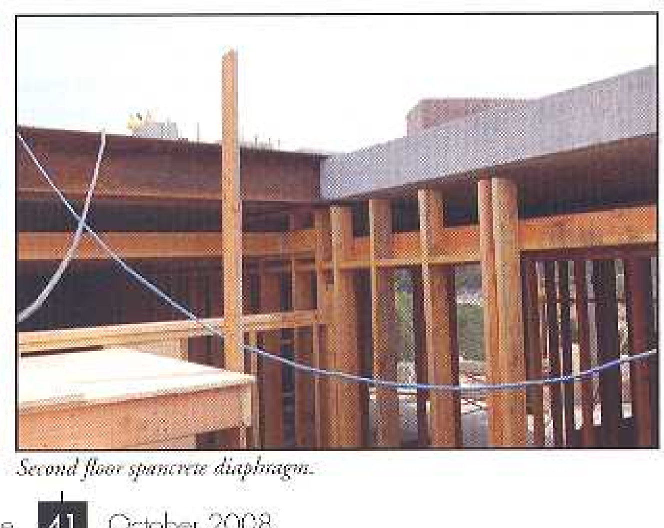
12-inch block: $V_{in\text{-}plane}$ = 75 psi x 11.63 x 12 = 10,467#/foot = 10.5 Kips/foot

16-inch block: $V_{in\text{-}plane}$ = 75 psi x 15.63 x 12 = 14,067#/foot = 14 Kips/foot

With these values for in plane shear capacity, no wood structural shear wall can compare or provide comparable strengths.

The shear wall configuration can accommodate a variety of architectural plans, and provides greater flexibility to the designer for more elaborate designs. For example, the architect is not constrained because of limited shear wall height-length ratios and doesn't have to provide hold downs, connection hardware, or diaphragm connectors. Openings can be designed to fit within the masonry allowable values, and because the loads are generally "low" (i.e., less than

Spancrete with steel beam system.



Second floor spancrete diaphragm.

Roof Truss Diaphragm connection.

Interior non-structural wall connections.

Exterior stucco application.

3,000#/foot of shear) for residential structures, the masonry shear wall concept is an excellent choice.

The precast panels provide a rigid diaphragm in combination with the lightweight concrete decking (usually 2 to 4 inches thick). Horizontal reinforcement ties the diaphragm to the perimeter masonry walls. The value of the precast panel diaphragm lies in both its cost and simplicity. Precast panels have been utilized for parking structures for decades, but have always had application for residential and commercial structures. It is common to have 20- to 30-foot span lengths for precast panels, and economical to have 40-foot spans. The panels are precast-prestressed and delivered to the jobsite ready for installation via an onsite crane.

The foundation system utilizes the precast floor panels for the 1st floor and spans from one end of the building to the other. The perimeter foundation support is a continuous grade beam resting on piles. No slab on grade system is utilized which eliminates onsite grading, over-excavation, recompaction, and dirt import/export. The piles are drilled, with cast in place steel W-shapes that further reduce the onsite cost of reinforcement. The final pile design does not incorporate any conventional reinforcement and connects to the grade beam using bolted connections.

It is also possible to utilize a continuous footing system instead of a pile and grade beam, because not all soil conditions require piles. For a continuous footing system, the precast panels rest on the foundation stem wall, just like a regular slab on grade. The difference in this system is that there is a sub floor system over a non-graded, non pad certified fill/cut material. The site development costs are significantly reduced by eliminating the onsite compaction/grading and soil work.

The basic structural advantages include:

1) The precast panels eliminate the need for interior structural shear walls, columns, and structural bearing elements which further reduce the overall foundation costs.
2) The precast panels create a solid (8- to 12-inch thick) fire barrier between floor-to-floor areas. This functions for fire resistance, but also creates suitable separation for noise abatement, mold/moisture resistance, termite infestation, and structural/earthquake resistance.
3) The rigid diaphragm provides very high in plane shear capacities (2 to 3k/foot) when compared to conventional wood frame diaphragms (0.5 to 0.8 k/foot max).
4) There is no flexure/vibration problem in the final floor construction. This is markedly different from wood-frame residential floors that "flex" under normal walking loads.

The only real disadvantage: The precast panels must be precast to precise dimensions that fit with their final field position. If the precast panels do not fit within established tolerances (+/- 2 inches max), then the panels will have to be field cut. This is not impossible, but requires additional field time with impact to crane costs.

Cost and Feasibility

A typical wood frame residential house in California will cost between \$90 – \$500+/square foot, depending on the quality, location, and type of floor plan (*Table 1*).

The structure cost in *Table 1* refers to all structural components, foundation, shear walls, diaphragms, roof trusses, etc… excluding onsite grading and offsite costs. Structure cost is approximate and inclusive of all the materials, labor, transportation and field assembly charges to put the basic building together. The other aspects of the nonstructural and interior elements are everything outside of the basic structure. In simple terms: The difference between the final building cost and the structure cost represents all of the non-structural elements and interiors.

	Finished BLDG*	Structure Cost
Low-cost Affordable Housing:	\$90 - \$120/sq. ft.	\$80/sq. ft.
Medium Cost:	\$120 - \$200/sq. ft.	\$110/sq. ft.
High-end Custom:	\$200 - \$500+/sq. ft	\$120-\$200/sq. ft
*Finished BLDG = Structure Cost + Nonstructural/Interior Cost		

Table 1.

The interesting point of *Table 1* is that the structural system of wood frame Type V construction is nearly the same across the board for all quality level buildings. It stands to reason that if a customer is paying for a premium high end custom home product, shouldn't he/she be entitled to an equivalent system that ensures against basic property loss risk? Most would agree, but the market has never reflected this fact. A $20,000,000 custom home in Beverly Hills for a movie producer will still use the same wood frame shear wall system with hold downs, wood diaphragms, and conventional foundations as for a community housing project in South Central L.A. The main differences are the finishes.

With the spancrete-masonry fire safe building design, the approximate cost parameters are shown in *Table 2*.

These costs will vary depending on location, labor, and material availability. The point of this discussion is that the final construction cost will be less than the conventional wood frame market with a far superior quality product.

Structural Element	Cost/sq. of bldg
Spancrete Floors	$20/sq. ft
Masonry Shear Walls	$30/sq. ft.
Roof Truss	$20/sq. ft
Grade Beam+ Piles	$20/sq. ft
Total Structure Cost	**$90/sq. ft**

Table 2.

Construction and Application

The photographs printed with this article are of a 6,100 square foot custom residence that is currently being completed in the County of Monterey, California. The structure cost for this building was higher than the estimated $90/sq. ft. for the following reasons:

(a) The steel cost rose from $0.42/# to $0.75/# during 6 months of the construction phase.

(b) The design of this building had a primary steel beam in the center of the floor span that split the floor diaphragm into two 20-foot spans. Had this been designed with one 40-foot precast panel span, this steel beam and associated columns would have been eliminated. The cost of this beam was $90,000. By subtracting this single item, costs would have been well below the normal range for a precast panel building.

The final construction cost for this building are shown in *Table 3*.

6,100 Sq. Ft. Custom Residence in Monterey, California near completion.

The appraised value of this building is $3,100,000. The owner was very pleased with the final product quality and he now owns the only fire-safe residential building in Monterey County.▪

Structure Cost	$140/sq. ft	$854,000
BLDG Cost	$290/sq. ft.	$1,770,000

Table 3.

*Dilip Khatri, Ph.D., S.E., is the Principal of Khatri International Inc. and Khatri Construction Company located in Pasadena, California. He has served as an expert witness for several construction-law firms and as an insurance/forensic investigator of structural failures. Dilip may be reached at **dkhatri@aol.com**.*

*Gina Keil Cruz, P.E. is the Principal at Khatri International Inc. Ms. Cruz has worked on the structural design of a wide range of projects, including numerous residential structures. Gina may be reached at **gcruz@khatrinternational.com**.*