Walls, Walls, Walls...

By James E. Amrhein, S.E. and James S. Lai, S.E.

Walls are the signposts that mark the location of civilization. The search for our ancestors invariably is centered on areas where people lived and built shelter for protection against climate and weather. This would leave outlines of shelters that may have been constructed of stone with mud as a mortar. These materials are still used today in many underdeveloped countries.

From the time of the ancient temples of Egypt and the Great Wall of China, humans have learned to build shelters to protect themselves from the elements, as well as houses of worship, defense fortresses, monuments and other structures. These walls were very thick and did not go very high. They were thick to support loads and be stable.

Clay brick replaced rubble stone and allowed walls to be straighter and somewhat thinner. Their strength was limited, as lime mortar was used in the construction.

Concrete masonry units replaced clay brick, and Portland cement mortar replaced lime mortar for stronger walls. The walls became thinner and taller with improvements in materials.

The Challenge

From the 1950-60s, reinforced concrete tilt-up walls were a great innovation and construction advancement. Walls could be built without expensive wall forms, by being cast on concrete slabs on the ground and lifted into final position to serve as architectural enclosures or elements.

Clients, particularly supermarkets, wanted taller walls than the 16 feet, 8 inches allowed for 8-inch concrete block. They wanted to use concrete block walls up to 18 or 20 feet high. In the case of concrete walls, second-order analysis was permitted by the building code and led to trends towards designing slender walls with little or no concern for long-term serviceability.

The Answer

The Southern California Chapter of the American Concrete Institute, under the direction of the late Joseph Dobrowolski, P.E., organized a Task Force Committee on Slender Walls, 1980 to 1982, to include the Structural Engineers Association of Southern California, Masonry Institute of America and the cooperation of many engineering offices and building officials.

Goals

The goal was to test concrete and masonry walls that exceeded the code limitations of height to thickness ratio. The panels were subjected to combined eccentric vertical and lateral loads to simulate gravity loads, and wind or earthquake lateral loads.

Research Program

The committee obtained a testing site, had concrete panels cast and masonry walls built, designed and built a testing frame, fabricated an air bag, and developed instrumentation for recording results.

Thirty full-size walls were erected and tested; *Table 1* shows the details of the test wall panels.

Test Results

It was interesting that there was a definite, two-part load-deflection performance. The walls would be stiff and hold together up until the modulus of rupture was reached and the initial crack formed. As lateral load was imposed, additional flexural cracks would be created, and deflection would rapidly increase. The deflection and load was increased until failure or excessive deflection occurred.

Slender Wall Task Committee (1980).

Results of the full-scale tests showed the response of panels under combined lateral and eccentric vertical load and demonstrated that there was no instability, which led to the development of new design methods.

After the tests were successfully completed, the committee worked on resolving, distilling and codifying the information. It involved not only safety to resist vertical and lateral loads, but also the introduction of a new concept: serviceability after a lateral force event.

The walls had to be serviceable and not experience damage. However, the limitation of wall deflection became a factor. The amount of permissible deflection was initially stated as 0.01 times the height of the wall. During subsequent review by code officials and structural engineers, the permissible deflection was reduced to 0.007 times the height of the wall.

Panels at Test Site (1980).

Wall Details

	Thickness	h/t slenderness	Strength
Concrete Tilt Up	9.5	30	3225 psi
	7.25	40	3225 psi
	5.75	50	3225 psi
	4.75	60	3225 psi
Concrete Masonry	Nom. 10	30	2460 psi
	Nom. 8	38	2595 psi
	Nom. 6	51	3185 psi
Clay Masonry	9.6	30	3060 psi
	7.5	28	3440 psi
	5.5	52	6243 psi

Table 1: Note all walls were 24 feet 8 inches tall.

This was the first time that serviceability was even considered and written into the building code for wall panels. This was a significant advancement, to the credit of the committee and the structural engineers who served on it.

As a result of this program, the committee developed strength design principles for masonry, bringing masonry into modern design methods.

Results

Due to the diligent work of the committee, the restrictive regulations were changed and design parameters included in the code to allow tall slender wall that would be safe under vertical and lateral wind or seismic loads. An alternate slender wall design procedure for masonry wall panels was introduced into the 1985 Uniform Building Code; similar provisions for concrete wall panel design were introduced into the 1987 Supplement of the Uniform Building Code. The design method incorporated the combined load effects due to eccentric vertical loads and the P-delta effect. Strength requirements are considered when selecting the reinforcing required. Deflection under service loads was established to provide a reasonable limitation on the stiffness of the wall panels.

This significant project has saved well over $5 million nationally. Savings continue by allowing the use of thinner walls and smaller foundations that reduced material quantities and speed construction, thus benefiting the consumer. Additional benefits include reduction of seismic forces imparted on the structure because of thinner walls. For the tilt-up industry, multi-story wall panels are becoming common for commercial office buildings.

Through the efforts of the engineering profession, advances have been made and will continue to be made in design, safety and utilization of materials. It is often said that an engineer can do for one dollar what the layman can do for two dollars. This is due to the engineer's knowledge of materials, the performance of materials, the interaction of members and systems, and continual testing and experimention to achieve better design.▪

Concrete Test Panel (1981).

CMU Test Panel (1981).

Tilt-up Building under Construction. Cottonwood Christian Center, Cypress, CA. Courtesy of R.M. Byrd Assoc., Ontario, CA.

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Please see next page for detailed references.

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