DEVELOPMENT AND UTILIZATION OF A "POURED ADOBE" BUILDING SYSTEM FOR SEISMIC AREAS

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ABSTRACT This paper describes the development, testing and use of a "poured adobe" building system made from on-site earth as a low-cost, energy-efficient building material for seismic areas. The method has been approved by California building officials, and has been used in the construction of a passive solar poured adobe home in Pacheco, California (eastern San Francisco Bay Area), which is in the Uniform Building Code Seismic Zone classification #4. The U.S. Department of Energy has awarded the Habitat Center a grant for further refinement of the method, as well as for seismic-related testing of several types of block and poured adobe building systems.

The context for the development of the poured adobe building system described below differs from the one that predominated at the Workshop. While the concept, if not many of the specific components, of the system could be used in developing countries, Habitat's poured adobe system was developed as a response to the building technologies and the materials, labor and energy costs characteristic of industrialized countries, particularly the areas of high seismic activity in the Western U.S. In these areas, the issue is not how to build with earthen materials more safely, as might be the case in developing countries, but how to resurrect the use of earthen materials in a culture that has ceased to build with them at all for the last 100 years because it has not been "economical" to do so. Now, however, the economics of industrialized countries are shifting as well, and, particularly because of rising energy costs, are making it an appropriate time to reconsider the use of adobe.

Adobe as an energy-efficient building material

Adobe is an energy-efficient building material in several ways. First, it is energy-efficient in manufacture, since it is simply sun-dried rather than fired as is red brick, or produced in high-temperature processes such as cement; in his book Natural Solar Architecture, architect David Wright says "It takes over 300 times more commercial energy to produce a concrete block equal in volume to a sun-dried adobe block." (1) Adobe is also energy-efficient because it can be mined right on the building site, eliminating the energy and cost expended in the transport of building materials to the site.

Thirdly, and perhaps most importantly, adobe can be used to reduce energy costs for building heating and cooling throughout the lifetime of the structure if it is used in conjunction with energy conservation, passive solar heating and natural cooling principles in building design. The effective use of adobe for the "sun-tempering" of buildings has a long and well-established record throughout the world. The work of architect David Wright finally established the formal integration of passive solar heating and natural cooling design principles with the use of adobe for thermal mass. "Passive solar adobes" are now built routinely throughout the American Southwest. The energy savings on building heating and cooling can be signficant in passive solar adobes, and not just in the clear, hot regions of New Mexico; the passive solar poured adobe home built by Habitat in Pacheco CA has not used any supplemental heating or cooling energy since the building shell was completed, and has consistently maintained a 57-77^{o}F temperature range winter and summer.

Thus adobe has many energy-efficiency benefits. It is also a very low cost raw material. This should be good news to the U.S., where escalating energy, building and financing costs have created a tremendous building slump in many parts of the country, particularly in the Western U.S. So why aren't more adobes being built? The problem is with the labor-intensive nature of adobe construction, and the costs of that labor.

Adobe and labor-intensity

Even for standard wood-frame construction, labor costs represent a very significant part of the total (currently 54% labor to 46% materials cost in the San Francisco Bay Area) (2). However, for block adobe construction in the same area, the labor costs rise dramatically, pushing the overall costs of an adobe building from 10-30% higher than that of a conventional wood-frame building (3). As a result, there are no adobe developments and very few custom adobe homes being built outside of the Southwest.

For owner-builder situations, the cost of labor is not a factor, but the amount of time is. Few owner-builders have the amount of time required to invest in the required labor, particularly if it involves making their own adobe bricks. The result has been few owner-built adobes outside of the Southwest.

Thus there is a need to capture the benefits of adobe -- energy-efficiency and low materials cost -- while escaping the high labor costs and/or time commitments for contractors and owner-builders. It was in response to this need that the poured adobe building system described below was developed.

Basic poured adobe system concept

Habitat's basic concept was to create a poured adobe building system that would:

- provide the necessary structural integrity in a high seismic area
- provide for rapid construction to significantly decrease the labor time and costs involved for both production builders and owner-builders
- meet "buildability" requirements for both production builders and owner-builders (low cost and availability of materials & equipment for a range of project sizes)
- create effective building thermal mass for passive solar heating and natural cooling

The basic structural concept was to use a double layer of welded wire mesh or similar reinforcing fabric between which the adobe would be poured. This fabric would be embedded in the concrete foundation and also in the bond beam. Thus, in case of severe crumbling of the adobe under extreme lateral loading, the adobe would still be held within the "fence" of reinforcing mesh.

Our original plan was to use a load-bearing system in which the two parallel layers of mesh would be vertically connected. However, both local structural engineers and building officials indicated reluctance to approve such a load-bearing design for a seismic area in the absence of actual structural test data, since standard engineering handbooks are of little help in dealing with the structural characteristics of adobe. Rather than delay all work on poured adobe until we found the funding necessary for such testing, we decided to proceed with a non-load-bearing poured adobe application to work out the mix, delivery and forming aspects of poured adobe systems. The evolution of the non-load-bearing system design and components are described below. We expect to use the results from the seismic-related structural testing performed under our U.S. Department of Energy grant to obtain building permits for future load-bearing applications (see final section of paper).

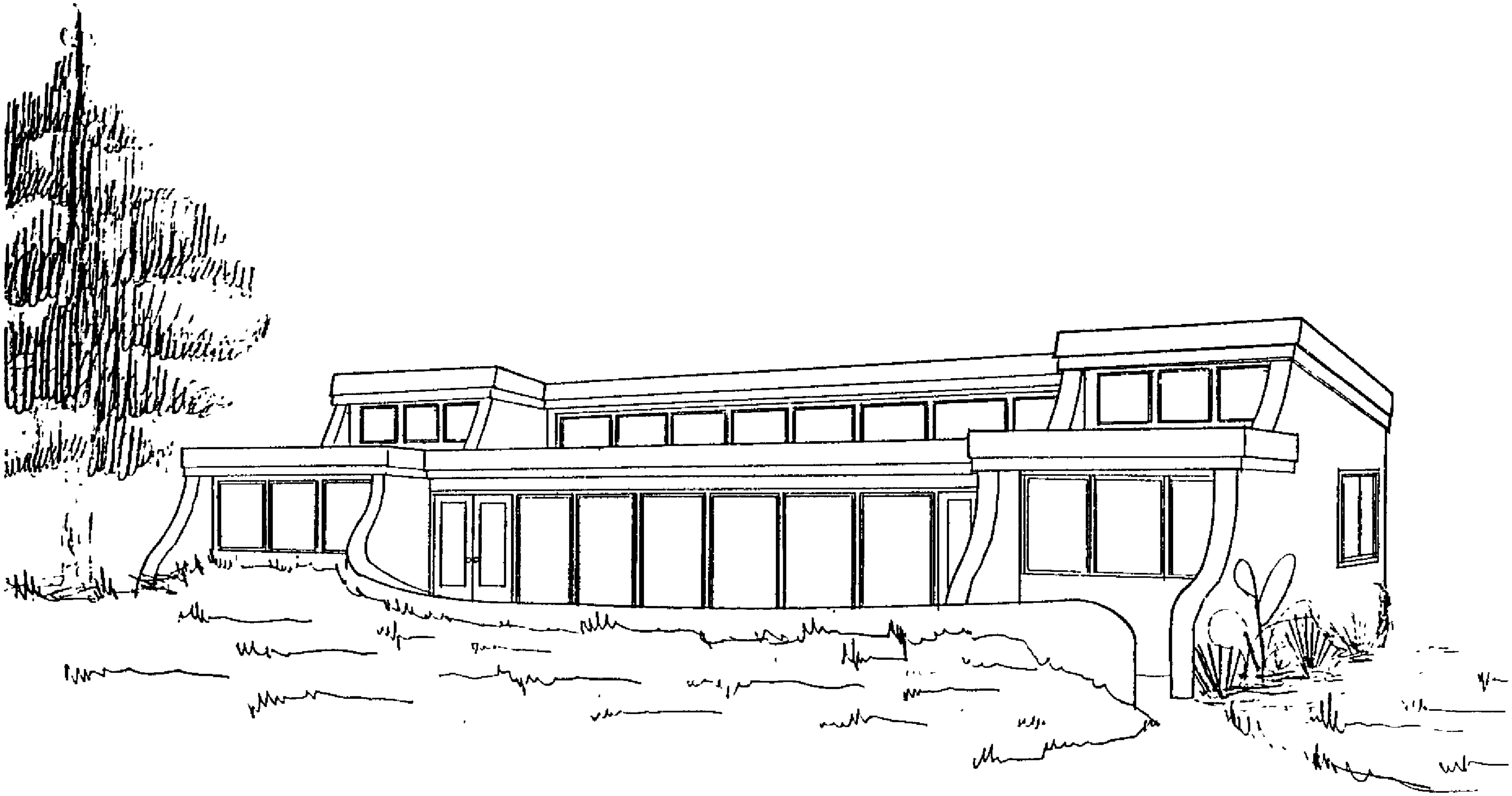
Poured Adobe Test Walls

To develop the specific poured adobe building system from the concept, we built a series of test walls on the site in Pacheco, California, where the passive solar poured adobe residence was to be constructed later. Although there were no previously successful full-scale adobe examples that we could use as a guide, the general advice we received from people in the field was (1) to use a stiff mix, (2) to use plywood or other solid wood forms, (3) not to try to pump the adobe into the forms -- that it wouldn't work, and (4) not to try to pour an entire wall height -- to use slip forms instead. As so often happens when theory meets practice, we found that none of these techniques worked and that in fact their opposites were the solution. We found that a stiff mix would not settle properly, and required so much tamping that the process began to resemble rammed earth. We found that using solid wood forms prevented the adobe from drying, causing slumping, and that drying occurred unevenly, producing severe cracking. We converted instead to forms made of expanded metal (commonly called "diamond lath") that would allow the water to evaporate quickly and evenly, and switched from a front loader (which requires too much space for maneuverability in an urban/suburban setting) to a standard concrete grout pump with a four-inch hose as the delivery system. We also poured test walls to a 6' height and found that the expanded metal forms could contain the wet adobe and withstand its weight. We found that the increase in wetness of the mix required for pumping did not result in significant cracking during the drying process. (The major determinant of cracking that we found was the size of the sand particles added to the clayey soil; the coarser the sand particles, the less the cracking.) We were also able to create a standardized modular forming system (described in more detail below) that could utilize all other elements of standard concrete forming such as snap ties, snap brackets, walers, etc.

Construction of the passive solar poured adobe residence

Based on what we learned from the poured adobe test walls, we moved on to the construction of an 1800 sq. ft. passive solar adobe home in Pacheco CA. The house design, which has received awards in both the California and the U.S. Department of Housing & Urban Development passive solar design competitions, is a non-load-bearing poured adobe application for building permit reasons (as previously discussed). A south elevation of the home (which has been closed in for the last year but has not yet received its final exterior plaster) in shown in the drawing in Fig. 1. A plan view of the forming and reinforcing system is shown in Fig. 2a, and a plan view of the finished poured adobe wall is shown in Fig. 2b. The overall poured adobe system and process used in the construction of this house can be summarized as follows:

The house is designed as a post-and-beam structure, with the poured adobe serving as non-load-bearing infill. The posts (in this case, pressure-treated telephone poles), were placed up to 13' on center, and extend about 4' down into the sandstone which underlies the site. The poles are set into steel rebar cages, levelled, and concrete is poured into the holes around the poles, forming caissons. 12-gauge welded wire mesh fabric is then stretched and attached on either side of the poles, forming an 8" "fence" into which the majority of the adobe is to be poured. The mesh is nailed to the poles, and extends 9" down into the foundation formwork. The concrete foundation is then poured through the welded wire mesh into the foundation forms, creating a substantial anchoring of the mesh in the reinforced foundation. For the perimeter walls, the 2" styrofoam insulation is then wired to the outside layer of welded wire mesh fabric.



PASSIVE SOLAR POURED ADOBE RESIDENCE

PACHECO, CALIFORNIA

Fig. 1

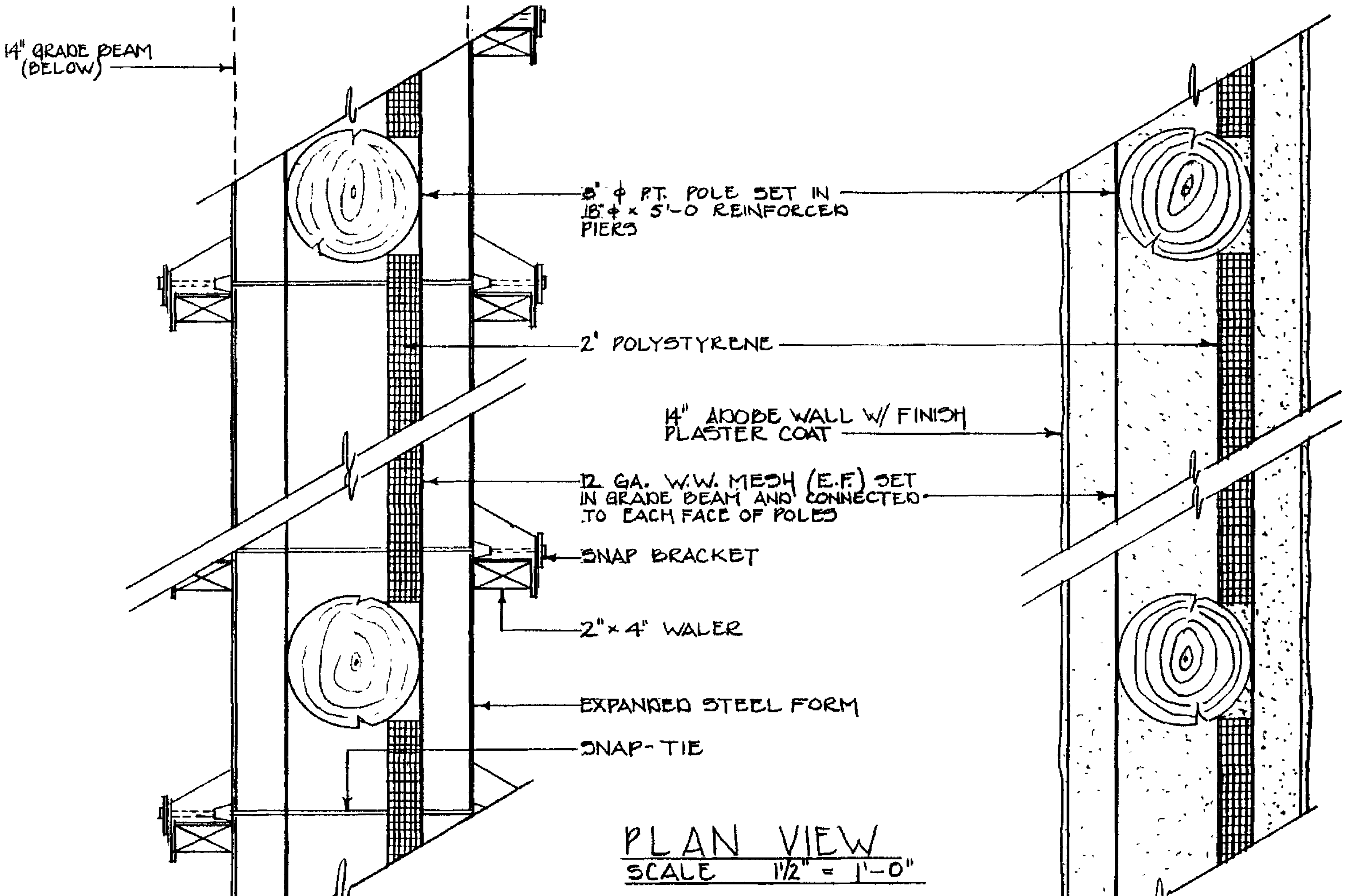


Fig. 2a

FORMING SYSTEM FOR POURED ADOBE WALL

Fig. 2b

COMPLETED POURED ADOBE WALL

Once the foundation is set, the forms for the poured adobe are set in place. The forms are constructed of galvanized expanded metal or "diamond lath" which is nailed onto 2x4 frames to make standardized form modules of 4'x8' and 2'x8'. The forms are attached using standard snap ties, snap brackets, walers, stiffeners, etc., as in concrete construction. Note that since the forms are set even with the outside edge of the foundation, there is a 2" gap between the forms and the posts.

The actual process of excavating, mixing and pouring the adobe is mechanized. A medium-sized backhoe is used to excavate the on-site earth (which may be soaked if the soil is too clayey to break up lumps). A backhoe or front-loader is then used to dump the excavated earth into a gasoline-powered plaster mixer, and the stabilizer and straw are added. In larger-scale applications, the adobe can be batch-mixed in a pug mill or even a concrete truck with a pug mill or other type of paddle mixing attachment to make sure the waterproofing is adequately mixed (4). The mixed adobe is then dumped into the hopper of a concrete pumper and pumped into the walls. The pumped adobe flows easily through the welded wire mesh fabric and the 2" space on either side out toward the expanded metal forms, so that both the pressure-treated poles and the welded wire mesh are completely covered by the adobe. Suprisingly, very little of the wet adobe oozes through the expanded metal formwork. The inch or so of adobe that does get through at the bottom is simply scraped off with a trowel and put back into the forms.

The forms are then left in place for 2-3 weeks before removing, to enable the adobe to hold its shape without slumping when the forms are removed. The use of expanded metal for the formwork is critical is being able to remove the forms within such a short time; it allows the adobe to dry evenly, and reduces cracking.

Construction at the Pacheco site indicates that one assistant running the loader for mixing, one monitoring the mixer and the pumper, and one person on the hose can excavate, mix and pour the 9' high (average), 14"-wide adobe walls for an 1800 sq. ft. home (both interior and exterior) within two days.

Since not all finish work has been completed on the residence, exact cost figures cannot be given, but they appear comparable to frame construction and 30-40% cheaper than poured concrete or block adobe/concrete applications. These cost estimates are conservative because of the non-load-bearing nature of the structure (which increased costs for the posts, beams and connections), and the general overdesign of the structure to accomodate building officials wary of a "first-of-a-kind" design. These costs should drop dramatically when the design is converted to a load-bearing structural system, which will be developed and tested as part of our U.S. Department of Energy grant work.

A patent on the aforementioned poured adobe forming system has been applied for by Lynn Nelson of the Habitat Center.

U.S. Dept. of Energy Testing Program

Habitat has recently received a grant from the U.S. Department of Energy Appropriate Energy Technology Program, Region IX, for further refinements of the poured adobe building technology and for a structural testing program for both block and poured adobe building systems. The details of the testing program are still being finalized, but the overall program approach can be summarized as follows:

In order to determine structural behavior characteristics of reinforced poured adobe walls, several types of strength tests appear to be desirable. One of the purposes of the tests is to determine the influence of different variables on the strength of the walls. Another is to determine the correlation of simple laboratory tests such as compression, modulus of rupture and diagonal tension with strength behavior under combined stress conditions.

A comprehensive testing program would require major commitments of time and expense. Within the constraints of a limited budget, we have decided to focus our attention initially upon the combined shear and compression behavior in poured adobe walls. This testing program will determine the influence of adobe mix, compressive strength, modulus of rupture, diagonal tension strength and percentage of reinforcement on load-carrying capability. Simple lab tests including compression, modulus of rupture, and diagonal tension will be performed on specimens made from several different adobe mixes to determine its influence on these strength parameters.

Several combined shear and compression tests will then be performed on wallettes to develop an understanding of the relationship between shear strength and compressive stress. These tests will also indicate the influence of reinforcement on shear strength. The same simple strength tests will be made for each wallette tested and these strength parameters correlated with the shear strength behavior.

It is anticipated that a later testing program will address the subject of combined bending and compression behavior in order to determine out-of-plane load-carrying capabilities of poured adobe walls.

We invite discussion regarding our proposed testing program, and will make the results available through both the Habitat Center and the U.S. Department of Energy upon completion in 1983.

References

1. Wright, David, Natural Solar Architecture, Van Nostrand Reinhold, New York, 1978; p. 22.

2. Sarviel,Edward, ed., National Construction Estimator; 29th edition, Craftsman Book Co., Solana Beach CA, 1980.

3. Personal communications with numerous contractors in Northern California

4. Personal communications, Tom Harley, Hans Sumpf Co., Fresno CA