

Earthen Architecture and Seismic Codes; Lessons From the Field

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INTRODUCTION: Getting Attention

It is, of course, no surprise to practitioners and advocates of traditional building technologies that "soft" buildings often out-perform "hard" ones during earthquakes. For several decades now the disciplines of architecture and engineering, in their authority as code and standard writers, have (with some notable exceptions) turned a blind eye to the seismic survival of tens of thousands of earthen buildings while pointing critically to those that failed. The seismic events of the past two years, however, have provided us with a better understanding of the survival rates for earthen buildings, and provided the general public with a clear demonstration that reinforced concrete fails at least as spectacularly as traditional construction. As Giacomo Chiari points out (in ICOMOS, 2000:112), we are also reaching the end of the useful life of many reinforced concrete structures, which, it seems, is only about 70 years due to chemical changes in concrete which compromise the reinforcing steel.

Whether the material is hard or soft, failure and success are linked to precisely the same phenomenon – the use of high quality materials in a regime employing good building practice and at least occasional maintenance. Code writers, particularly those in seismic areas, tend remarkably to demonstrate a mistrust of soft materials based, I believe, in a profound misunderstanding of those materials' characteristics. Given the remarkable behavior of well designed and constructed earthen buildings during seismic events, this mistrust borders on downright stubbornness.

The weakness in most recommendations for codes and standards regarding adobe is exemplified in one recent and remarkable study of "alternative" building technologies in the southwestern United States that comments outright that the issue of retained moisture is "beyond the scope of this study." (Bruce: 24) It is the examination of moisture-related pathologies that must be at the core of an examination of a building's ability to resist seismic events. A healthy building will better survive a shaking. A building that has been accumulating moisture for thirty years because it is plastered with Portland cement may be at the peak of its vulnerability.

The purpose of this paper is to point out some the basic, simple and successful technologies that we have observed in the southwestern United States for keeping buildings dry. We have augmented these older traditions with some newer (but also very simple) interventions for buildings that have suffered deferred maintenance or neglect. All of these technologies could and probably should be acknowledged in building codes.

(1) BUILDING AND REPAIRING DURABLE EARTHEN STRUCTURES: Local Knowledge from New Mexico

Lesson One: The “Dog-prints” Go Down

When the wooden forms in which adobe bricks are cast are lifted away from the fresh mud, the upper margins of the brick are dragged upwards. This configuration remains in the finished product and results in a slightly concave cross-section occasionally exacerbated by passing canines. The bottom, at the time of casting, is flat or even slightly convex, the result of slumping when the partly-dried brick is turned on edge to dry faster. When laying the brick, the top becomes the bottom so that the concave side seats firmly in the mud mortar. When the course above is added, the adobe laid in this manner is less likely to shift than is the adobe set with its convex side down.

Both single and multiple-wythe walls depending on the coursing, remain drier when laid according to traditional wisdom. Moisture introduced to the top of the wall is inclined during its downward migration to follow the interface of the brick and its mortar. In a wall laid "right side up" the moisture is inclined to accumulate in the central mass or "bowls" of the brick. Conversely, water is directed outwards, to the interior and exterior surfaces where it can evaporate from walls laid with the dog-prints down.

Lesson Two: Avoid Portland Cement

Allowing, to say nothing of encouraging, Portland-based mortars (and plasters) in adobe structures is perhaps the most egregious and misleading component of present and proposed codes. Failures of earthen walls directly attributable to Portland mortars and plasters are ubiquitous and abundantly documented (CRATerre-EAG, 1990; The Getty Conservation Institute, 1990; DGEMN, 1993; ICOMOS, 2000; among others). Soft earth and hard cements cannot bond into a monolithic or even an inherently strong structure.

An adobe laid in a bowl of cement mortar and encased with hard cementitious plaster is doomed to moisture retention and loss of integrity. Separations around wooden elements and the tendency of all plasters to crack inevitably leads to moisture accumulation in the wall. If it can't escape, the wall becomes the sacrificial component, a role that should be reserved for mortars and plasters, a point that code writers seem unable to acknowledge.

Insisting on the mixing of permeable with virtually impermeable materials codifies a technology that is guaranteed to fail even without a seismic event. Moisture problems aside, the interface between the hard and the soft materials results, during thermal cycles and seismic events, in the loss of the softer material.

Lesson Three: Earth is Stable

Code writers and enforcers love the idea (probably because the terminology appeals to them) of "stabilized " soils. They see adobe as inherently weak and made weaker yet if

exposed to water. Well, they're right, a wet adobe is weaker than a dry one, no argument there, but code writers, and most engineers in my experience, are often slow to acknowledge is that by trying to make adobe waterproof by amending the mud or sheathing adobe in "waterproof" plasters, they really decrease strength and longevity. They also encourage false confidence in a material that, like any other, needs maintenance. It has been demonstrated through centuries of exposure of earthen blocks that it does not hurt them to get wet, even very wet, as long as they can dry out rapidly.

But it is human nature to tinker with things – even when there is no need. The notion of "stabilizing" mud seems to have first occurred and gained currency in the United States in the 1950's. The thinking of the day was to use Portland cement (considered a thoroughly modern material though it had been around for centuries) to make buildings stiffer and more durable. Seismic retrofits included, among other things, replacement of "traditional," or un-amended, adobe blocks with a newer version that contained ten-percent or more Portland cement in the mix.

The Portland-stabilized blocks, though demonstrating slightly more compressive strength, proved equally as brittle during an earthquake as the standard variety. No gain.

In New Mexico where there is little seismic threat adobe was, and is, amended for different reasons. In some cases the soils used in commercial adobe production have very little clay in them and so an emulsified asphalt (about 6% by volume in the water) is used as a binder. These blocks are considered semi-stabilized. An adobe that is fully stabilized will contain 12% or more asphalt emulsion, not in an attempt to bind the aggregates, but to waterproof the block.

We have found that you cannot build well with stabilized blocks and there are many reasons why not. This position is not speculative. Many years and many millions of dollars have been spent by organizations such as the Getty Conservation Institute in Los Angeles, The Catholic University of Perú, The US National Park Service and the Ecole d'Architecture de Grenoble, France, among others, researching the efficacy of amended muds. Ultimately, most agree that doing things the old fashioned way results in a better looking, safer and more durable product than one that has been riddled and smeared with everything from lacquers, ethyl silicates, discarded motor oil, acrylic polymers, and floor sealants to modified polysiloxanes. I have enjoyed watching and, truth be known, participating in some spectacular failures.

If the case can be made that un-amended adobe is durable, then I would conversely argue that "stabilized" adobe is unnecessary, and worse. Stabilized mud is intended to be waterproof or, at minimum, water resistant. That means that in order to plaster it you must first lath it because neither mud nor any other plaster can bond to an impermeable substrate. In order to lath stabilized adobes you must drive nails into it, usually 16d or 20d nails. Do that to an adobe brick and watch it shatter. It is remarkable to me that one would take the time to build with adobe, only to weaken it significantly in an effort to protect it.

Another problem with stabilized adobe is a lack of bonding between the block and mortar. Again, the inherent water-resistant qualities of the materials prevents a bonding between the wet mortar and the dry adobe at the time of construction. This weakness leads to a poor response to expansion-contraction cycling which reduces or eliminates any bond that may have existed.

Despite these proven faults, code writers continue to insist on the use of stabilized adobe (Tibbetts, various refs.)

Lesson Four: Plaster is Sacrificial

The issue of permeable plasters is of sufficient interest and importance as to warrant the many publications that already exist on the topic. The maintenance of plaster on earthen walls has proven the single most misunderstood component of earthen buildings. In modern times it has been assumed that soft plasters require high maintenance and that assumption has led to the fallacy of the "permanent" solution of hard plasters. Earth, earth-lime and lime renders need not be higher maintenance propositions than Portland or the newer elastomerics.

However well published, the science of soft plasters seems not to be on the reading list of code writers. This paper will do no more than to add a footnote to the volumes on the topic by briefly exploring the most prevalent manipulation of muds as practiced in the southwestern United States: That is, the use of straw to cut erosion and thus increase the maintenance cycle.

It is an oft-heard phrase among the old *adoberos* of New Mexico that "*un adobe sin paja is un adobe sin alma*" ("an adobe without straw is an adobe without soul"). In a verbal, axiomatic tradition, this was a method of saying "Use straw!" without explaining why. It is understood that straw performs certain functions, including balancing the granulometry in adobes and mortars. It has other functions in the exterior mud renderings of buildings as well that may not always be understood, though they are still practiced.

Straw, cut to roughly two-inch lengths, in the plaster mix and embedded either horizontally or only a few degrees off the horizontal as the mud is applied is an effective "preventive" technology.

A rivulet of rainwater or melting snow, beginning at parapet height, encounters the embedded straw, and is diverted to one side. A few inches below, it is again diverted, and in some cases divided by the straw. The downward velocity is broken and erosion reduced because the straw helps water sheet over wall rather than cut into it.

Regardless of how well the plaster is designed, it is a sacrificial layer intended to protect the structural substrate of the wall. Mix and apply a good plaster with the knowledge that it will need to happen again in a few years. By using hydraulic lime reinforced plasters or some variety of cap on parapets, by being attentive to the detail at the base of the wall,

and by taking care in the designing of the mud plaster, we are now regularly achieving a 10+ year maintenance cycle on exposed adobe walls.

Lesson Five: Tie the Corners

In his 1990 paper, Lamar Sumanov refers to "wooden belts" in the earthen buildings of Macedonia (in The Getty Conservation Institute 1990, pp 131-136). The wooden grid in those applications consists of two parallel longitudinal beams that are connected by smaller cross-pieces forming a horizontal "ladder" that is embedded in the perimeter adobe walls. Buildings that are now a hundred years old and have been subjected to repeated seismic events have withstood the shocks practically with impunity, a true anomaly in multiple-story earthen buildings. The division of the mass of the adobe walls into several planes allows the segments to work independently of one another during an earthquake. Because the belts are embedded in the walls and tied at the corners, the weight of the adobe above and the jointing of the beams where they meet combines the advantages of gravity and tensile strength to diminish the threat of shear cracking and wall separation.

Ladder belts are an effective method of bonding corners of walls that are differently loaded. In New Mexico we have modified the technology only slightly by using rough-cut 4 X 6 beams. The four-inch dimension allows for the adobe coursing to be vertically uninterrupted. Instead of mortising and pinning, we lap and tie with a single, loose fitting pin at each joint. The idea is not to make a rigid structure, but to allow for whatever flexibility local conditions require, now or in the future. We anticipate movement knowing that even without our disruptive interventions buildings are constantly shifting to maintain their equilibrium as weather, groundwater and maintenance conditions change.

Lesson Six: Bond the Beams

Code writers have long thought it a challenge for the builders of earthen structures to adequately tie the bond beam to the wall. Engineers advocate the use of Portland and point to the ability of a liquefied material to enter the cracks, crevices and irregularities of the earthen substrate and thus enhance the connection. They also appreciate the span strength of reinforced concrete.

We earth-builders like wooden bond beams which most engineers, in my experience, consider difficult to attach to the wall. They also find wood lacking the rigidity and span strength necessary to compensate for what they consider the inevitability of failure of the soft material beneath. (Failure, of course, is a self-fulfilling prophecy if the code writers succeed in entombing soft materials in rigid, impermeable shells.)

Wooden bond beams, identical to the "ladder belts" described above but placed on top of the wall can be very successfully tied to the masonry below in simple and inexpensive ways. (Pay no attention to the code-enforcer who insists that you drive three-foot spikes

through the wood and deep into the earthen wall, thus shattering the supporting fabric below.)

As the wall is being built or rebuilt, lay a five or six foot long strap of two-inch polypropylene across the top of the adobe about five courses down from the top. Do this every six feet or so, and leave the ends hanging wild. When the top course has been reached, bed it thickly with mud mortar and install the ladder belt. Then tie it into the wall by pulling both ends of the strap up and over the wooden beams and nailing, screwing or stapling. The roof may then be attached to a structural element that is firmly bonded to the wall.

If an existing wall is not to be rebuilt, the strapping can be passed through the wall as the chosen height and attached to new, or existing, wooden elements.

(2) THE BEST OF THE NEW

Light-weight Grout

Voids in earthen walls, caused by disintegration from moisture, differential settlement, seismic events, roots, animal activity or any other invasive process, diminish the mass and weaken the wall. The repair challenge is to fill the voids without dismantling the structure, and to use a filler that is compatible with the earth in compressive strength, hardness and vapor permeability.

Many compounds have been adapted and experimented with, including epoxies, fiberglass resins, Portland cement-based grouts and various polymers. In all cases, these materials can be introduced by an injection system that is relatively non-invasive, and thus meet the first criterion. None, however, meet the second criterion of compatibility.

Hydraulic lime grouts have been successfully used in archeological settings for the past decade, often to adhere architectural plasters to an earthen substrate. (Matero, 1995) The grouts, properly designed, meet all the compatibility criteria. These grouts are typically injected in very small amounts using syringes. We have adapted the technology by manipulating the archeologically-inspired mixes and building equipment to inject the material in large volumes.

After experimentation with adhesion, cohesion, permeability, compressive strength and pumping characteristics, we settled on a mix of 1:2.5 moderately hydraulic lime to ceramic microspheres with enough water to result in a fluid with the consistency of heavy cream. The use of microspheres rather than sand as an aggregate provides several advantages: first, the very small diameter (450 microns) allows the grout to be pumped through a small nozzle inserted into cracks and voids; second, the light weight helps prevent separation of lime and aggregate while being pumped through up to one-hundred feet of 3/4-inch hose; and; third, the resultant extremely light weight material is less of a threat to fragile walls during the injection process.

The material is mixed by pumping clean, potable water through a homemade venturi-style hopper at high pressure. The mix is continuously recirculated or, in one of our devices, kept in suspension by a slow speed rotating paddle. The flow of the material at the injection end is controlled by a hand-held valve.

Grout injection follows a brief rinsing and preparation of hidden surfaces by pumping clean water into cracks and voids with the same equipment. The damp wall retards the set of the grout and enhances adhesion. The process always begins low in the wall and proceeds in lifts that are mostly dictated by condition. Large cracks to be filled are first sealed with mud, and an observer armed with a bucketful of stiff mud monitors for discharge on the opposite side of the wall.

In most instances the grout begins to set almost immediately, and is substantially solid within 6 hours. In deep, enclosed zones the hydraulic set may take up to several days.

Experimental walls that have been built with old adobe, injected and then dismantled demonstrate extremely good flow penetration, adhesion and low shrinkage. Rilem tests demonstrate that the grout is always at least twice as porous as even the softest adobe.

Belting

Earthen walls that have cracked or separated as a result of settlement or out-of-plane movement often appear more threatening than they actually are. There are many examples of walls that are visually terrifying but are really quite stable and repairable.

Over the years we have learned to predict the behavior of certain materials, including earth, in various situations. This premise was at the core of the research by the Getty Seismic Adobe Project during the decade of the 1990's, and which has recently been published. During a seismic event, or even when a building is subjected to minor degrees of differential settlement for any reason, cracks appear and walls are separated into very predictable and understandable segments. If those masonry blocks can simply be bound together and kept more-or-less in plane, two advantages are achieved. First, the occupants of the building have been given considerably more time to vacate a damaged structure, and second, the building stands a much better chance of being on the repair list rather than the demolition list.

The Getty's research, monitored by an oversight committee, demonstrates the efficacy of binding structures together in anticipation of catastrophic movement.

The results of the GSAP, based on multiple shaking table tests in California and Macedonia are, I believe, very sound – though I dislike the use of stainless steel cables, corner brackets and hardware that they used in their test case. Again, in our experience softer, more flexible materials are preferable.

We have retrofit many earthen buildings in New Mexico with belting, or banding systems using high strength woven polypropylene strapping. We prefer a four-inch wide band

with a 20,000 lb breaking test and a maximum of three percent stretch. The banding, being extremely flexible, can go around sharp corners (protected by a wooden rub-plate) and through walls with great ease. During installation, we always attempt to wrap the entire building with one piece of strapping, thus avoiding splices and joints.

Once the design is agreed upon, the strapping is hung loosely in place, then pulled tight with a ratcheting, hand held "come-a-long" or tensioning device. When the strap is pulled tight, and the majority of stretch has been taken up, we melt grommet holes in the polypropylene with a hot welding rod and affix the strap to the building with four- to six-inch brass decking screws. We design the installation to cross over as many lintels and beams or embedded wooden elements as possible. Where we cannot screw into wood, we do not hesitate to screw into the adobe, directly. The screws spaced at approximately 16-inch intervals bond very successfully to the adobe.

Once installed, the strapping can be plastered over without the use of lath.

In seismic zones the builder may wish to choose a strap with more stretch than polypropylene. There is a large variety of nylon to select from, including a three-inch wide material with 15,000 lb break test and up to 20% stretch.

The advantages of the belting are its light weight, flexibility, availability, economy, ease of installation, ability to be hidden and great strength. Used in combination with ladder belts and helical piers, as described below, the material offers many possibilities for use in traditional buildings.

Helical Anchors

Invented over seventy years ago, helical piers or screw anchors have been used on a widespread basis in place of "dead men" for guy-wire tie-downs on utility transmission lines. Over the past twenty years they have also proven an effective and moderately priced solution to stabilizing both new and older buildings on unstable soils. The principle is simple; soil testing provides a profile of the subsurface, including moisture content, voids, and granulometry. Then, by calculating the load to be supported and configuring the intervention to the soil profiles, a system of helical piers can be installed to support practically any load. The piers, reminiscent of an auger, but with single helices instead of a continuous spiral, are hydraulically screwed into the ground at calculated intervals. The tops of the piers are then attached by any number of devices to the base of the walls. Once attached, the walls can be moved up or down to straighten out openings and correct for settlement.

Helical piers can be used to retrofit virtually any type of structure, whether it has a foundation or not. Earthen buildings are particularly likely subjects for pier-based retrofits because the inherent limits of the material usually result in buildings that, though often massive, are not particularly large or beyond the load limits of helical technologies.

Though none of the manufacturers of screw anchors fabricate connection brackets specifically for earthen buildings without footings or for those in seismic zones, adaptation to both is not rocket science. In New Mexico we have developed a "basket" support system that attaches to the pier stems via a standard mounting bracket. We fabricate the baskets for individual applications. For example, in a situation where we have a triple-wythe wall on unstable soils, we build a basket slightly narrower than the wall thickness and install it in four-foot segments supported by two piers opposite one another in cross section. The baskets, once installed, are welded into one continuous, steel grade beam.

The advantage of the basket is that it not only provides structural support, but a capillarity break as well. The basket is engineered for a specific load, and is deep enough to be filled with five inches of 3/8-inch river rock which effectively separates the base of the earthen wall from moist soils.

Though we have not installed a basket support system as a seismic retrofit, it seems logical that the polypropylene strapping system described above could include vertical components that buckle to the baskets or to the mounting brackets themselves. Such a configuration would provide an effective tie-down system which, coupled with ladder belts and horizontal ties would likely limit out-of-plane displacement to a considerable degree.

CONCLUSION: Simplify, Simplify.

Each of the technologies described here is simple to understand, easier to apply than alternative methods, far less costly than other interventions, and is applicable both in new earthen construction as well as retrofit situations.

The specific points raised above serve to illustrate the dichotomy in thinking between the code-writers and, for lack of a better word, the traditionalists. When contemplating the repair of an old building or the construction of a new one, code enforcers tend to ask "how much is enough?" The code writer, possibly unfamiliar with the historic success of many adobe technologies in seismic zones, and having his fears augmented by visions of whole communities laid waste during an earthquake, responds by seeking higher and higher-tech solutions, typically incorporating dissimilar materials. The traditionalist changes the question to read "how much is too much?"

Nothing is more exemplary of this than the advocacy by code writers for hard plasters and replacement of soft materials by rigid posts, beams, moment frames and the like. The challenge is to develop as strong a lobby for low-tech, inexpensive and time-proven traditional remedies that have never been bettered as exists for the steel and Portland cement industries.

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