Pisé – a New Earthen Construction Technology

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History has proven the durability and appropriateness of natural earth as a building material. Current architectural trends as well as the new awareness for sustainability in building practices have combined to create a rapidly growing appreciation for massive earth walls. The pise' process was developed in response to this new appreciation, with the object of improving traditional monolithic earth wall construction systems to make them faster, safer, more reliable, more flexible, more readily adaptable to current construction practices, and in compliance with accepted seismic design approaches.

The word pise' (pronounced pee-zay) is an acronym for Pneumatically Impacted Stabilized Earth. We chose it as the name for our new process because the word has long been in use. Pise' de Terre, or simply pise', is the French translation of rammed earth. When we developed this modified version of rammed earth construction and began to introduce it to the building industry, we thought it would be fitting to choose an old name, one that had long been associated with traditional masonry architecture.

We were confident that pneumatically impacted earth would significantly increase the opportunities to use monolithic earth walls in new construction.

What is pise'?

It is a process of constructing solid, load bearing walls using native soils and other clay-based aggregates. It utilizing sophisticated mixing and delivery equipment combined with skills borrowed from an existing industry. Other earth wall construction techniques that have been in use for centuries are sun-dried adobe bricks, cob, wattle and daub, and rammed earth. (See *The Rammed Earth House*, by David Easton, published by Chelsea Green). All four of these ancient techniques are very well adapted to owner-builder and low-cost applications, in that they are labor intensive and can be accomplished by relatively inexperienced builders. The new pise' process, like it's direct ancestors, rammed earth and cob, is used to create monolithic walls, i.e. without support posts or mortar joints. Unlike rammed earth and cob, however, which are slow to erect because the soil material is mixed in small batches and placed in the wall by hand or with shovels, a pise' wall can be completed in a remarkably short period of time. It is this speed of construction that affords the opportunity for earth walls to compete in the marketplace with other popular building systems.

What makes pise' so much faster is the use of high pressure air to both convey the soil mixture to the form work and provide the force of impact which contributes to wall strength and durability. In traditional rammed earth construction, strengths are achieved by virtue of compacting (ramming) the soil mixture into the forms. The moistened soil is placed into the forms layer at a time, and each layer is carefully compacted to achieve the required density. Without adequate compaction, a rammed earth wall will soon begin to deteriorate. In the pise' process compaction is achieved through the use of air pressure to blast (impact) the soil mixture into place against the form work. Rather than shoveling material into a form layer at a time and compacting each layer, as in traditional rammed earth, with pise' the soil mixture is continuously and simultaneously delivered and impacted against the form, thereby eliminating both shoveling and ramming. Realistic daily production levels for mechanically assisted

rammed earth are on the order of 10 to 15 cubic yards of placed material per day. Pise' daily production levels range from 40 to 60 cubic yards. A typical house with 18" thick earth walls totals between 100 to 150 cubic yards.

Although pise' may be mistakenly thought of as crude or primitive because of it's associations with ancient earth building practices, it is in fact a highly sophisticated technology which requires hard work, skill, experience, and attention to detail. It is not a method recommended for owner-builders.

Why pise' instead of rammed earth?

In addition to the increased speed of installation, there are several other factors that make pise' a more practical, efficient, and economically viable method of constructing monolithic earth walls than rammed earth.

1. Earthquake safety. Although solid earth walls have traditionally been built without any reinforcing, current building code interpretations in California and other seismically active regions of the country require that earth walls be steel reinforced, much like concrete walls. In rammed earth, due to the complicated, closed-in form work, which is typically set in short lengths, and to the very nature of compacting in horizontal layers, steel reinforcing is difficult and very time-consuming to incorporate into the wall. Pise' on the other hand, with its one-sided form set in runs of 100 linear feet or more, and its reliance on impact from the face rather than compaction in layers, is well-adapted to a conventional steel reinforcing grid, whether of tied reinforcing bars or welded reinforcing mats. Another engineered component that has been added to rammed earth walls systems to make them more earthquake resistant is the concrete bond beam, a separate, reinforced wall cap which is poured in place on top of the walls once they have been completed around the perimeter of the building. This bond beam includes additional horizontal reinforcing steel, as well as anchor bolts to attach the roof plates. The purpose of the bond beam is two-fold: to provide additional stiffening to the walls system and to securely encase the anchor bolts. In pise', the separate concrete bond beam can be eliminated altogether, with the earth wall remaining homogenous from foundation to roofline. This is because of higher bond strengths between the reinforcing steel and the earth mix when it is shot rather than rammed, and because the nature of air-placed earth directed from a nozzle allows for more thorough encasement of both steel and bolts. Elimination of the separate step of forming and pouring the concrete bond beam has the additional consequence of reducing the cost of a pise' wall in comparison to rammed earth.

2. Improved quality control. Rammed earth has traditionally been mixed in small batches on the ground near the work site, either by hand or with small tractors. Proportions of soil, cement, and sometimes an admixture are measured by shovel or tractor bucket. The ingredients are combined using shovels, small garden rototillers, or the bucket of the tractor. Water is added by eye and checked by feel. With these imprecise methods, unacceptable variations can occur in the uniformity of the mixture delivered to the forms for compaction, especially from one batch to the next. Moisture content is particularly critical in the construction of a durable earth wall. The work of ramming each layer of soil mix is done by a person standing in the form, using a hand-held backfill tamper. To obtain proper compaction, the operator must thoroughly work down every square inch of the soil mix. If the layer is too thick, or if not enough time is spent in a given area, improper compaction can result. In the pise' process, mixing takes place in one of several different

types of specialized equipment, where soil, cement, and water are accurately proportioned, thoroughly blended, and delivered continuously. Ratios of soil to cement can be varied by controls that are an integral part of the mixing equipment, in response to changes in mix designs and strength requirements that might be specified by the structural engineer. The blended soil and cement mixture is delivered to the form in a continuous flow and is uniformly impacted into place, which results in a more consistent density to the finished wall. The replacement of imprecise field batching methods and hand-held backfill tampers with continuous proportioning mixers and air-placed delivery is a significant quality control advancement in earth wall construction.

3. Integration with existing trades. Rammed earth construction is a specialized trade, in which form building, steel reinforcing, mixing, compacting, and even some plumbing and electrical installations are all performed by the same wall building crew. Building a set of walls for a residence can take several weeks to even months, during which time other tradesmen would typically not be on site, except for short and sporadic work periods to integrate their rough-ins with the solid walls. The pise' process on the other hand utilizes a range of trades people: carpenters for form building and iron workers for reinforcing. After the formwork is set and the reinforcing steel is tied, the electrician and plumber can complete the installation of all of the rough electrical and plumbing at one time. Once all preparation work of the walls is finished, including the lay-out of roof rafters and any required beam pockets or embedded hardware, the pise' crew can bring their mixing equipment and big air compressor to complete the wall system. This smooth sequencing of different trades people, with each having a familiar task which is clearly defined, is what will make the pise' process more readily assimilated into today's construction industry.
4. Simplified formwork. Forming for a rammed earth wall is very time-consuming and cumbersome. Think of the work involved in forming for a cast-in-place concrete wall and double it. Rammed earth places higher stresses on the forms than does a ten foot high concrete pour, and the nature of

having to maintain a free working space inside of the forms for the tamper operators precludes the use of standard concrete form ties spaced at reasonable intervals. A pise' wall is formed on only one side, with full sheets of 3/4" plywood. Backing is typically vertical 2x4's at 24" with diagonal braces at 48". A horizontal 2x4 at the top of the wall is used to align the wall. Our crew can typically set 100 linear feet of wall form per day.

5. Conservation of materials. The plywood and braces used in the pise' forming system can be either left on site for use in the partition walls and as roof sheathing, or moved to a future job site for re-use as wall forms. Because the forms take little abuse during the installation process, they can be used numerous times before eventually becoming roof sheathing and blocking stock. In the first case, where wall forms are used for other parts of the same project, it means that some of the lumber in the home is recycled. In the second situation, plywood and bracing are used over and over as wall forms, then eventually serving some useful function in a structure, but never ending up in the land fill.

6. Increased public and professional acceptance. Each of the advantages to the pise' process listed above contributes in some degree to a greater level of confidence in the finished wall system. Those who would otherwise be skeptical of earth as a modern construction material are reassured by the steel reinforcing and quality control measures of the pise' process. Builders, developers, general contractors, and trades people all recognize the various components of the system, can see how the pieces fit together, and appreciate the speed and efficiency. Bankers, insurance agents, realtors, and building inspectors are comforted by engineered drawings, specifications, and laboratory test results.

At the time of this writing, the pise' process has been utilized to construct approximately fifty structures, comprising a total of 250,000 cubic yards of placed material. The tallest walls are on the order of 35 feet. In the fifteen years since its initial development by the author, pise' has gained a noteworthy popularity among architects and owners, unfortunately in a very limited geographical area. It's success in Northern California would seem to indicate that it could be introduced to other regions of the country, possibly with greater success in regions where threat of earthquake is less severe than in California. The primary cause currently limiting the distribution of the technology is cost. There are several factors that contribute to the current pricing structure of pise' wall systems. (1) Being a more industrial process than other earth construction methods, pise' is more difficult to master. Developing the requisite skills can take weeks of training under the supervision of experienced installers or months of trial and error. (2) Capital investment in equipment is substantial, with an anticipated slow rate of return prior to creation of a substantial client base. (3) Because the end product is viewed by the marketplace as "industrial", specifications drafted by engineers and architects are more rigid, and the tolerances for error less forgiving than with other earth construction systems. (4) Lack of structural documentation and an undue conservatism on the part of the engineering community result in over-engineered earth

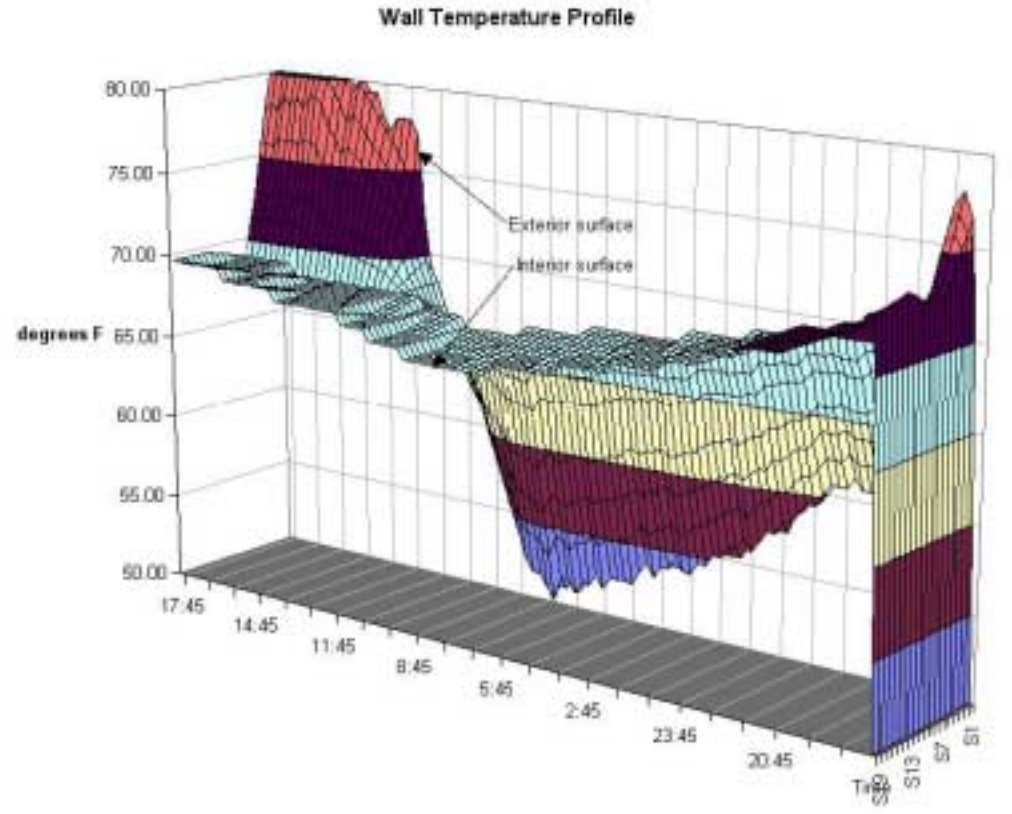
walls. Reinforcing steel, cement ratios, and special inspections beyond those dictated by reasonable safety factors can increase the cost of a wall system by as much as 50%.

Pise' as veneer

In recent years, as various alternative building systems such as straw bale, rastra block, and composite wall panels have increased in popularity, the pise' system has revealed itself as an efficient method for applying structural and thermal veneers. Its great advantages are speed of application and bond strength. The force of impact against the substrate not only increases the bond but can also reduce shrinkage, thereby allowing for veneers to be completed in a single layer. A minimum thickness of two inches is required to provide adequate waterproof covering. At increased thicknesses the veneer provides significant thermal storage. Rates of production on the order of 1000 square feet of wall surface can be achieved under optimum conditions.

Thermal Performance

For several decades, much debate has focused on the energy performance of uninsulated thermal mass walls. In fact, performance varies depending on many factors: architectural design, wall exposure, life style, landscaping, and of course both the micro and macro climate. Pure mass performs exceptionally well in temperate climate regions and poorly in extreme climate zones. The graph below describes the energy flowing through an 18" thick uninsulated west facing pise' wall in Napa California on a September day. The study was conducted by David Scheer of the Berkeley School of Architecture using temperature sensors embedded in the wall. Colors indicate location of sensors through the wall. Note the extremes of the exterior surface versus the relatively constant interior surface.



In summary, the construction industry today is coming under increasing pressure to develop materials and methods that reduce the use of non-renewable resources. Architects and designers have the responsibility to intelligently improve the way our buildings function and consume energy. .Economics, however, continue to demand that both architecture and construction remain financially competitive so that healthy, safe, high quality housing can be remain affordable to as many people as possible. The pise' process responds to all of these guidelines. It uses a resource conserving material such as earth and combines it with an efficient construction technology to create a durable wall system that can survive for hundreds of years with little maintenance.