Non-Traditional Coastal Construction Practices

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TABLE OF CONTENTS

EXECUTIVE SUMMARY

Due to the devastating damage from Hurricanes Dennis, Katrina and Rita, there will be a significant amount of rebuilding in the Southern United States in the near future. This widespread destruction of residential and commercial buildings opens an opportunity for structural mitigation against future-hazard events, and therefore, potentially reduces future damages. In addition to the recent hurricanes, the 2004 hurricane season and the Indian Ocean Tsunami have led to shortages of many essential building materials. Due to the shortages, construction costs will be rising, both for in-kind replacement and alternative coastal construction. However, one of the main goals, of the ***Non-Traditional Coastal-Construction Practices,*** is to improve construction performance during future-hazard events, and therefore, reduce long-term damage costs making mitigation-construction measures cost-effective.

This report provides information for homeowners, business owners and local officials to make informed decisions about building practices, specifically targeting improvements and/or performance enhancing characteristics for areas subject to severe flooding and hurricane-strength wind forces in coastal environments. This report will address many construction techniques that are designed to improve the performance of residential buildings, including concrete-panel building, insulated-concrete form (ICF), modular homes and log-frame houses. This report will also address the hazard performance of a high-performance metal building designed for commercial, retail, civic, school, residential or industrial use. This report will describe the benefits of a hurricane-proof wind screen, a non-structural mitigation measure that can be used on either type of building, residential or commercial. Alternative construction methods, such as the thin-shell concrete monolithic dome and the superadobe building, will also be described. Finally, this report will briefly outline the benefits and needs for higher-hurricane standards.

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Introduction

Hurricanes have repetitively caused extensive damage in the coastal areas of the United States, especially in the South. They will continue to do so in the future. Lessons, learned from the past two years, are that the severity of these events is increasing, and will continue to do so for the next 15 to 20 years, as we have not yet reached our asymptotic limit. This is nothing new to Professor William Gray, an atmospheric scientist, who is the country's foremost prognosticator of hurricanes. His long-term average is 9.6 named storms, 5.9 hurricanes and 2.3 intense hurricanes per year. In May of 2005, due to the lack of an El Niño, Gray increased his forecast and predicted that activities would be 170% greater than an average season. See http://hurricane.atmos.colostate.edu .

Hurricanes Dennis, Katrina and Rita passed over the Southern United States in August and September of 2005. Although these storms weakened in the hours before they made landfall (Katrina and Rita from a Category 5), major beach erosion, storm-surge flooding, over wash, torrential rains and high-wind damages occurred along a stretch of shoreline extending from the Florida panhandle to the Texas coastline, a distance of some 800 miles. The damages from Katrina were considered the worst in US History, eclipsing all other disasters in American history by more than an order of magnitude. Media sources have reported that private insurance estimates were varying from \$100 to \$200 billion. Devastating storm surge from 10 to 30 feet above normal tide level washed over southern coastal areas and inundated coastlines, including the central business districts of Biloxi, MS and Gulfport, MS. High-water levels of nearly 30 feet were measured locally in Biloxi Bay. About fifty percent (50%) of the housing stock in the coastal counties sustained major damage or was destroyed. Eighteen-thousand wooden power poles were wrecked by winds and downed trees in New Orleans alone, about one hundred thousand collectively from Texas to Florida.

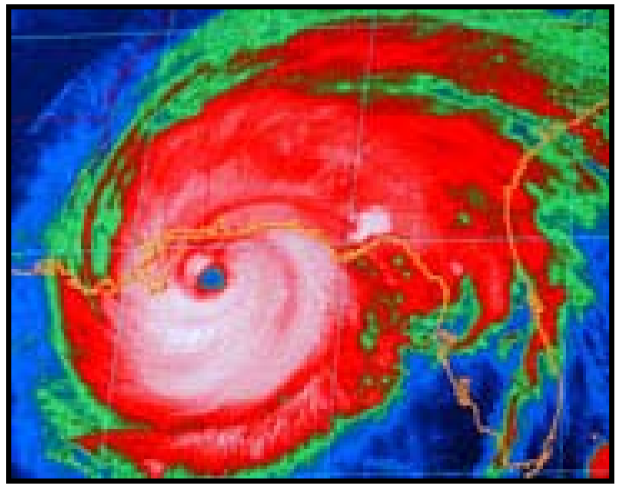

Figure 1

Obviously, hurricanes are known to cause damage due to high wind and high-velocity water. However, areas such as Mobile, AL, Biloxi, MS and New Orleans, LA will likely have a large number of homes destroyed by slow flooding. Unlike the high winds and fast-moving waters, the slow floods did not rip off roofing, destroy walls or cause immediate structural damages. However, many homes will be permanently uninhabitable because the water carried contaminants that that cannot be removed easily from wooden structures. Long-term submersion in fresh water will make most structures un-repairable. This is a likely scenario for a large share of the two-hundred thousand homes in the *Crescent City*, New Orleans. In Mississippi, reports indicate that more than eighty percent (80%) of the estimated one-hundred seventy-one thousand homes on the coast were heavily damaged or destroyed completely.

RESIDENTIAL CONSTRUCTION

1. Concrete-Panel Building

Concrete-panel buildings are considered system-built structures. The exterior shell of residential and commercial buildings in concrete-panel buildings uses insulated walls and roof panels that are erected quickly and easily (see cover and Figure 2). The stress-skin wall panels consist of two sheets of off-the-shelf construction-grade fiber (cellulose reinforced) cement board laminated to a 4-inch low-density polystyrene core. Wall panel meet ASTM E 330-90 (Standard Test Method for Structural performance of exterior windows, curtain walls and doors by uniform air pressure difference) and wind-resistance requirement of the most aggressive building ordinances. Panels also meet Southern Building Code Congress International (SBCCI) SSTD 12-99 large-missile impact test, which determines impact resistance from wind borne debris. Wind tunnel test shows that the roof/wall panels can withstand 9,000 cycle of up to 200 mph with no damage.

Figure 3

The wall panels are cut to shape and provided with door and window openings and wiring/plumbing chases. The roof panels are

Figure 2

similar to the wall panels, consisting of a 6-inch (or thicker) polystyrene core clad in aluminum. Traditional roofing, such as asphalt shingle or metal roofing, is not required, but can be added for aesthetic purposes.

Since 1935, the industry has called this type of construction *Structural Insulated Panels* or *SIP's*. It was invented by the U.S. Forest Service's Forest Product Lab. Typically, the panels, or skin, were made of standard *Oriented Strand Board* (OSB), an engineered wood product made from smaller trees. The insulated cores were made of expanded polystyrene (EPS) or polyurethane-foam insulation. The skin and core were joined using the standard-industry methods and adhesives. SIP's are amazingly strong, experience very little air leakage and have a high-insulation rating. This means that it takes substantially less energy to heat or cool in comparison to more traditional construction.

Figure 4

Figure 5

However, the OSB was not completely disaster proof; it had one major weakness. When exposed to water, OSB deteriorates rapidly and provides a breeding ground for mold. This problem is rectified when concrete panels are used instead of OSB in SIP construction.

The concrete-panel building system uses new and advanced design methods. The process initially begins, as in the case of all SIP construction, a polystyrene slab covered in adhesive is laid between two pieces of 5/16" standard high-impact, composite cement-fiber board. However, the resulting "sandwich" is placed in a stack with nine other panels and the entire stack is placed in a huge vacuum bag that applies 1,000 pounds per square foot of pressure for two hours. This process cures the glue and creates a structurally sound panel. These cemetitious panels are tested in a lab to ensure proper building code compliance and quality control.

Once the wall panels are cured, they are cut and prepared for delivery. At the job site, the wall panels are attached to the foundation and to each other, using stainless-steel fasteners and galvanized spline. They are joined to roof panels using proprietary aluminum connectors. This building process forms a strong and energy-efficient structure. The resulting structure has been determined to withstand up to 200-mph winds. The concrete-panel building methodology has also been certified to be in compliance with the building code in major hurricane areas and the International Building Code (IBC).

Design Parameters and Issues:

- The welded-steel wind frame supports a continuous-steel ridge beam where the roof panels are attached. The roof panels are also bolted to a cap installed atop the wall. Once the structure is completed, the steel beams are hidden by the interior walls.

- The wall and roof panels are extremely strong. The panels have a breaking strength of approximately 7,000 pounds, and are so strong, that they can even be used as header beams over the garage doors. This design allows only ¼" deflection at 1,000 pound per foot load. The panels are joined with heavy-galvanized metal splines that are fastened with stainless-steel self-tapping screws. Exterior walls have wiring and plumbing roughed in during erection process.

- The roof panels feature 6-inch-thick polystyrene insulation and a variety of interior and exterior finishes. Panels are so durable, that standard roofing is not needed, except for aesthetic reason.

Figure 6

Due to the strength of the welded-steel wind frame and the roof panels, there is no need for an attic space with trusses (and their required ventilation) or other supports. The structural panels serve as both the roof and the ceiling.

- Steel-moment framing are used for wind resistance and steel studs to increase termite and mold resistant. (Figure 5)

Benefits:

- **Cost Effective:** Building costs can be reduced by as much as 75 percent in comparison to traditional construction. Cost of erecting shell is approximately $25 per square foot.

- **Less Construction Time:** The building-shell creation process is completed in only three days. On *Day One*, the steel wind frame and the walls are erected (Figure 2). The roof can be completed the next day (Figure 6). Finally, on *Day Three*, the doors and weatherproofing can be finished. At this point, the doors and windows can be locked (the house is now completely secured) and the interior can be finished at the contractor's convenience, regardless of the weather. (Figure 3)

- **Minimal Construction Crew:** The major construction can be completed with a four-person crew. There is no need for block masons, truss installers, roofers or insulators. Concrete-panel building construction also does not require heavy-lifting equipment, such as cranes or forklifts.

- **Hazard Resistant:** The concrete slab building is designed to weather multiple hazards, including hurricanes, tornadoes, earthquakes, floods, fire, insects and termites. Three homes build just before Hurricane Charley hit, survived the 145 mph continuous wind (with gust to 178 mph), while surround homes and trees were leveled. Only damage was cosmetic (tree fell on one of the eaves), which was quickly repaired. (See photographs on cover of this manual and Figure 4.)

- **Flood Resistant:** The concrete-panel building system uses no wood or other absorbent material (highly resistant to moisture absorption). Therefore, if a home is flooded, it can be stripped of carpeting, sanitized and dried out. Within days the home can return to normal service. Since the walls are concrete and closed-cell foam, there is no habitat for mold and mildew. They will not support the growth of black molds. Interior walls uses a highly mold-resistant paperless interior gypsum panel, which scores a ten, the highest level of performance for mold resistance under ASTM D 3272 test method. This means no molds growth in a 4-week controlled laboratory test. Interior steel-wall studs are flood resistant and provide no media for mold growth.

- **Wind Resistant:** At the heart of the system is a welded-steel wind frame that can withstand winds of more than 200 mph.

- **Ventilation:** Since there is no enclosed attic, the usual requisite attic ventilation is not needed or required. There is not entry point for horizontal rain during major events to destroy the interior.

- **Energy Efficient:** The wall panels have an insulating value of at least R-20 and ceilings provide at least R-30 (higher R-values are available). This is higher than conventionally built houses. Based on EPA's Energy Star rating, concrete-panel house scored an 87.6, which means it uses 38% less energy than a standard reference home.

- **Green:** The system uses no wood. The wind frame is constructed of steel. The walls and roofs are made of structural insulated panels. The wall studs are steel. The drywall is paperless. There is nothing to rot, mildew, nothing to attract termites. By conserving energy, this system contributes less pollution to the environment.

- **Insurance Reduction:** One of the largest insurance underwriters in Florida is considering premium reductions for hurricane-hardened houses using concrete-panel building.

- **Flexible Assembly:** If needed, portions of the house can be disassembled and replaced. For that matter, the whole house can be disassembled and re-assembled in another location at some future time (time/storage is not a limiting factor).

- **Versatile Style:** Houses using concrete panels can be built to resemble conventional American homes, including the historic styling of the traditional New Orleans tract home (i.e. the ginger bread, the unique tile roofing, wrought-iron railings, etc). The graphics below demonstrate some of the sample designs that would be ideal for replacing homes destroyed by Hurricane Katrina. These economical, hurricane-resistant homes would coordinate with any New Orleans or Gulf Coast community. There are other designs that may also be well suited to the architecture and climate of the Gulf Coast. (Figure 7-10)

Case Study:

- The U.S. Department of Defense is involved with a concrete-panel manufacturer on a pending proposal requesting 4,000 portable shelters designed using the concrete-panel system.

- The proposal includes two-different styles of shelters.

Figure 7

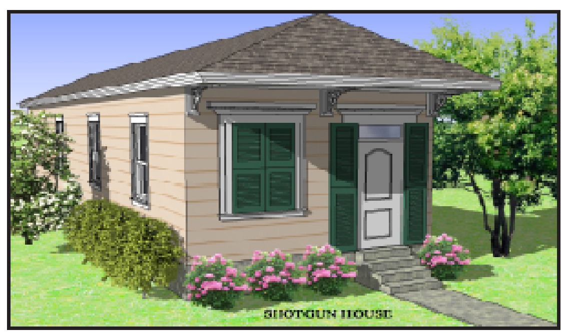

Figure 8

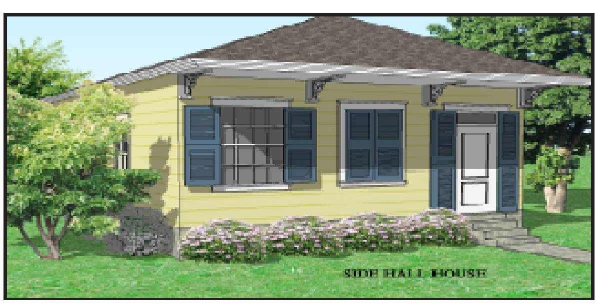

Figure 9

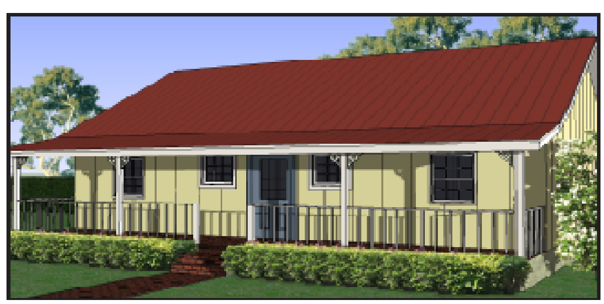

Figure 10

- In one military version, the concrete panels are drawn together with stainless steel cable. This is ideal for rapid deployment in areas such as Bosnia (Figures 11, 12).

- In the other version, the concrete panels screw together with stainless-steel fasteners and may be taken apart later.

- Modular designs: drop-in all-in-one kitchen, drop-in all-in-one bathrooms, drop-in partitions, vinyl flooring.

In Lieu of Manufactured Home Temporary Housing:

- Units could be quickly assembled or unassembled (in a manner of speaking: out of the box and then back into the box).

- All parts of the shelters (walls, floors, roofs) could be stored outdoors and be exposed to the elements for years with no degradation of performance.

- Units would be rapidly shipped on flatbed semi-trucks for significantly faster deployment than mobile homes. Generally, mobile homes must be shipped *one at a time*, moved only at night (according to most state laws) and are hampered by frequent breakdowns of tires, axles, suspension, frames.

- These structures would be rated to withstand 200-mph winds. Unlike mobile homes, the victims (residents) would be sheltered in disaster-proof housing with engineered tie downs.

Figure 11

- It is expected that 97% of the cable-banded military-version units would be reusable for future events. It is expected that 80% of the screw-together version would be reusable. Manufactured homes, after 18 months, are usually considered totally unusable, due to their fragile construction and susceptibility to vandalism. These damaged manufactured homes are auctioned off by GSA and are never to be used again for disaster purposes (i.e. victims housing).

Limitations:

- The buildings appear traditional and conventional. Manufacturer have not scaled up the engineering of very complex architectural design as of yet.

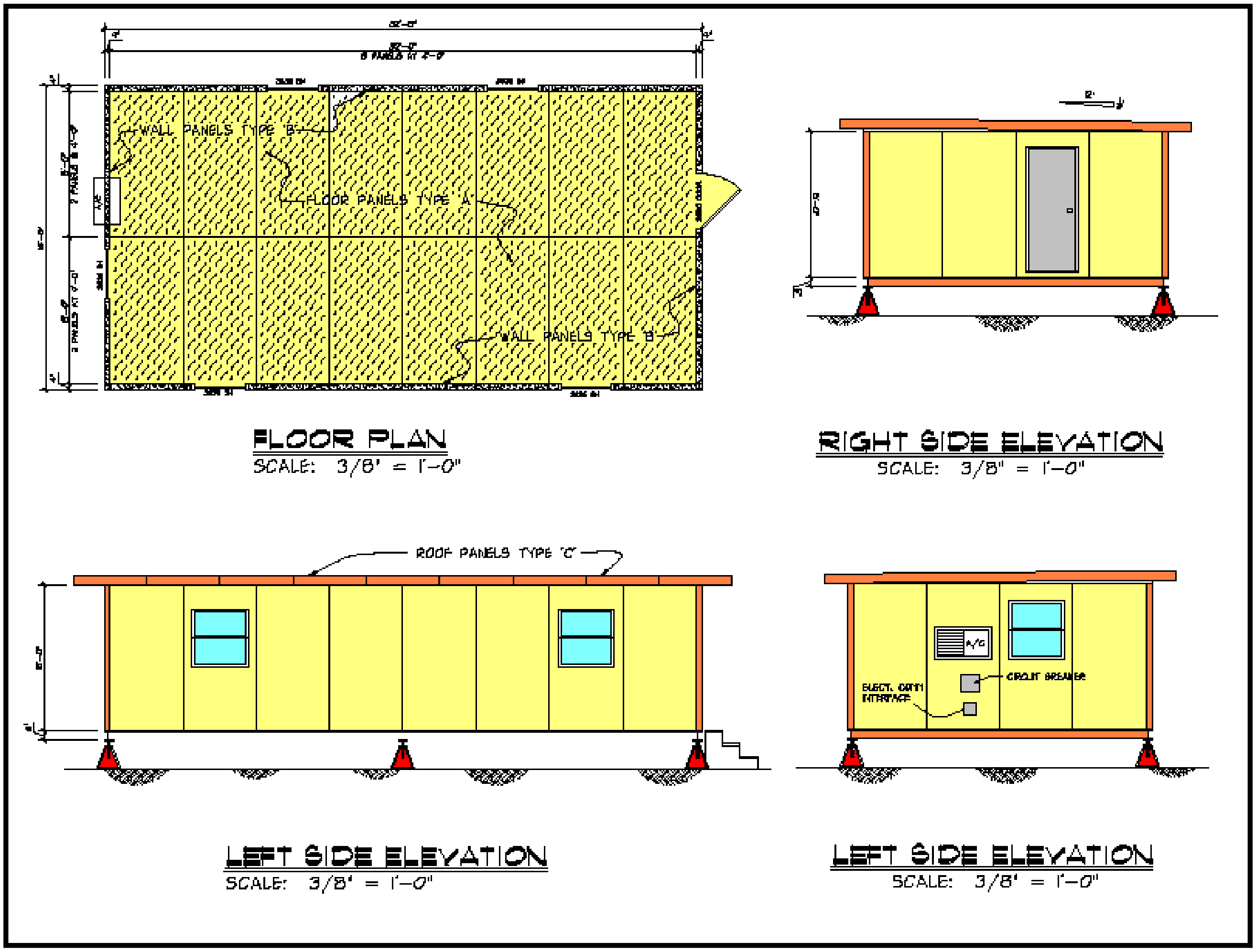

Figure 12

2. Insulated Concrete Form (ICF)

Figure 13

ICF is a system, where large-panel forms, made from closed-cell insulation, such as polystyrene foam. This allows builders to pour a solid-concrete wall. Once the concrete is cured, the foam remains. The foam provides insulation, a nailing surface and a vapor barrier. Channels can be cut into the foam to provide raceways/chases for electrical lines and plumbing. As with any type of installation below grade, conventional waterproofing, usually a non-petroleum based product, such as latex, is applied (sprayed or rolled on) or a solid membrane is applied (self adhesive). Wooden or plastic members, incorporated into the foam at planned locations, provide attachment points for windows and doors.

Figure 15

Design Parameters and Issues:

- Polystyrene foam, commonly used in ICF construction, is treated to not support combustion. Foam also has less ability to transmit an outside fire source than wooden construction. (Figure 15)

- Insulated concrete form is accepted by all major code models.

Figure 14

Benefits:

- **Cost Effective:** Insulated-concrete form is comparable in cost to building with 2"x6" wall construction.

- **Energy Efficient:** Many ICF walls have effective insulation values up to R-40; this is much greater than a

Figure 16

standard insulated 2”x6” wall. Therefore, the ICF’s higher-insulation value results in 50-80% savings on heating and cooling costs. High-thermal mass will help with power loss and provide even buffering of the HVAC. (Figure 16)

- **Strengthen Structure:** The concrete in ICF walls is 50% stronger and uses 30% less concrete than traditionally poured walls.

- **Hazard Resistant:** ICF’s have a record of withstanding hurricanes, fires, floods and tornadoes, while nearby wood structures were often destroyed.

    - Figure 17 shows a house that survived Hurricane Ivan, as a Category 5, over the Grand Cayman Island.

    - Figure 18 shows one of the very, few houses that survived Hurricane Ivan, as a Category 3, in Fort Walton Beach, Florida. This is also an example of an ICF’s that is raised above *Base Flood Elevation* (BFE), as designated by the locally adopted *Flood Insurance Rate Maps* (FIRM) for each community participating in the *National Flood Insurance Program (NFIP)* by FEMA.

Figure 19

Figure 17

    - Figure 19 shows a house that was partial under construction that survived the tornado in Stoughton, WI. It was the only house left standing in the neighborhood. The structure is under roof, with windows installed, and brick cladding had been started. However, the house was not totally enclosed. As a result, the building envelope was pressurized, which resulted in some of the roof sheathing blowing out. Still, all in all, it survived extremely well. If the building was finished, it would likely not have any damages.

Figure 18

- **Optional Safe House:** Using design criteria in standards such as ASCE/SEI 7-05, ICF structures can be engineered / built to easily withstand hurricane and tornado force winds without any significant damage. In another words, the Safe Room would be, effectively, the whole ICF house. Another option is to install smaller, traditional safe room (e.g. bath room doubles as safe room).

- **Longevity:** There are fewer repairs and maintenance and structures may last centuries.

- **Economical.** Cost is just 0.4 to 4.0% more than stick-built (i.e. conventionally built without prefabricated parts) homes.

- **Styling.** ICF homes can also be built to resemble conventional American homes, including the historic styling of the traditional New Orleans tract home (i.e. the ginger bread, the unique tile roofing, wrought-iron railings, etc). These economical, hurricane-resistant homes would coordinate with any New Orleans or Gulf Coast community. There are other designs that may also be well suited to the architecture and climate of the Gulf Coast. (Figures 13, 14, 20)

Limitations:

- ICF requires workers with construction experiences, including concrete placement and carpentry. However, ICF construction generally requires fewer workers than wooden construction.

Figure 20

3. Modular Homes

Modular homes are also considered system-built structures. They are built in sections in an indoor factory setting, where they are never subjected to adverse-weather conditions. The sections move through the factory where every step is checked and quality controlled. Finished modules are covered for protection and transported to the building site. They are placed on a pre-made foundation, joined and completed by a builder. (Figures 23, 24, 26, 27, 28, 30)

Figure 22

A *modular home* is not to be confused with a *manufactured home*. Modular homes are regulated, like site-built homes, by building codes. However, manufactured homes, formerly known as mobile homes, are regulated by the U.S. Department of Housing

Figure 23

Figure 21

and Urban Development (HUD) building code.

Unless one was there to see the house delivered and assembled, one might not guess it was a modular home. Modular-home manufacturers use computer-aided design programs to draw plans to a customer's specifications. Plans can be modified and tailored to any specific need. In theory, nearly any home design can be turned into a modular home. Even a legendary NASCAR stock car driver built a multi-level modular home. It's true that some modular homes are very basic and resemble double-wide manufactured homes, but the two types of structure are still built in different ways.

Design Parameters and Issues:

- Modular homes are built in sections at a factory. Sections of the home are transported to the building site on truck beds and then joined together by local contractors. Local building inspectors check to make sure a modular home's structure meets requirements and that all finished work is done properly. (Figure 23)

Figure 24

Figure 25

- As with site-built houses, modular homes are generally built, at a minimum, with 2”x6” walls, 2”x8” floor joists, fully-engineered wood trusses and a continuous-load path from roof ridge to foundation. (Figure 24)

- Each module is 12 to 15 feet wide and 50 to 66 feet long. Any size house can be built, depending on the number of modules. It takes one day to combine all the modules and make the house weather tight.

- Modular homes are built to conform to all state, local or regional building codes at their destinations, not HUD standards.

- Modular homes can be built, regardless of local codes, to the maximum code the manufacturer is capable of meeting (e.g. 150 mph) or beyond.

Figure 27

- Modular homes can be raised above the ***Base Flood Elevation*** **(BFE)** (Figure 25), as designated by locally adopted *Flood Insurance Rate Maps* (FIRM) for each community participating in the *National Flood Insurance Program (NFIP)* by FEMA.

Figure 26

- **Versatile Style:** Modular Homes can also be built to resemble conventional American homes, including the historic styling of the traditional New Orleans tract home (i.e. the ginger bread, the unique tile roofing, wrought-iron railings, etc). These economical, hurricane-resistant homes would coordinate with any New Orleans or Gulf Coast community. There are other designs that may also be well suited to the architecture and climate of the Gulf Coast. (Figures 21, 22)

Figure 28

Benefits:

- **Cost Effective:** When used as a replacement for a manufactured home, modular homes only cost 10% more for equivalent sizes. Cost is typically $38 per square foot, without land, or about $48-$50 per square foot with land. This does not include installation and sale margin. Cost is from $60 to $70 per square foot, if all factors are included. Cost is also about ten to fifteen percent lower than on-site stick-built home.

- **Energy Efficient:** Many modular homes are very energy efficient, which helps reduce heating and cooling costs.

- **Wind Resistant:** Modular homes can be designed for 150-mph wind load, regardless of local building ordinances. Modular homes have withstood tornadoes and hurricanes. All different types of modular homes survived Hurricanes Frances, Charley and Andrew, with occasional minor cosmetic surface damage from debris missiles. In comparison, usually all of the nearby mobile homes were completely destroyed. Often, modular homes have higher wind-load performance than site-built stick-built

Figure 30

homes, even though both are regulated by the same building codes.

Figure 29

- **Insurance Reduction:** One of the largest underwriters in Florida is considering premium reductions for hurricane-hardened houses, such as modular homes.

- **Zoning Restrictions:** Modular homes have not typically experienced the zoning restrictions and discriminative ordinances applicable to manufactured homes.

- **Strengthen Building:** Systems-built modular houses often are stronger because they exceed local codes. They have to be strong enough to be trucked long distances and then lifted up by a crane onto the foundation.

- **Longevity:** A well-built modular home should have the same or better longevity as its site-built stick-built counterpart, while increasing in value over time.

- **Style and Popularity:** Modular homes are becoming main stream, which makes them easier to be accepted as forms of mitigation. Thirty percent of new houses are system-built and eighty percent use factory-built roof trusses,

- walls and floor panels. Again, modular homes are often less expensive per square foot than site-built houses.

- **Optional Safe Room:** Modular homes can be built with safe rooms, such as a storm room with Kevlar-reinforced wall panels that are rated to withstand winds of 250 mpg. They are marketed as a refuge from tornadoes and the wind-borne missiles they generate (Figure 29) and they meet FEMA's performance standard for hurricane and tornado shelters.

Limitations:

- Modular homes are not as disaster resistant as concrete-panel or monolithic-dome structures. Nevertheless, they are still a vast wind-performance improvement over standard conventional homes.

- Modular homes are also not flood resistant; they have the same limitations as any stick-built house.

4. Log-Frame Houses

Historically, Americans used logs not only to build houses, but also to build commercial structures, schools, churches, gristmills, barns, corncribs and a variety of outbuildings. Modern log-frame homes are typically system-built structures like the modular and concrete-panel houses. Log-frame houses that are built in a controlled factory setting are sturdier, because human error is reduced, and they are inspected before being transported to the home site. That makes them tighter and better able to withstand high winds. Though log cabins suggest pioneer days, rather than cutting-edge technology, they have stood the test of time and have survived severe storms because of their strength and weight.

Figure 32

Design Parameters and Issues:

- Log-frame houses, by their very nature, have built-in continuous load path.

- The log frame may be updated/enhanced by the use of additional continuous load path, i.e. hurricane strapping.

- Traditionally, logs are laid horizontally (i.e. stackwall). However, vertical-log cabins have increased-compressed strength by taking advantage of the natural grain of the timber. They also have even greater natural continuous-load path from top to bottom, therefore

Figure 31

increasing the wind-load capacity. The vertical orientation also reduces rot and the overall maintenance costs.

Benefits:

- **Wind Resistant:** Log homes have withstood tornadoes and hurricanes. A log house in Santa Rosa Beach, Florida, suffered no damage when Hurricane Ivan swept through with winds exceeding 100 mph. Besides the strength of the solid log walls, this home had hurricane straps connecting the timber roof to the log walls. Because the walls are solid logs, there is less issue with pressure differential from high-velocity winds.
- **Fatigue Resistant:** A factor in most

Figure 33

Figure 34

conventionally designed and built homes, is the fatigue induced by constant cycling of wind loads on structure. Due to the extreme size of the wall component (walls are not made of many small components loosely fasten together), log-frame houses are subject to very little wind-induced fatigue. Logs are also “spiked” from one to the next, providing for a very robust continuous-load path.

- **Monolithic dome:** Essentially, a log-frame house is a monolithic dome. Monolithic means "formed of one large-block of stone." The monolithic dome is just that -- essentially a well-insulated, reinforced, hollow rock. In this special case, the hollow rock is made of well pinned-together logs, interlaced at the corners.

- **Insurance Reduction:** One of the largest underwriters in Florida is considering premium reductions for hurricane-hardened houses, such as log-frame house.

- **Style and Popularity:** Log houses are used for more than just vacations; now ninety percent (90%) are primary residences. They come in a variety of styles and interiors. (Figures 31-36)

- **Strong mounting for windows and doors.** Most conventional building uses very lightly framed openings for installation of doors and windows. In a log-frame house, the doors and windows are essentially bonded to the logs.

- **Flood resistant:** Due to the nature of the logs, as opposed to cut-up lumber, they have many superior features. Most woods retain nature toxin and preservative, such as resins and saps (e.g. turpentine). While this is generally not a problem for home owners, it helps the logs resist molds and the effects of flood water. It is often, anti-fungal/anti-rot in nature.

Figure 35

Limitations:

- Log homes are economically suitable mostly for homes, small businesses and offices.

- Log homes are more expensive than traditional construction, ranging from \$150 to \$300 per square foot. Without interiors, cost range from \$30 to \$40 per square foot.

- This type of structure is resource intensive, involves more labor and has a longer construction time.

Figure 36

COMMERCIAL / RETAIL / CIVIC / SCHOOL / INDUSTRIAL CONSTRUCTION

High-Performance Pre-Engineered Metal Building

Traditionally, pre-engineered metal buildings (PEMB) have been chosen because they were relatively inexpensive. They were generally designed using low-grade steel, fasteners and frame, and the minimal finishing. PEMB's are most commonly used for offices, civic centers, schools, churches, storage, etc. PEMB's are not commonly used for residential buildings.

However, PEMB's can be and have been designed to withstand the harshest weather conditions on earth including heavy snow, hurricanes, tornadoes and even earthquakes. These durable all-steel metal buildings are highly versatile, vermin-proof and fire-resistant. The problem with constructing a high-performance metal building is finding a vendor who is willing to design and approve a hurricane-rated plan, and an applicant willing to pay for quality and higher performance.

Figure 37

Figure 38

Design Parameters and Issues:
PEMB's have been around for nearly a century. There are many companies that manufacture them. For most of the other non-traditional buildings in this report, the buyer has little chance for input, as the manufacturers designed them as turn-key system. However, PEMB customers can request the upgrading of certain design elements to greatly improve the performance of the building. ***Appendix A*** has sample suggested upgrades that can be used. In general, to improve performance:

- Upgrade to higher-tensile strength steel wall and roof panels, larger corrosion-resistant fasteners, increase cable bracing, closer spacing of steel-cross members (i.e. purlins, girts), hurricane-rated doors and windows, reduced deflection rate than what codes requires, use of corrosion-resistant metals and finishes, etc. (Figures 37, 38, 39, 40, 41, 42, 43)
- Use of dedicated, certified inspectors.

Figure 39

Figure 40

Benefits:

- **Cost Effective:** According to vendors, high-performance PEMB's may cost less than many other standard designs. The cost of using an 80,000 psi tensile steel wall is only about $0.10 per square foot more. The high-performance building cost is usually $18 per square foot for building shell. Sometimes, this is less than the standard design. However, in some cases, it may be more.

- **Improve overall performance:** Not only is the high-performance PEMB's substantially more hurricane resistant, but they have higher snow-load capacity (many metal buildings collapse from high-snow loads), and are more earthquake, flood and tornado resistant.

- **Any damages may not be lethal to building:** Traditional PEMB's are more easily twisted by winds and debris. Key building component may fail inspection, such as the metal wind frames, having exceeded design specification. High-performance PEMB may suffer damages in one section. Due to its high strength and capacity, damaging loads are less likely to be transferred to other key component. Building has higher chances of being repaired, instead of being red-tagged and required to be torn down.

Figure 42

- **Maintain performance for longer period:** Due to better corrosion resistant finishes, metals and fasteners, there should be little degradation in long-term performance.

Figure 41

- **Alternative to non-traditional coastal construction practices:** Using suggested specification will still greatly improve building performance over standard building.

- **High-performance home:** Traditional-style home can be built (Figure 42) with substantially higher performance than stick-built.

Limitations:

- The wind limits of the design are approximately just less than 200 mph. Therefore, the concrete-panel buildings and monolithic-dome construction are far superior.

- This type of construction can be very labor intensive.

- Standard PEMB's generally require more maintenance to prevent exponential rate of failure during hazard events. Performance declines rapidly when exposed to constant wind-load cycling (i.e. metal fatigue). However, this can mitigated by use of the high-performance methods discussed in this section, e.g. high-performance finishes, larger corrosion-resistant fasteners using aggressive fastening schedule, reduce deflection rate (to reduce fatigue failure from wind cycling), etc.

- Only 2% of the PEMB manufacturers are willing and/or able to design and build high-performance metal buildings.

Figure 43

NON-STRUCTURAL MITIGATION MEASURE

Hurricane-Proof Wind Screen

Instead of using an alternative design for the structure, if the structure is adequately built to reasonable hurricane-rated code, it is possible to improve performance using cutting-edge high-impact windscreens. The protective wind screen can cover a window or an opening, continue over the roof, and secure to the foundation, tie beam, or roof trusses. The wind screen can also completely cover entire buildings, manufactured homes, storage sheds, signs, boats on trailers or planes. Hurricane-proof wind screens are a cost-effective method used to mitigate against damage from wind load and wind borne missiles. (Figure 44)

Figure 44

When using approved vendors, high-impact wind screens meet the large-missile impact test of communities with high-performance hurricane codes. Wind screens may cut the wind by up to 97 percent; a 100-mph wind becomes a 3-mph breeze. They are flexible, thus making them ideal for lanais, patios and large-exposed areas. They have been shown to be effective for fire stations (Figure 45), especially their most vulnerable area, their tall bay doors. One of the most attractive features is that they are easy to put up, take down and store neatly away in a small area. This is important, as the more difficult it is to install a product, the less likely that this will be done. These high-impact wind screens are also call hurricane nets.

Figure 45

Design Parameters and Issues:

- Except for the whole-house style, the wind screens are bolted at the top and bottom to rustproof metal anchors.
- They are strong, durable, flexible woven-polypropylene monofilament-geotextile fabric screens, customized by vendors, for an exact fit at each opening or for whole house.
- Many high-impact wind screens meet the requirements of the building code for hurricane protection (e.g. ASTM-E1886 & 1996, SSTD-12). Some wind screens have been load-factor tested up to 195 pound per square foot (276 mph) and for large-missile impacted with 5 times the force required by some high-performance hurricane building codes.
- They can be sloped away from the base of doors, such as bay doors at fire stations, which helps to channel winds and rain away from the building.
- When not in use, screens are rolled up and secured, or stored away.

Figure 46

Benefits:

- **Cost Effective:** High-performance winds screens are a cost-effective alternative to rebuilding with higher standards or retrofitting buildings with other protective measures, such as traditional shutters. The cost for material alone is approximately $15 per square foot and increases to about $20 per square foot with installation. As a comparison, electric shutters installed, range from $22 to $35 per square foot, plus from $350 to $589 per motor, and from $150 and $189 for manual over-ride. Electric shutters have failed often, especially low-end types, as observed by building performance assessment teams sent out after Hurricane Charley.

- **Wind Resistant:**
  - Another unique feature of the high-impact wind screen is its ability to 'share' the wind with whatever it's protecting. This screen slows down the wind and disrupts the vortex forces created around corners and roof edges; this provides acceptable levels of wind for whatever it's protecting.
  - The fabric is approximately 50% closed (density), so 140-mph winds will be reduced to sub-hurricane levels, forces which can be handled by whatever it is protecting, and without the worry of impact, uplift, or overturning. There is no wind force that could be generated that would tear the material.

- **Debris Reduction:** Flexibility of material absorbs the impact of windborne debris and keeps it from hitting windows and doors, or the house when using the whole-house style.

- **Secondary Benefits:** These screens are transparent from the inside, allowing occupants to see out. They also allow ventilation. This is effective in keeping occupants cooler and reducing molds and mildew. They also provide an emergency exit when needed for door and lanai openings (Figure 46).

- **Insurance Reduction:** One of the largest underwriters in Florida is considering insurance premium reductions for hurricane-hardened houses.

Limitations:

- Weakness in some products, e.g. improper attachment, such as the use of grommet as tie downs, instead of using full-length load distributing attachment strip. This may result in total screen failure during high-wind events.

- Some vendors may not have UV-rated material. If screens are left continuously deployed, deterioration is a performance concern. It should be rated, at least, at 90%, ASTM G-53 test method.

ALTERNATIVE CONSTRUCTION STYLES

1. Monolithic Dome

The monolithic dome is a super-insulated, steel-reinforced concrete structure used for homes, schools, gymnasiums, bulk storage facilities, churches, offices, and many other uses.

The monolithic dome (Figure 47) has a concrete-ring foundation that is reinforced with steel-reinforcing bars (commonly called *rebar*). For smaller domes an integrated floor and ring foundation may be used. Vertical-steel bars embedded in the ring-beam footing are later attached to the steel reinforcing of the dome itself. The airform, fabricated to a proper shape and size, is attached to the concrete base. Using fans, the airform is inflated – creating the shape of the dome. The airform is both the form for construction of the dome and the outer-roof membrane of the shell when it is finished. The inflator fans run throughout the construction of the dome shell. Approximately three inches of polyurethane-foam insulation (considered a very high-performance insulation) is applied to the interior surface of the airform. Rebars are attached to the foam using special "hooks" embedded in the foam. The rebars are placed in an engineered layout of horizontal and vertical hoops. *Shotcrete*, a special spray mix of concrete (typically rated at 3,000 psi) is sprayed onto the interior surface of the polyurethane foam, embedding the

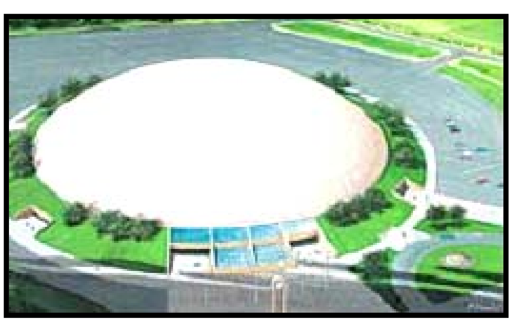

Figure 48

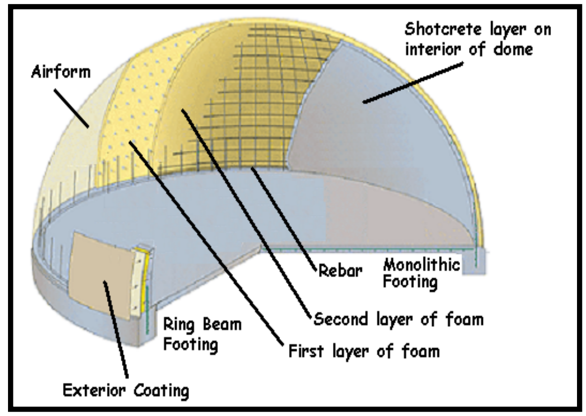

Figure 47

rebars. After three inches of Shotcrete is applied, the monolithic dome becomes a steel-reinforced, thin-shell concrete structure.

A monolithic dome (Figure 48) should not be confused with the many domes often used for major league sporting events, such as the *New Orleans Superdome*. The latter is an example of a conventional metal building, regardless of its outer covering/sheathing. The major difference between monolithic domes and the Superdome is in the term "monolithic." Monolithic means "formed of one large block of stone." The monolithic dome is just that – essentially a well-insulated, reinforced, hollow rock. There is nothing a hurricane can tear off and nothing for wind to grab. Monolithic domes around the world have and will continue to survive hurricanes, tornadoes, earthquakes, fires and more. On the other hand, conventional structures like the New Orleans Superdome have not performed nearly as well. The word dome used in this report will only refer to what is generically called a monolithic dome.

During severe-storm events, many owners have decided to ride the storm out in their domes. To date, no monolithic dome has ever been destroyed in the damage path of a hurricane, tornado, earthquake or fire. Friends, neighbors and associates often stay with them, as their own structures were damaged or destroyed.

Design Parameters and Issues:

- When considering large-public buildings, it only makes sense to believe they will be used as shelters. Every community could have dome disaster shelters disguised as arenas, schools, churches and public buildings, hangars, etc. (Figures 49, 50)

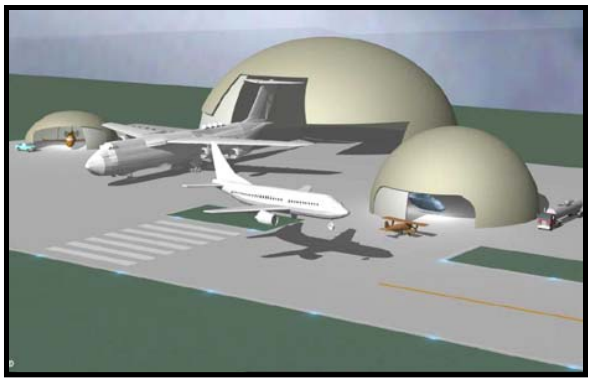

Figure 49

- The dome's construction costs are usually far less for these types of uses than those of conventional buildings.

- Most common beach homes use 45 wooden or concrete pilings. Beach domes only needs 16 pilings, 13 inch in diameter, commonly made from recycled plastic.

- Typically, a dome home weighs about 850 tons; in comparison, a similar size wood house weighs about 30 tons.

- Dome is designed with a wind-load capacity of 2,000 pounds per square feet. Winds at 300 mph will create 404 pounds per square foot on a dome. Domes cause the wind to move over and around the shell, reducing the resultant forces on the walls.

- Concrete structures have to be built with a much larger margin of safety. It's not unusual to use a 20% safety margin on a steel building (e.g. New Orleans Superdome) and a 500% margin on a monolithic-dome structure. (To help account for the uncertainties for a structure, engineers apply a factor of safety, or FS, to the design. Most often, the FS appears as a number by which all loads are multiplied. For example, if a bridge is required to carry a ten-ton truck, it may be designed to carry a fifty-ton truck, providing a safety factor of 5. Monolithic dome has an unusually large safety factor.

Benefits:

- **Cost Effective:** Construction cost is much less than conventional building designs. Based on a dome footprint, construction costs $30 per square foot for an un-insulated dome and $50 per square foot for insulated dome shell. For buildings, such as a school, gym or church, the dome is about one-half of the cost of conventional design.

- **Energy Efficient:** Not only are monolithic domes generally less expensive to construct, but they are proven to pay for themselves in about 20 years (or less in many cases) in energy savings. A dome requires only a minimal one ton of air conditioning for e

Figure 50

s

quare feet of footprint, far less than what is required for conventional buildings (on low end, about two tons of air-conditioning for insulated conventional building, to high end of four to five tons for poorly insulated buildings.).

- **Strengthen Building:** Concrete structures are also much stronger than steel buildings.

- **Ideal Storm Shelter:** Domes make ideal storm shelters for communities. For example, a storm shelter disguised as a high school gymnasium (Figure 51). Another huge advantage a monolithic dome has, as a storm shelter, is that it maintains its temperature far better, far longer. If it loses its electrical service, the building's temperature will very gradually change over a matter of day. In a metal building, the same change will happen within a matter of hours. This is due to the thermal mass of the concrete in the monolithic dome combined with the superior insulative value of polyurethane foam.

- **Hazard Resistant:** Blast-resistant, fireproof, tornado, earthquake and hurricane proof, no monolithic-dome structure has ever suffered structural damage from a fire, flood, tornado or earthquake. In addition, the system for the shell uses no wood or other porous/absorbent material that would be susceptible to fire, flooding, molds, mildew, etc.

- **Wind Resistant:** Dome is rated at 300 mph conservatively.

- **Longevity:** The dome may last centuries.

- **Insurance Reduction:** One of the largest underwriters is considering premium reductions for hurricane-hardened houses. Fire insurance may only cost a fraction of standard structure, as the building may be deemed fire proof by insurance carrier.

Figure 51

Limitations:

- Aesthetics is the major limiting factor. Many people do not like having a small business or home shaped as a dome. Recent architectural design has drastically lessened this problem. However, in the case of a very-large dome, this does not quite appear to be a limiting factor. Most major-league sporting-event stadiums are shaped like a dome (but are not monolithic domes).

2. Superadobe Building

Superadobe building uses a simple sandbag and barbed-wire technology. Superadobe construction methods are based on ancient-clay building styles. They use a dome-shaped design and withstand severe heat, cold, rain, snow, wind and earthquakes. Superadobe uses un-fired earth, stuffed into sandbag coils set in layers, connected by barbed wire. This method easily accommodates windows, doors and skylights.

Between 1993 and 1996 models were constructed and tested for the City of Hesperia, California, Building and Safety Department, in consultation with International Conference of Building Officials, in the forms of arches, vaults, and domes. These models have successfully passed the required California codes. Superadobe is a patented system and is offered free to the owner / builder; however, licensing is required for commercial use. It was developed by Nader Khalili, architect and founder of **Cal-Earth** (The California Institute of Earth Art and Architecture), a non-profit foundation dedicated to research and educating the public on environmentally oriented arts and architecture.

Design Parameters and Issues:

- Sandbags and barbed wire are used to create a safe shelter in most regions of the US. (Figures 52, 53, 54)
- This type of building uses a minimum amount of purchased products and maximum amount of free earth (i.e., dirt).
- Shelters created will provide maximum protection from natural and man-made disasters.
- Classes and video are available for anyone to build one of these superadobe buildings.
- This design is being used in third-world nations to solve the problem of housing, without the usual cost, while providing high-performance disaster protection that normally does not exist for third-world structures. Superadobe would also be ideal as a project for ***Habitat for Humanity International***, a nonprofit, ecumenical Christian housing ministry dedicated to eliminating substandard housing and homelessness worldwide. As a result of 2005 earthquake in Pakistan, numerous requests have been made to Cal-Earth for use of superadobe for earthquake-proof housing that can be economically and rapidly put together in disaster areas of Pakistan.
- The universality of the material and design has caused these houses to be seriously considered for the moon and Mars by NASA scientists interested in in-situ utilization of planetary resources.

Figure 52

Figure 53

Figure 54

Benefits:

- **Hazard Resistant:** Superadobe is wind, hurricane, and tornado proof and termite resistant.
- **Flood Resistant:** When modified with Portland cement, sandbags will resist the damaging effects of flooding.
- **Minimal Crew:** Group of people, mostly untrained and even uneducated, can form to build a shelter or house with minimum help. Ideally an expert would guide the group.
- **Cost Effective:** A 314 square-foot structure requires only $600 worth of materials.

Three-vaulted Prototype:

- Three-vaulted house prototype has been in development to allow maximum space, light, and interior ventilation, while using the traditional form of the vault. The spaciousness of the interior design derives from this pattern of these three-offset vaults which allow a maximum view through the house's open-plan area, and from the height of the vault. (Figure 55)
- Three-vault system can be combined with domes and apses, or repeated back to back to form a variety of aesthetic and efficiently planned house designs.

Figure 56

Figure 55

- A prototype three-vaulted house has been tested and approved for California's severe earthquake codes and natural elements, in the harsh climate of the Mojave desert – over 100°F summer temperatures, freezing winters, flash floods, high wind, and the highest US earthquake (zone 4). (Figures 55, 56, 57)
- View through depth of two vaults increases the sense of interior space.
- Offset vaults eliminate the need for corridors.
- Simple design based on repetition of a single-vault design unit simplifies construction.
- More vaults can be added at a later

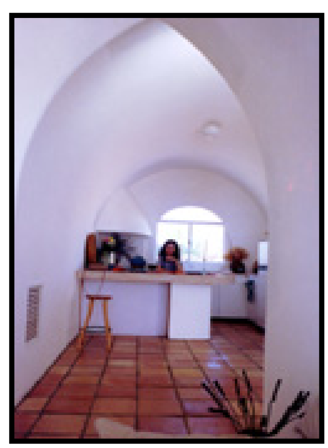

Figure 57

time.

- Variety can be introduced through the placement of windows and other small elements such as niches.
- Arches and vaults are inherently aesthetic, especially if repeated in a series.
- A two-story wind-scoop faces prevailing summer breezes for cooling.
- The vaulted curve of the roof, combined with the sun's path overhead, creates sun and shade zones which encourage circular air movement inside the house.
- The play of light and shadow minimizes the need for decoration.
- The combination fireplace and wind-scoop enhances both heating and cooling functions (also called an energy tower).

3. Eco-Dome

Cal-Earth has existing plan for approximately 400 square-feet (interior space) dome. This makes it a manageable structure for the person who is a first owner/builder. The finished "very-small house" is self-contained and can become a small-guest house, studio apartment, or be the first step in a cluster design of vaults and domes. (Figures 58-65)

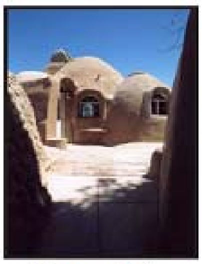
Figure 58


Figure 59


Figure 60


Figure 61

- Built from local earth-filled superadobe coils (soil-cement or lime-stabilized earth)
- Tree free
- Maximum use of space through alternative options
- The main dome and four niches, depending on local code approval, can function as:
    - main living room, entrance hall, kitchen, bathroom, bedroom, or
    - Living room, entrance hall, and three bed-rooms, or
    - Living room, entrance hall, two bedrooms, and a bathroom.
- Self-contained single unit (potential for a guest house or studio apartment).
- Can be repeated and joined together to form larger homes and courtyard houses.
- Can be built by a team of 3-5 persons.
- Designed with the sun, shade and wind in mind for passive cooling and heating.
- Wind-scoop can be combined with a rated furnace unit, depending on local code approval.
- Interior furniture can be built-in with same material.

Limitations:

- As with monolithic dome, aesthetics will always be a limiting factor. However, a shell can be built around it to provide the appearance/façade of a conventional structure, while still maintaining all the virtues of a superadobe.


Figure 62


Figure 63


Figure 64

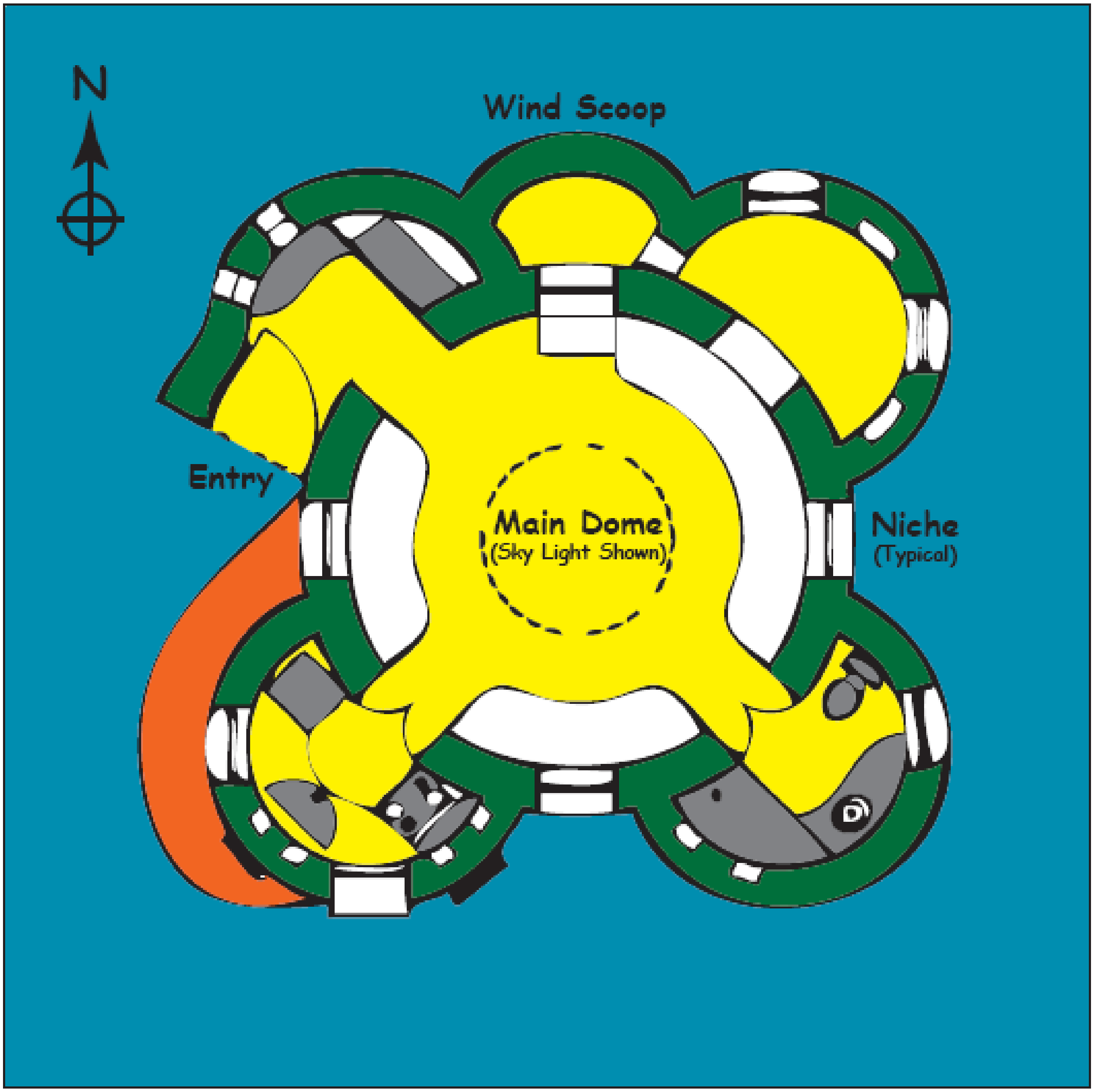

Figure 65

HIGHER-HURRICANE BUILDING CODE STANDARDS

Many parts of the country have dealt with frequent hurricanes. After major events such as Hurricanes Andrew, Camille, Charley, Frances, Hugo, Ivan, some areas were able to enact more-stringent building-code standards. In an ideal world, at the minimum, hurricane standards should be based on the *American Society of Civil Engineer's* (ASCE) 7-1998 standards. Still, realistically, building codes are often the minimum standards that are the maximum politically feasible. They may fall short of standards like those of the ASCE. However, this is a substantial improvement over having no codes.

One example of improved building code is when homeowners may be required to meet the increased wind standards by using impact-resistant doors and windows that use laminated glass similar to that found in car windshields. This type of building code improvement can be also achieved by persuading contractors and homeowners to build structures to these higher hurricane standards or by getting local officials to adopt part or all of the higher-performance standards. Building codes may not and do not restrict people from building stronger.

Design Parameters and Issues:

- What does it mean, if a product meets hurricane standards? Many areas are subject to some of the harshest wind conditions and have developed strict building codes in an attempt to ensure the quality and durability of the building products available. The products have often undergone approval testing established by communities in the wake of a catastrophic hurricane. These community testing procedures are generally considered to be more stringent than other national product-certification groups. There are many communities that have higher standards that could be used as models.

- Buildings should be able to withstand the strongest winds in the country, which means that owners of those buildings subject to lesser winds can have absolute confidence that their roof will remain in place. There are many sources of products that are designed for higher standards. Contractors and home owners can find many vendors by browsing/searching the Internet.

- Manufacturers have to pay to have their products tested and certified or join a certain trade organization (this high cost often is passed down to the consumer level). So the fact that a product does not carry a label, or if the manufacturer chose not spent extra money to become a member of a trade group and have their certificate for all to see, does not necessarily mean it's an ineffective product. It may just mean it has not been submitted for testing, which is voluntary.

- As example of a high-performance hurricane-building code, a certification may require that when a 9 pound 2" by 4" is fired at a window at 34 mph, it should not penetrate the window. But the ASTM standard (formally known as the American Society for Testing and Materials) allows a 2" by 4" to penetrate the window if the hole it creates is small enough that a 3-inch sphere cannot pass through it.

Benefits:

- **Cost Effective:** Increased cost is only a nominal 10-15% more than

- construction built to standard building codes.

- **Product Availability:** On the positive side, post-hurricane code changes in many jurisdictions have spurred a boom in the hurricane-protection industry. This movement is leading to lower prices, broader selection and product improvement.

Limitations:

- Remember, any code developed is only a minimum standard. There is no restriction on using more aggressive methods and materials which are readily available in the market place.

- It is cautioned that the way a product behaves in a test does not necessarily reflect "what happens in a real storm." A specific real-world event does not guarantee the absence of problems

Figure 66

APPENDIX A – HIGH PERFORMANCE PEMB SPECIFICATION

Detailed specification for High-Performance Metal Building (PEMB)

- Upgrade from common place 30,000 psi tensile steel (conventional low-carbon steels) wall and roof panel (in some cases, 50,000 psi steel which is starting to be more common due to market forces) to 80,000 psi steel (improved-formability high-strength low-alloy [HSLA] steels which meets ASTM A715 and/or conforming to ASTM A-446E-75). Premium costs for 80k psi is only $0.10 per square foot more than for 50k psi steel. Cost is 24% more for 80k psi over 30k psi steel. Do not use low-grade steel panels for any project.

- Minimum screws size is #12. However, should upgrade to #14 stainless-steel self-tapping screws with synthetic grommet (sealing washer) to resist corrosive effect of corrosive atmosphere commonly found on hurricane-prone coastal areas. This should be coupled to a heavy-fastening schedule (e.g. fasten roof/wall panel every 4 inches).

- Increase purlins and girts, by spacing 2 to 3 feet apart, as opposed to industry standard of 4 to 6 feet apart. Provide pipe / purlin struts in end bays of building (again, not required by code). Purlins and girts should at least 55,000 psi minimum yield strength, 8" deep zee, 14 gauge at the minimum, preferably 12 gauge.

- Install gussets underneath cap plate on top of columns.

- Eave struts must be bolted to masonry when applicable.

- Minimum thickness of framing members

    - Cold-formed primary framing member...........14 gauge
    - Cold-formed secondary framing member.........14 gauge
    - Intermediate pipe columns.........................3/16"
    - Webs of welded built-up members.............12 gauge
    - Flanges of welded built-up members...............3/16"
    - Bracing (cable standard)......................1/4" diameter
    - Bracing (rod optional)......................1/2" diameter

- Include cable-brace bays at both ends of building (not required by code).

- All hot-rolled steel sheet, plate and strip for built-up sections, shall have a minimum yield point of 55,000 psi.

- Hot-rolled structural section shall conform to the requirement of ASTM specification A570/A607, 55,000 psi.

- Require minimum tensile strength of 65,000 psi on all cold-formed section 12, 14, 15, & 16 gauge materials. This will result in a minimum yield point of 55,000 psi.

- Each frame should be bolted-up at the factory to ensure a perfect fit.
- Factory should have on-site AWS certified welding inspectors.
- Use hot-form instead of cold-form steel for cee's and zee's used for purlins and girts.
- Use high-performance corrosion-protected finished on all steel materials.
- Use hurricane / tornado-rated doors/latches and windows
- Increase use of cross bracing (cables) and increase size of cable.
- Use ASTM A-572 Grade 50 specification steel, radius welded for "H" and "I" beam for use as primary structural framing members. For example, do not use cold formed cee's welded together to form "H" or "I" beam.
- FM1-160 rated metal for coping, gutters & flashing.
- Use 55% Aluminum-Zinc alloy coated sheet steel (best known in the trade as GALVALUME®), ASTM specification A-792. Galvalume-coated steel is seven times more rust resistant than Galvanized steel. It is also called Zincalume®, Zintro-Alum™ and Galval™.
- All exposed metal surfaces, including galvanized or Galvalume coated, will be coated with polyester finish.

Special Note on building sag or sway

- All buildings sag or sway, and this is perfectly normal, to a degree. This is allowed for in IBC codes. Table 1604.3 of IBC 2000 (same for 2003, 2005 version) lays out a schedule of values for engineers to determine how much sway to allow for. One of the root problems is that the paragraph substantially lowers these requirements for steel structures. Over time, excess sway loosens fasteners and wallows out screw holes until the day a high wind comes along, that's strong enough, so that the building opens up, ever so slightly. Once the building box is "open", the dynamics of the engineering change and the building may fail. The approach suggested here, for achieving a high-performance PEMB (used by manufacturer of high-performance PEMB), is to increase building strength by raising deflection values to a higher level than the table. This does not eliminate the sway, but by reducing it in the neighborhood of 50%, this significantly and *exponentially* lessen the chance for fatigue and possible mass/catastrophic failure during major wind events. If codes require H/60 deflection, suggestion is to increase to H/120 or higher, for non-brittle exterior wall system. Less deflection means less failure from fatigue from wind cycling. For example, in a ten foot tall building, standard deflection would be to use H/60, which would allow two inch of sway. For high performance, suggest is to allow only one inch of sway at the eave of the building, i.e. H/120 standard. If the wall finish is brittle, such as masonry, brick, etc, the industry standard is to use H/100. Suggestion is to use H/240 as a standard.

APPENDIX B – PHOTO CREDITS

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Figure 66 FEMA staff photography

42

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Non-Traditional Coastal Construction Practices 2nd Draft November 2005

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