CASE STUDY:

DISASTER-RESISTANT GUAM HOUSING

BIG WIND RESIDENTIAL DISASTERS

DISASTER RESISTANT HOUSING (DRH)
WEBSITE ADDRESS:
http://www.tornadoproofhouses.com

CLOYD E. JOE WARNES, PE

CEO: CPMA - Contract Project Management Associates

USAID Construction Contractor Mentor: Romania, Poland, Russia

Specialist: Disaster-Resistant Concrete Dwellings
Precast Concrete Structural Systems
Computerized Project Management Systems

STRUCTURAL DESIGN

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- COO - CYS Engineers, Sacramento CA
  Structural Engineering Consultants
- Past President: Structural Engineering Association of California (SEAOC)
- Chairman: SEAOC Seismic Committee for UBC Seismic Provisions
- Chairman: SEAOC Wind Committee
- Chairman: SEAOC Existing Buildings Committee
- Voting Member: ACI-332, ACI-369, ACI-408, ACI-550 & ACI-560

INSULATED DISASTER PROOF CONCRETE HOUSES

FOR THE FIRST TIME IN THE HISTORY OF MANKIND, WE TODAY HAVE A SOLUTION TO THE AGE OLD CHALLLENGE OF BUILDING ATTRACTIVE ENERGY-CONSERVATIVE HOUSES THAT ARE COMFORTABLE AND AT THE SAME TIME SECURE FROM DESTRUCTION BY THE SEVEREST FORCES OF NATURE

EARTHQUAKES
HURRICANES
TORNADOES

PERFORMANCE

- This presentation is about:
- **PERFORMANCE OF Reinforced Concrete Single Family Houses designed according to DRS Box-Frame criteria under the forces of LARGE EARTHQUAKE S AND VERY HIGH WIND VELOCITIES**
- It is **not** about design and construction procedures other than to emphasize their contributions to the construction and **STRUCTURAL** performance of **REINFORCED CONCRETE** houses

CONCRETE HOME DEFINITION

- Our definition of a **"CONCRETE HOME"** is:

  "Single family house built with cast-in-place **or** prefabricated (precast or tilt-up) reinforced concrete **walls** PLUS cast-in-place reinforced concrete **roofs**

- This presentation considers the structural resistance of authentic **"Concrete Homes"** (according to our definition) against disastrous forces, both **natural** and **man-made**

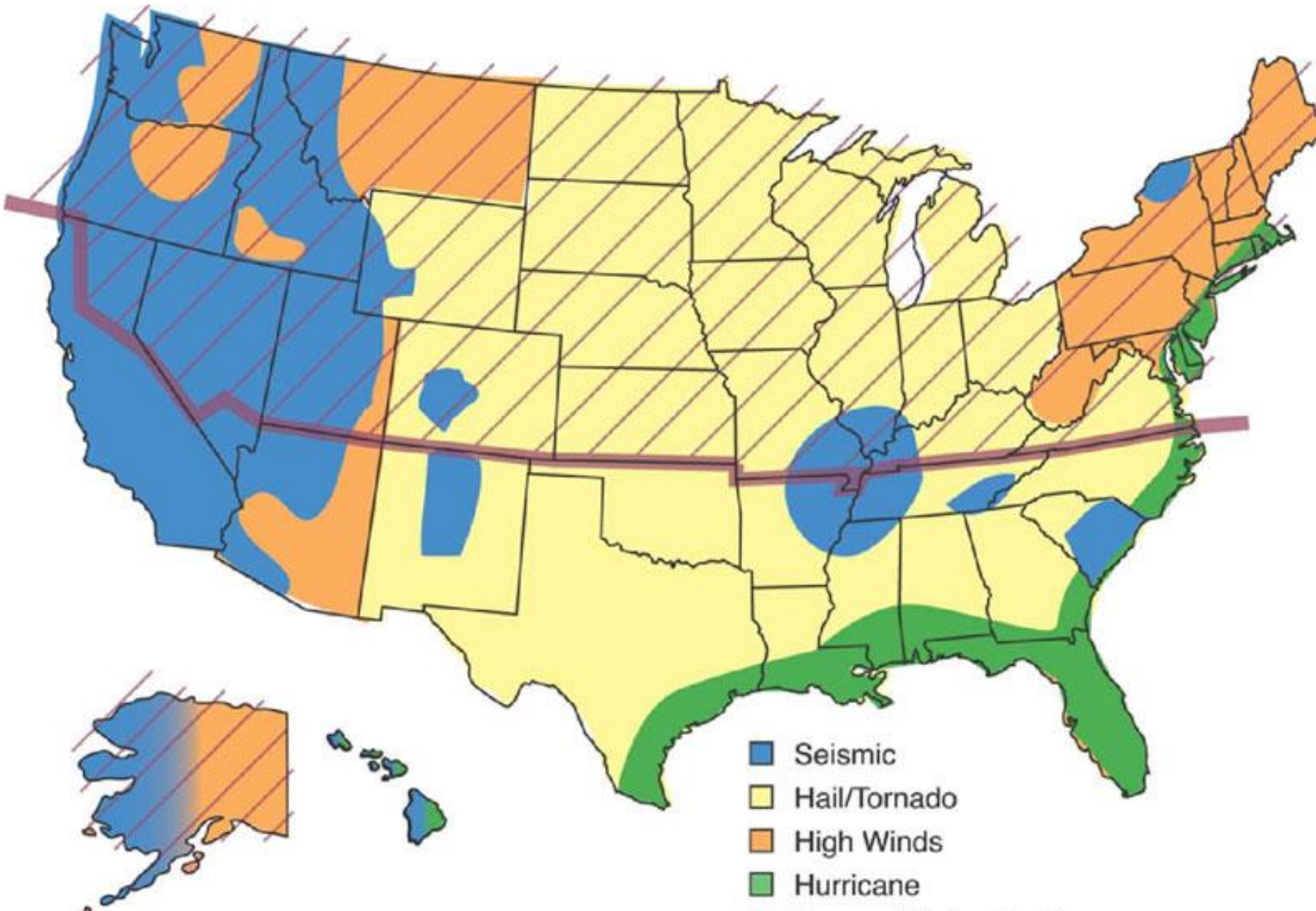
- **If the roof is not a reinforced concrete slab intimately connected to reinforced concrete walls and floors – then most of the disaster-resistant attributes are not achievable**

- **MOST OF THE SO-CALLED "CONCRETE HOMES" BEING CURRENTLY CONSTRUCTED IN NORTH AMERICA ACCEPT THAT WOOD-FRAME ROOFS WILL BE SACRIFICED IN A BIG EVENT**

DISASTERS IN GENERAL

DISASTER MAP OF THE USA

(Does not include fire storms, floods, storm surges or tsunamis)



DISASTERS CONSIDERED

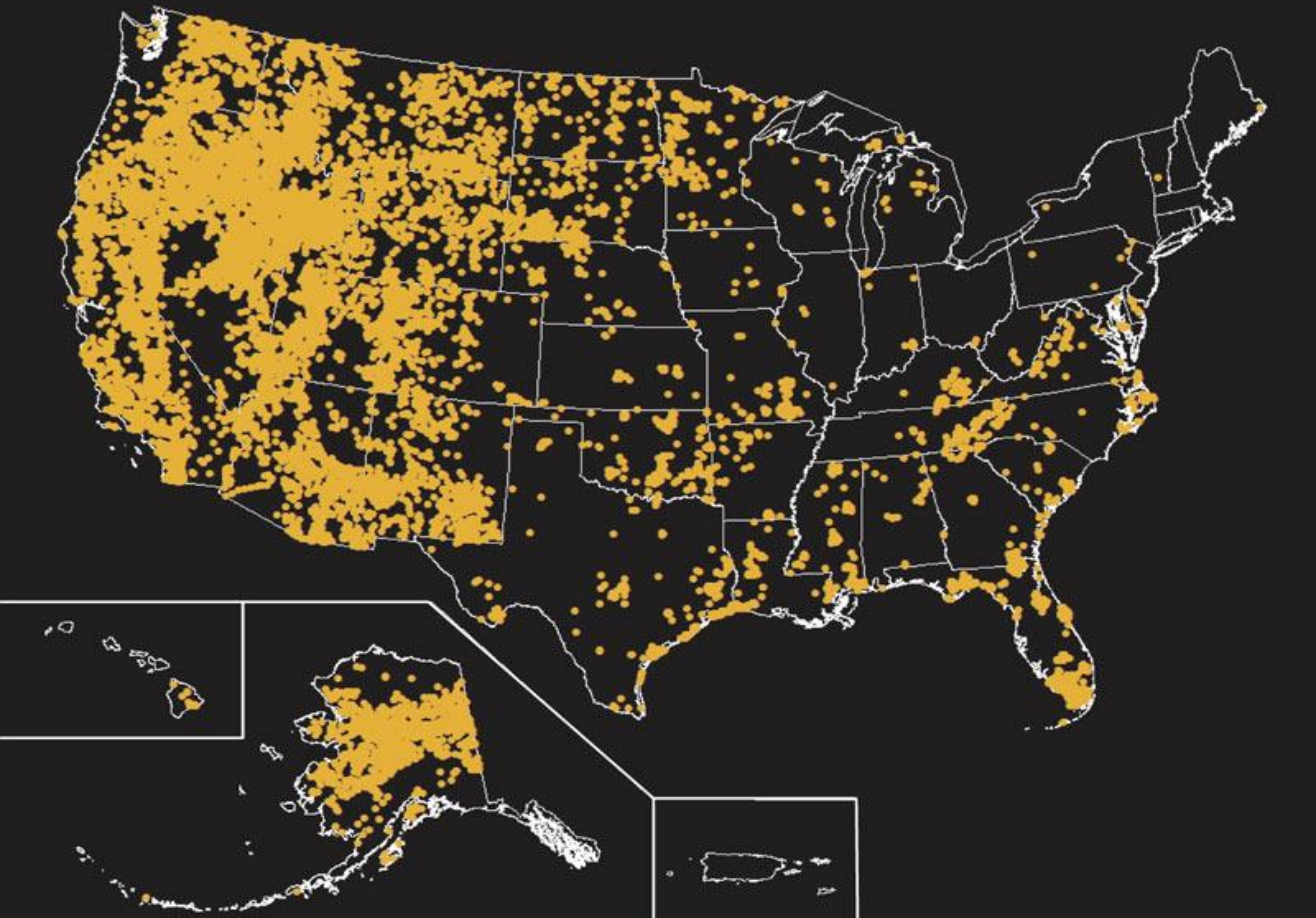
- THE PRESENTATION DOES NOT ADDRESS ALL DISASTERS THAT CAN IMPACT THE HUMAN ENVIRONMENT
- IT WILL MAINLY DISCUSS THOSE DISASTROUS FORCES THAT SIGNIFICANTLY IMPACT HUMAN LIFE AND HABITATION <u>YEAR AFTER YEAR</u>.

- EARTHQUAKES
- HURRICANES = TYPHOONS = CYCLONES
- TORNADOES
- FIRESTORMS
- FLOODS

STRUCTURAL DISASTER RESISTANCE COMPARED

TYPE OF CONSTRUCTION	FIRE	CAT 5 H-CANE	RICHTER 8 E-QUAKE	CAT 3 -5 TORNADO
Total Wood Frame	None	None	Partial	None
R/C Walls & Frame Roof	None	Partial	Partial	Partial
R/C Walls & R/C Roof	Total	Total	Total	Total

FIRESTORMS



FIRESTORMS AND WILDFIRES

- ***The map shows locations that experienced wildfires greater than 250 acres, from 1980 to 2003. (23 years) Map not to scale.***
- ***Sources: Bureau of Land Management, U.S. Forest Service, U.S. Fish and Wildlife Service, Bureau of Indian Affairs, National Park Service, and the USGS National Atlas***
- ***Particularly impacted are regions in the western United States***
- ***Few states are unaffected***

FLOODS

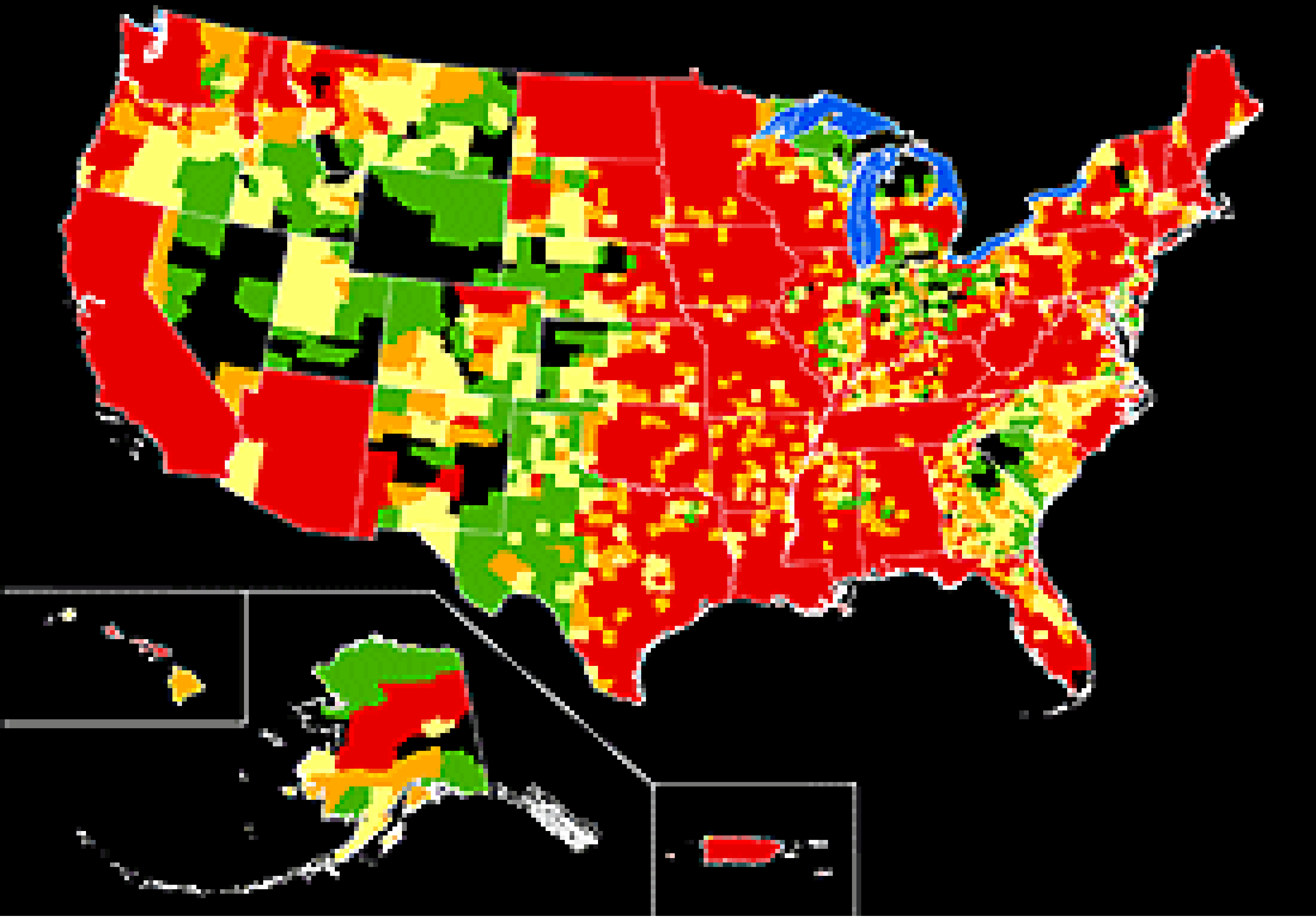
STORM SURGES

TSUNAMIS

U. S. FLOOD MAP

Presidential disaster declarations related to flooding in the United States, shown by county: **Green** areas represent one declaration; **yellow** areas represent two declarations; **orange** areas represent three declarations; red areas represent four or more declarations between June 1, 1965, and June 1, 2003. Map not to scale. Sources: FEMA, Michael Baker Jr., Inc., the National Atlas, and the USGS

(38 YEAR PERIOD)



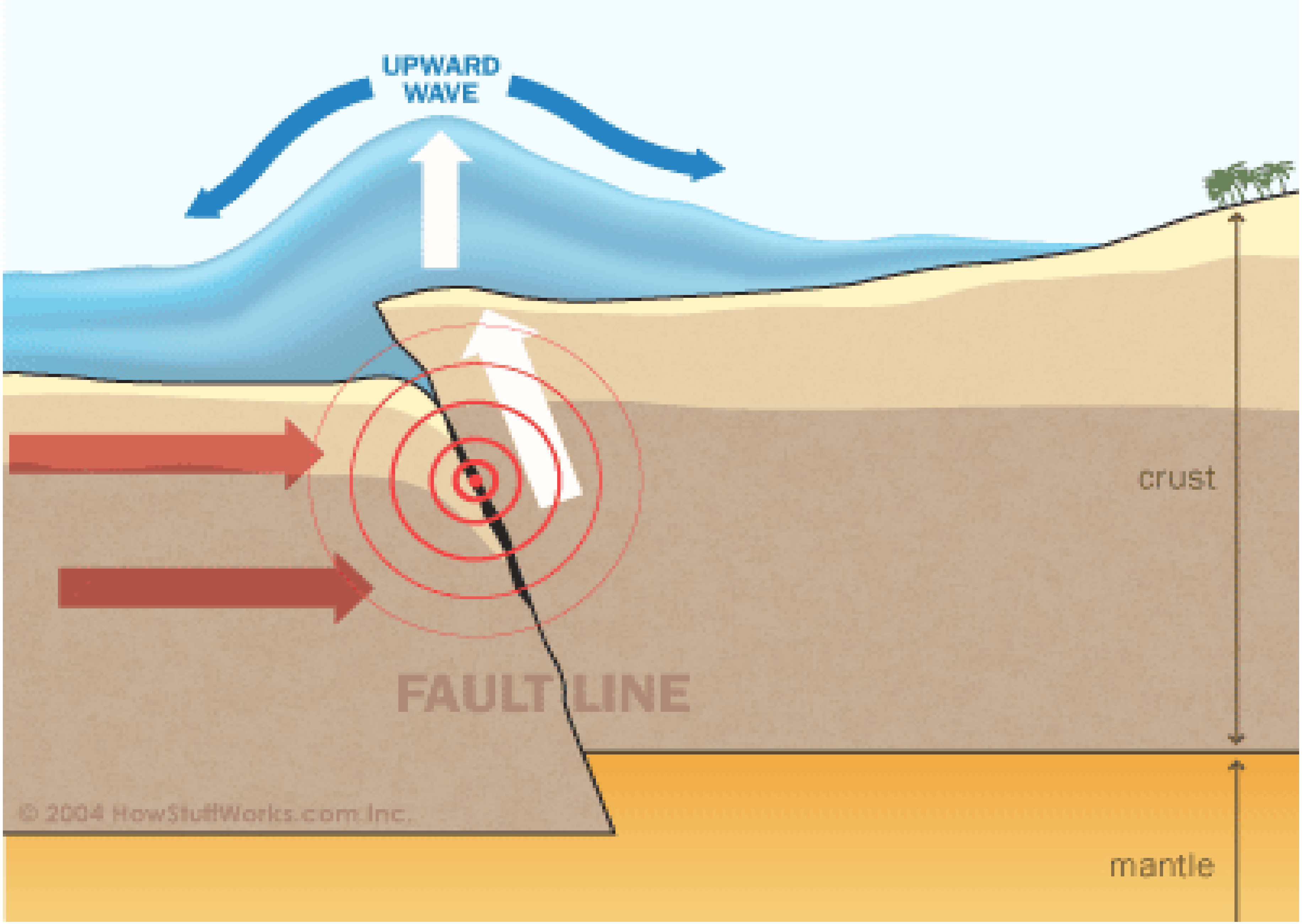
FLOOD DAMAGE

- In a concrete house, the most vulnerable elements to water damage are non-structural and would be the interior gypsum board drywall and the wood trim and cabinetry
- The coatings industry has developed interior wall treatments that are quite superior to conventional drywall boards
- Plastic and acrylic trim is readily available.

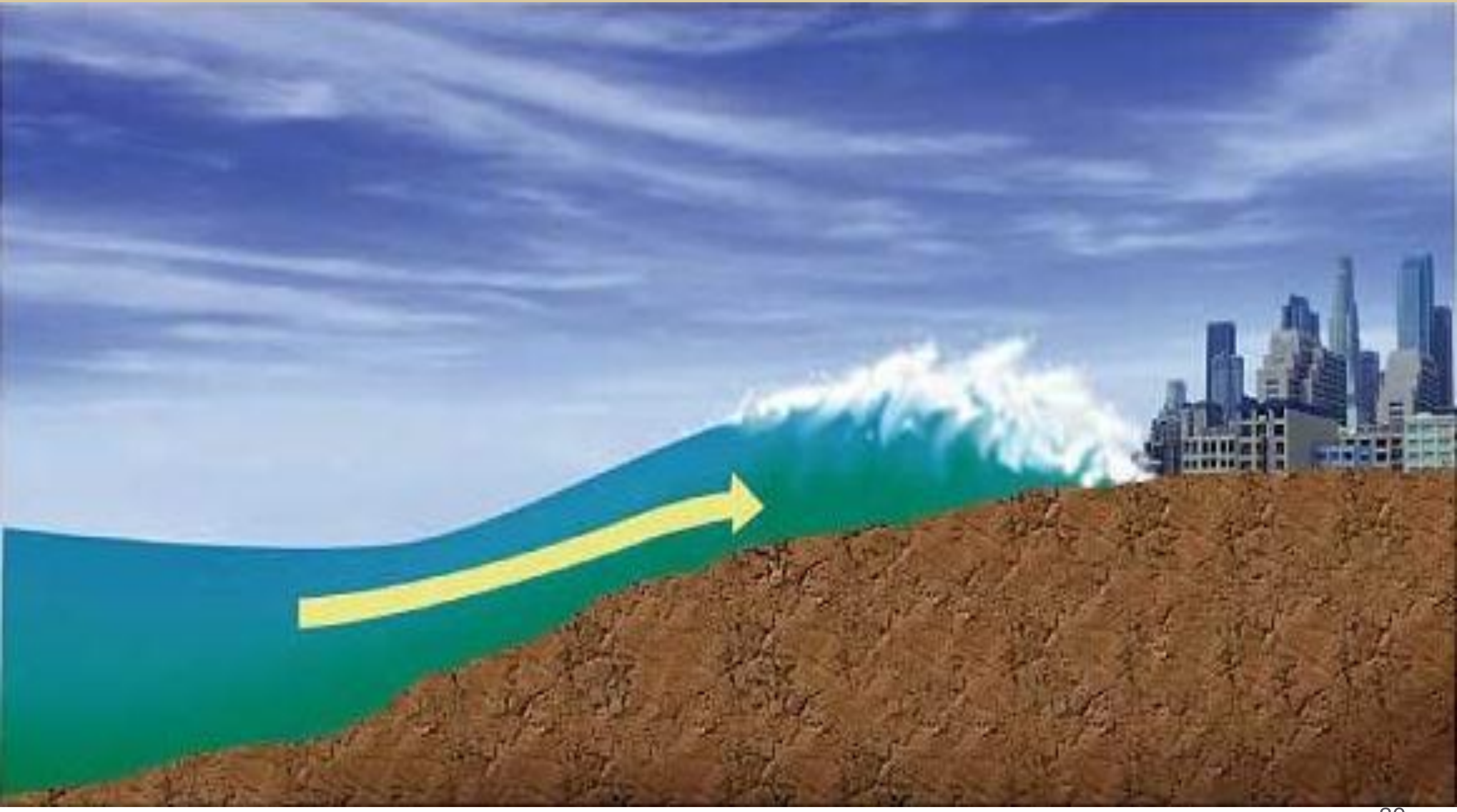
LATERAL FORCE RELATED DISASTERS

TSUNAMIS

How Tsunamis Work: Tsunamigenesis



ANATOMY OF A TSUNAMI



LATERAL FORCE

RELATED

DISASTERS

EARTHQUAKES


KRZYWY DOMEK

WELL-KNOWN EARTHQUAKES
SHOWING RICHTER INTENSITY NUMBERS

- **1812 New Madrid - Missouri 8.3**
- 1906 San Francisco 7.3
- **1964 Alaska 9.2**
- **1985 Mexico City 8.1**
- 1989 Loma Prieta (San Francisco) 6.9
- **1993 Guam 8.1**
- 1994 Northridge (Los Angeles) 6.7
- 1995 Kobe Japan – 6.9
- 2010 Haiti 7.0 – 7.3
- **2010 Chile 8.8**

Red font = 8.0 or larger

- Note that San Francisco, Kobe, Loma Prieta, Northridge and Haiti were rather minor -- compared to ***Guam 1993***

LATERAL FORCE
RELATED
DISASTERS

HURRICANES

HURRICANES

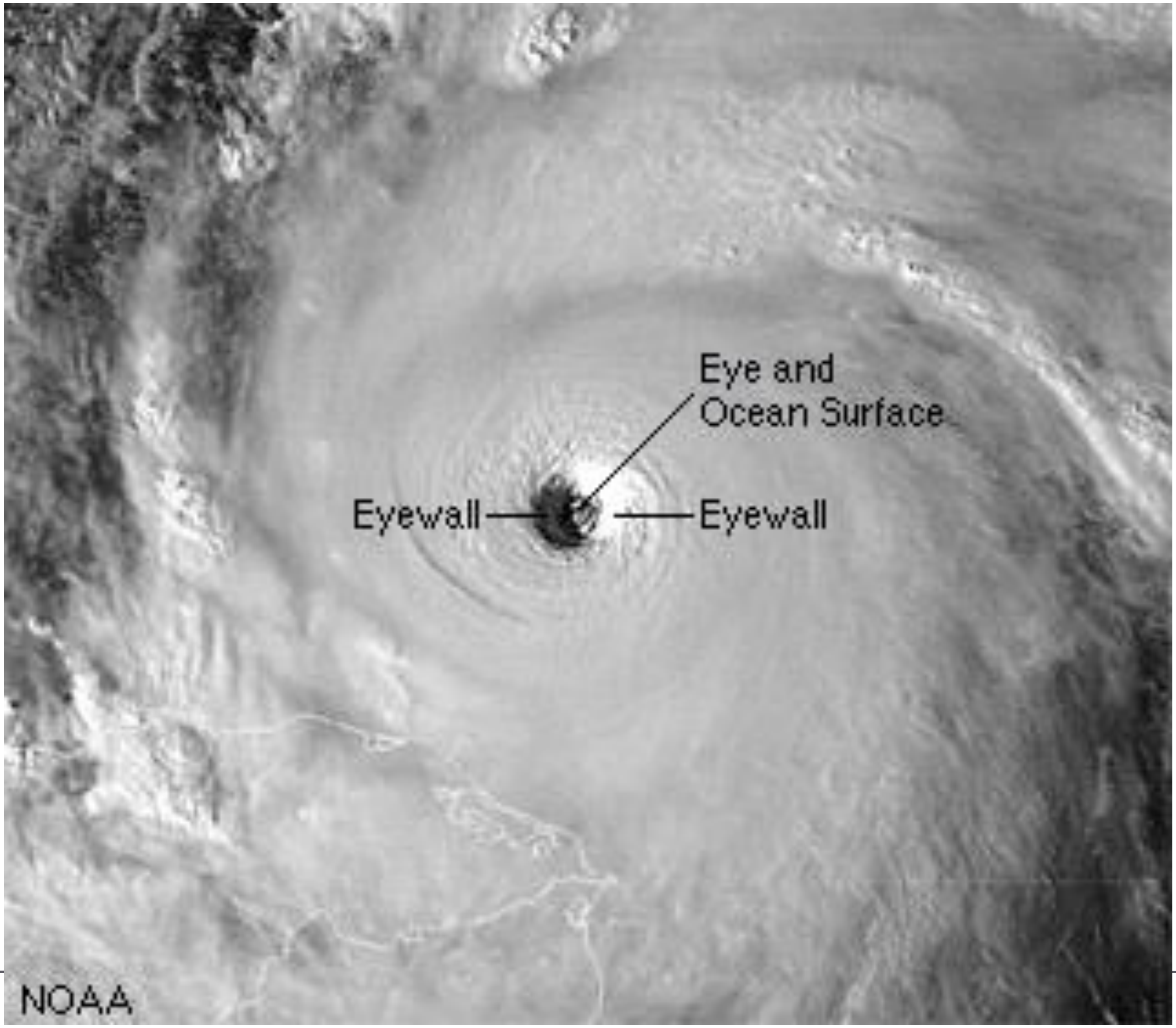
(Source = FEMA: ANDREW IN FLORIDA)

SAFFIR-SIMPSON HURRICANE SCALE –
(U. S. classification of hurricane intensity)

Category	Wind speed mph (km/h)	Storm surge ft (m)
5	≥156 (≥250)	>18 (>5.5)
4	131–155 (210–249)	13–18 (4.0–5.5)
3	111–130 (178–209)	9–12 (2.7–3.7)
2	96–110 (154–177)	6–8 (1.8–2.4)
1	74–95 (119–153)	4–5 (1.2–1.5)
Additional classifications		
Tropical storm	39–73 (63–117)	0–3 (0–0.9)
Tropical depression	0–38 (0–62)	0 (0)

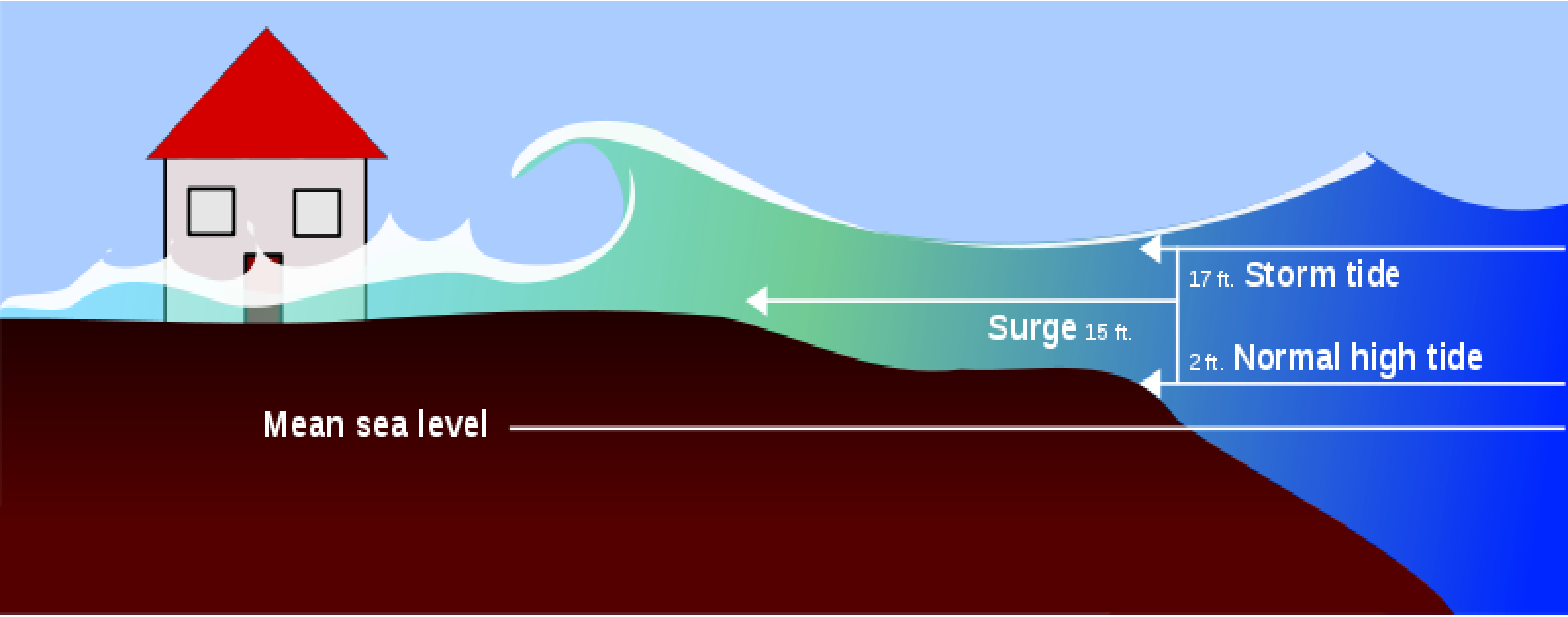
STORM SURGES

EYE OF A HURRICANE --
STORM SURGE UPPER LEFT



STORM SURGE

During Katrina, storm surge at Pass Christian, east of New Orleans, was 27.8 feet



LATERAL FORCE RELATED DISASTERS

TORNADOES

EF5 TORNADO

Greensburg Kansas, 2007

http://www.kansas.com/static/slides/050507tornadoaerials/

TORNADOES

- TORNADOES CAN BE ALMOST FOUR TIMES AS DEVASTATING TO BUILDINGS AS A CATEGORY 5 HURRICANE (TYPHOON) OR A MAXIMUM CREDIBLE EARTHQUAKE IN NORTH AMERICA
- PUBLIC ATTITUDE SEEMS TO BE THAT WOOD-FRAMED HOUSES WILL BE SEVERELY DAMAGED AND THAT VERY LITTLE CAN BE DONE ABOUT IT. “SO LET THEM BLOW AWAY AND WE WILL REBUILD QUICKLY TO GET FOLKS OUT OF THE WEATHER”

FUJITA F-SCALE FOR TORNADOES

Current designation is EF (Extended Fujita)

CATE-GORY	WIND SPEEDS mph	SUBJECTIVE DESCRIPTION
F0	40-72	GALE
F1	73-112	MODERATE
F2	113-157	SIGNIFICANT
F3	158-206	SEVERE
F4	207-260	DEVASTATING
F5	261-318	INCREDIBLE

THE TORNADO RECORD -- USA

- From **THE TORNADO REPORT:** *www.**tornadoproject**.com/*
- Historical Records up through the end of the year 2000 show that:
- Every state in the USA has experienced at least one tornado
- Some states have been affected by quite a few as will be shown in the next slides
- 592 **Serious** Tornadoes
  - Over 11,000 deaths
  - Over 70,000 injuries
  - $ billions in destruction. Houses totally disassembled

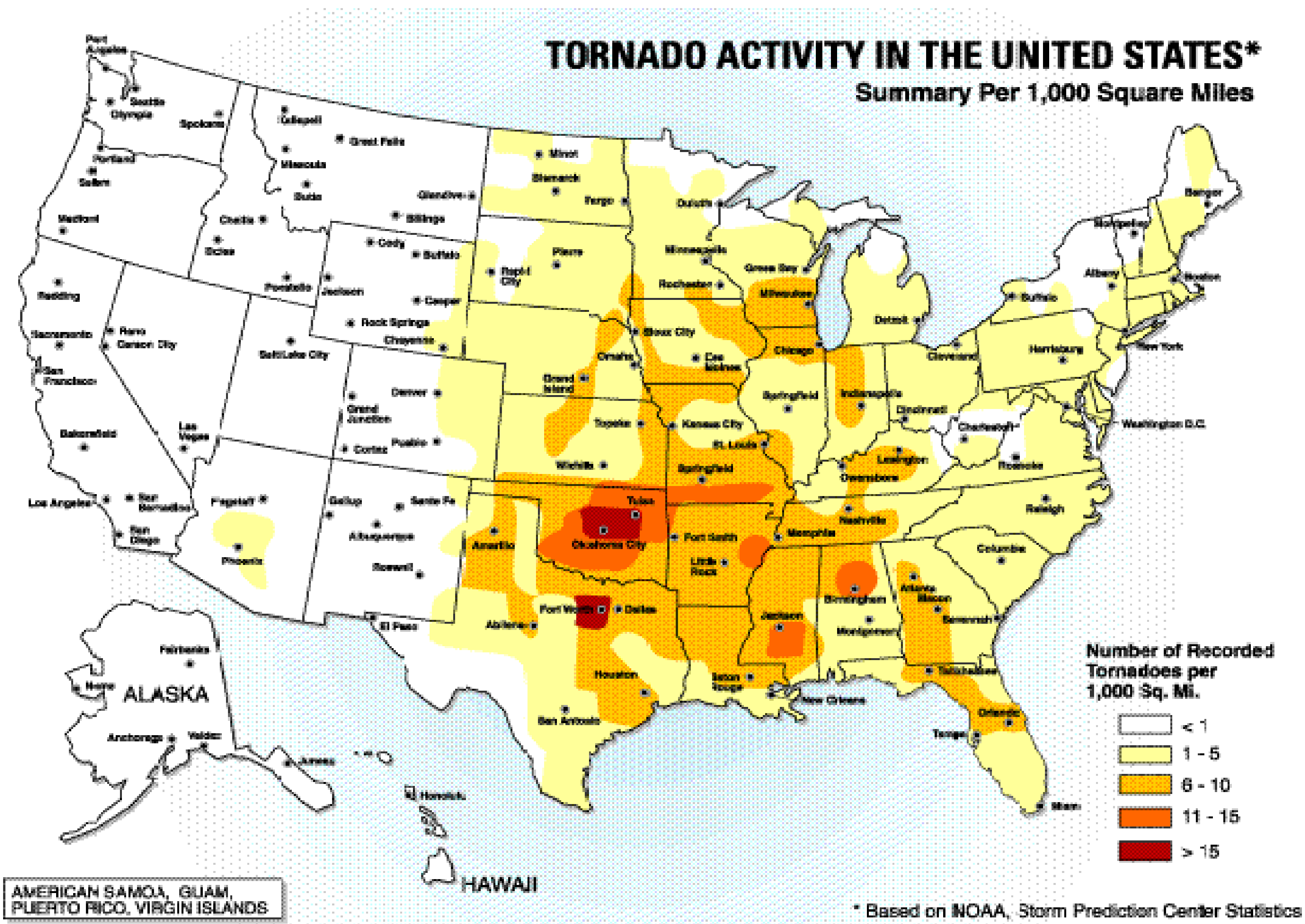


Figure I.1 The number of tornadoes recorded per 1,000 square miles

FLAGSTAFF ARIZONA

Category EF1 (Little one) Tornado

October 2010

DESIGN OF DISASTER RESISTANT SHELLS

“DRS”

WOOD FRAME ROOFS VERSUS REINFORCED CONCRETE

- WHEN THE WALLS ARE REINFORCED CONCRETE AND THE ROOF IS WOOD FRAME, THE CONCRETE WALLS ARE BRACED OUT-OF-PLANE ONLY AT THEIR BOTTOMS AND AT THEIR ENDS
- REINFORCED CONCRETE WALLS ARE NO LONGER SUPPORTED AT THEIR TOPS AFTER THE WOOD FRAME ROOF IS GONE
- WHEN THE ROOF IS AN R/C SLAB (DIAPHRAGM), WALLS ARE PERMANENTLY SUPPORTED ON ALL FOUR EDGES
- STRUCTURE BECOMES A 3-DIMENSIONAL "BOX"

FOUR INCH ICF CONCRETE WALLS

- IT HAS BEEN DEMONSTRATED THAT FOUR INCH THICK ENGINEERED REINFORCED CONCRETE WALLS USED IN A DRS CONFIGURATION ARE STRUCTURALLY ADEQUATE FOR USE IN SINGLE FAMILY HOUSES WHICH WILL NEED TO RESIST THE MAXIMUM HISTORICAL RECORDED FORCES OF:-----

- EARTHQUAKES
- HURRICANES = TYPHOONS = CYCLONES
- TORNADOES (ALMOST FOUR TIMES AS SEVERE AS THE ABOVE)

WHY A CONCRETE ROOF ?

- **Reinforced Concrete roofs** provide substantial strength increase and disaster resistance over any other roof system
- **Concrete shells** with monolithic reinforced concrete walls and roofs are significantly stronger than non-monolithic concrete walls and roofs

STRUCTURAL ANALYSIS

of

790 Square Foot Residence

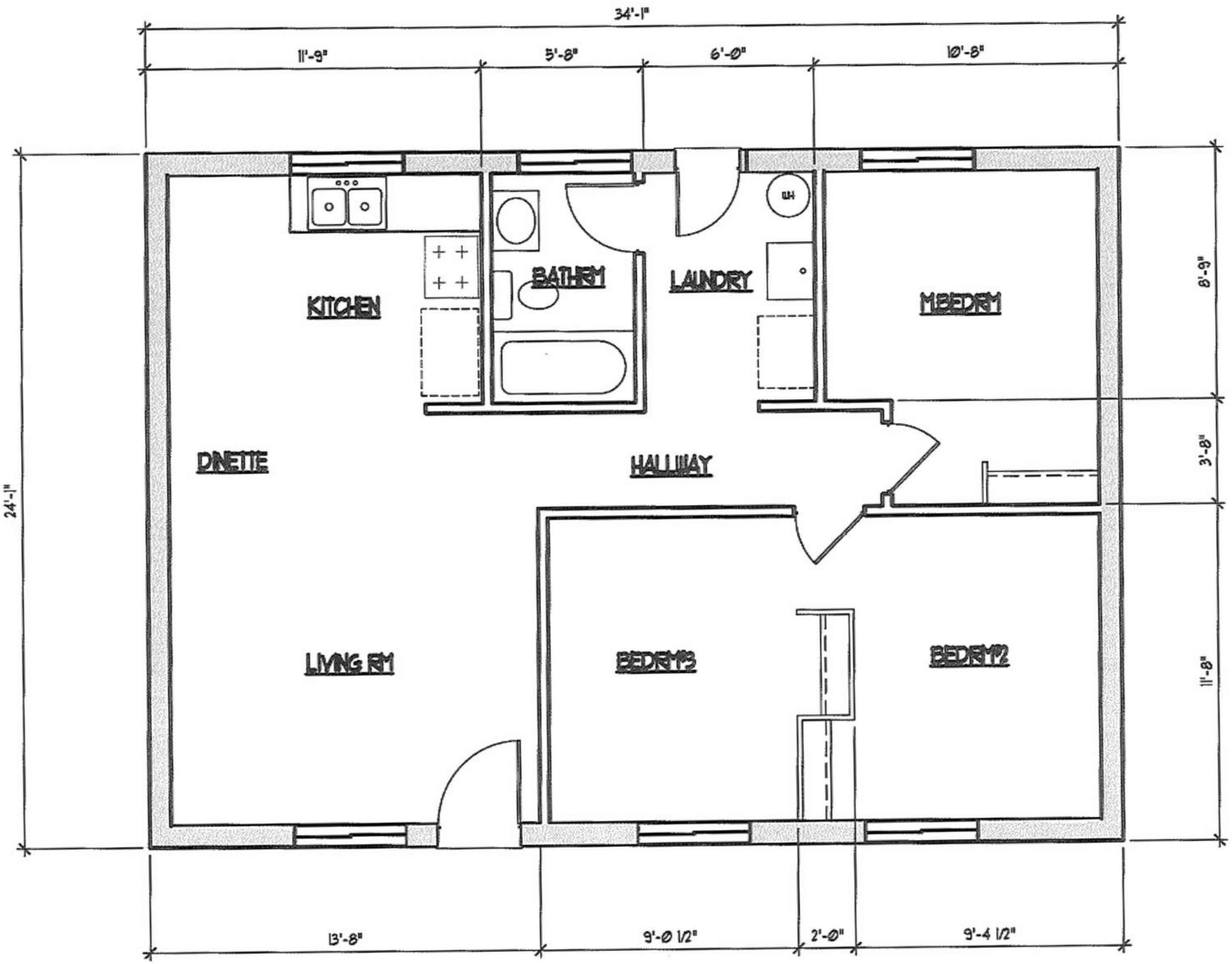
with 4" Thick ICF Walls

Subjected to Hurricanes,

Tornadoes & Earthquakes

CYS

Structural Engineers Inc.

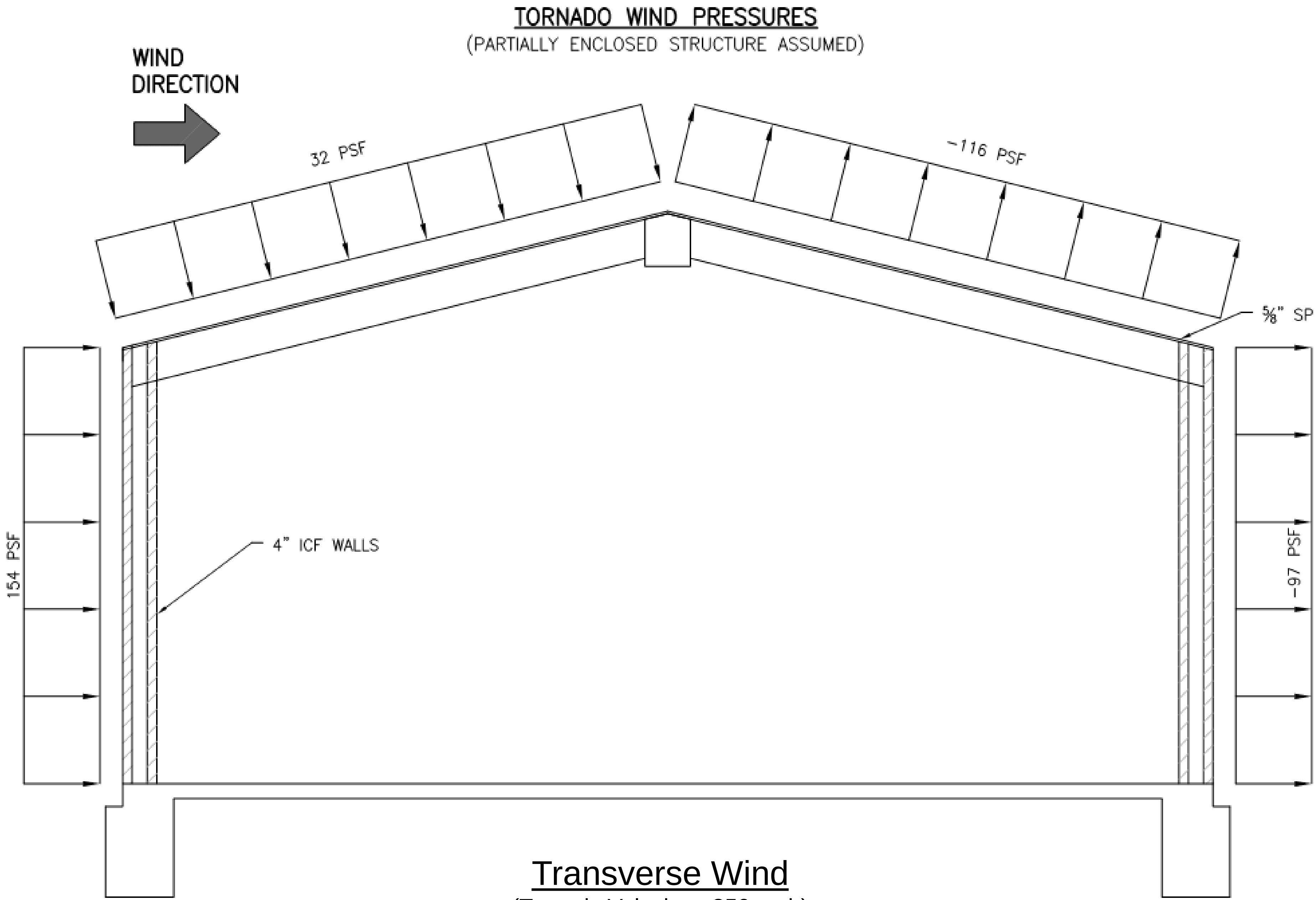


A / A1 FLOOR PLAN

1/4" = 1'-0"

High Wind Forces and Resistance Capability of Structural Systems

307 mph Wind and Seismic Compared

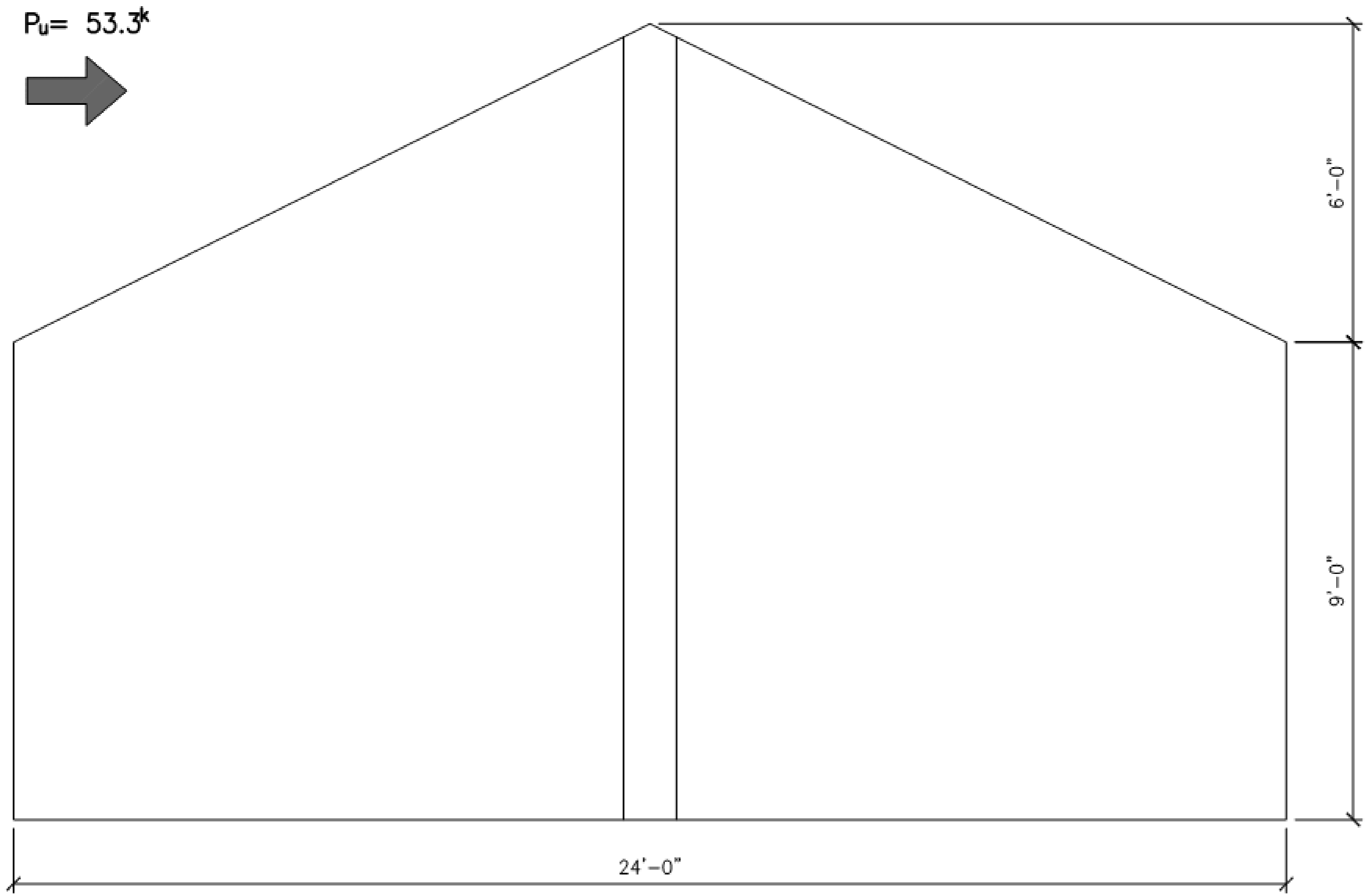


Transverse Wind

(Tornado Velocity = 350 mph)
(Hurricane Velocity = 307 mph)

IN-PLANE SHEAR DESIGN

TORNADO (307 MPH) FORCE



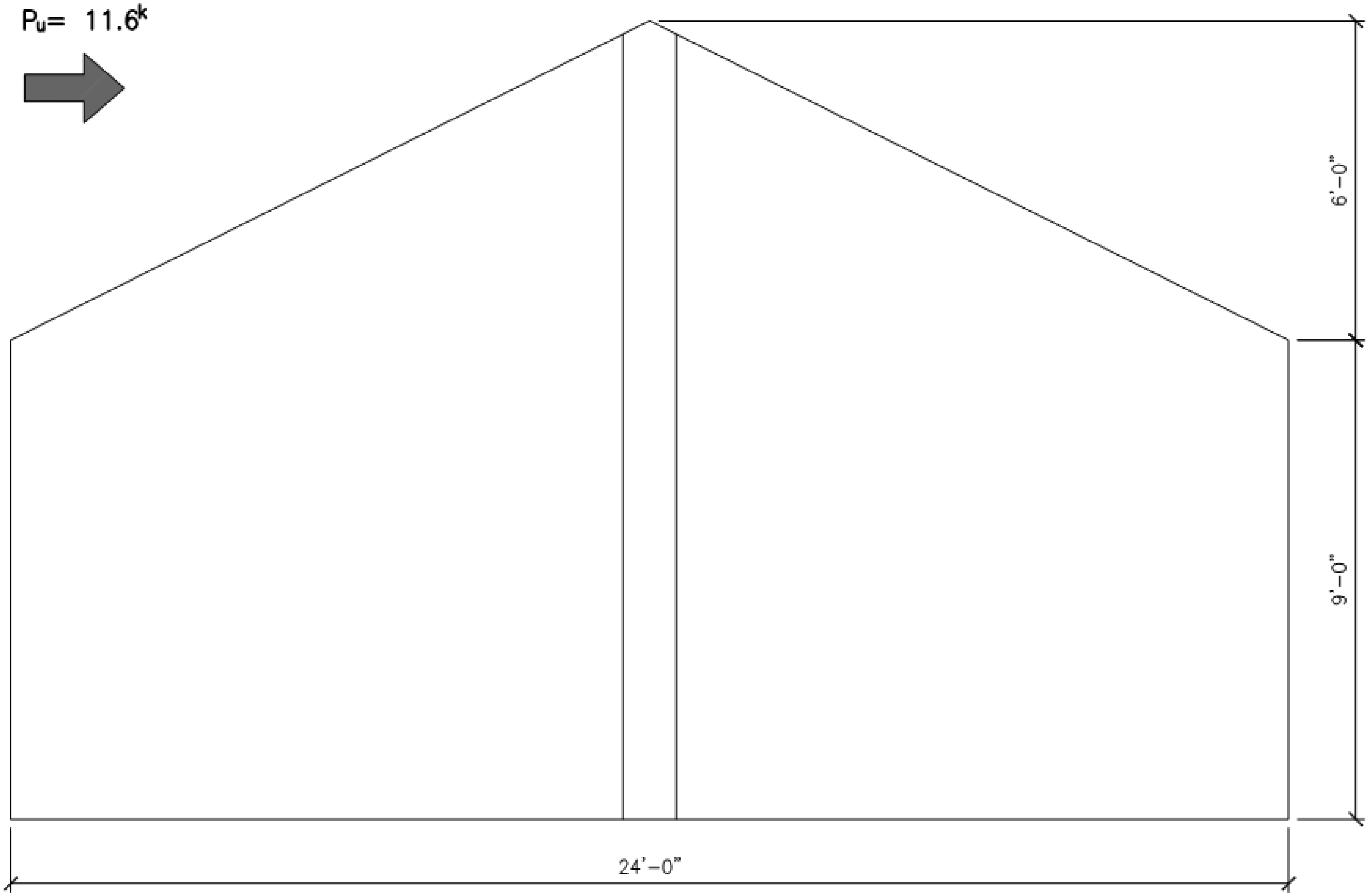
END WALLS (t=4")

HORIZONTAL REINFORCING = #3 @ 12" OC MIN

VERTICAL REINFORCING = #5 @ 12" OC

IN-PLANE SHEAR DESIGN

MAXIMUM CALIFORNIA SEISMIC FORCE



END WALLS (t=4")

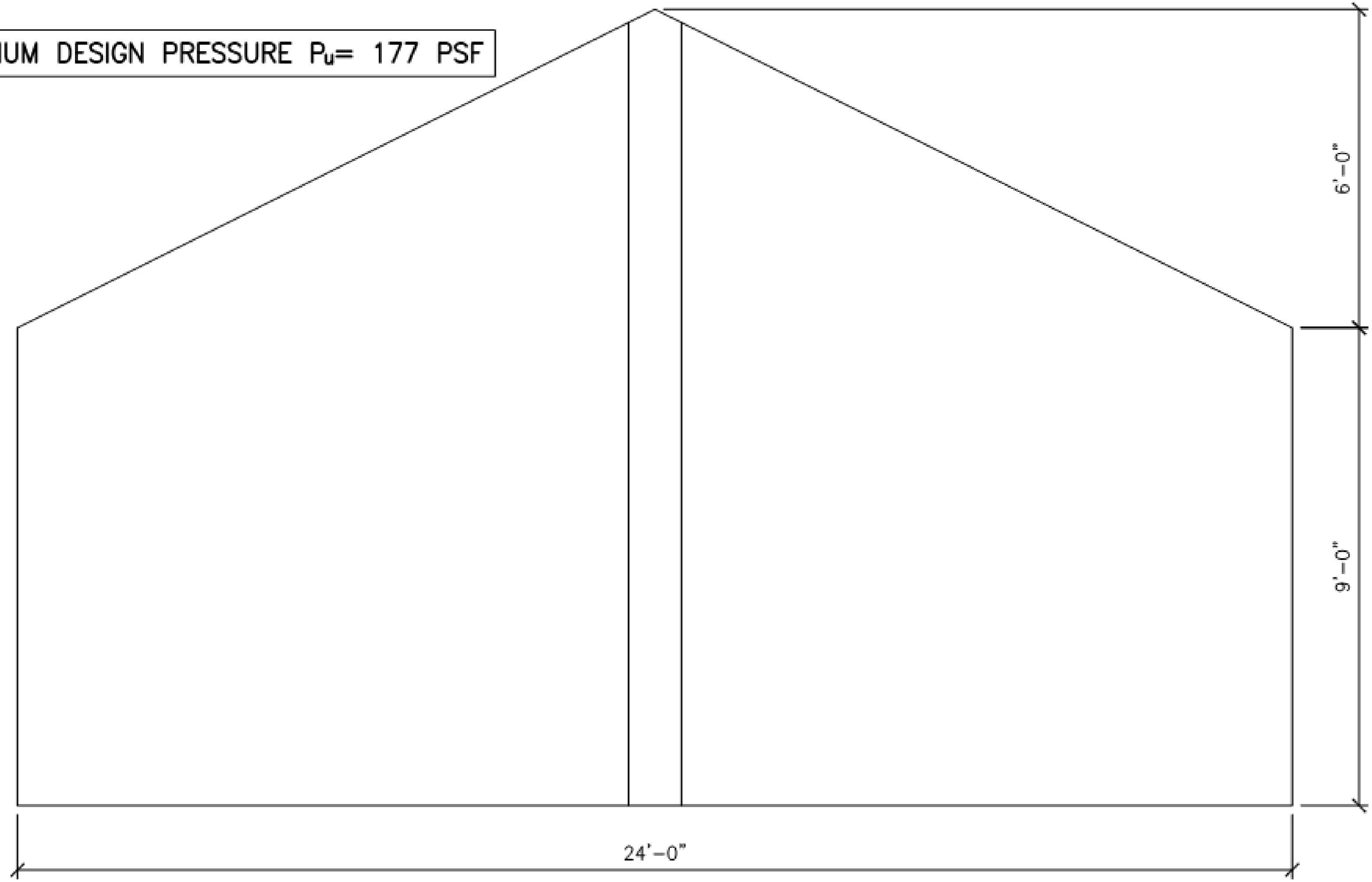
HORIZONTAL REINFORCING = #3 @ 12" OC MIN

VERTICAL REINFORCING = #3 @ 12" OC MIN

OUT-OF-PLANE WIND LOADS

TORNADO (307 MPH) FORCE

MAXIMUM DESIGN PRESSURE P_u= 177 PSF



END WALLS (t=4")

HORIZONTAL REINFORCING = #5 @ 10" OC

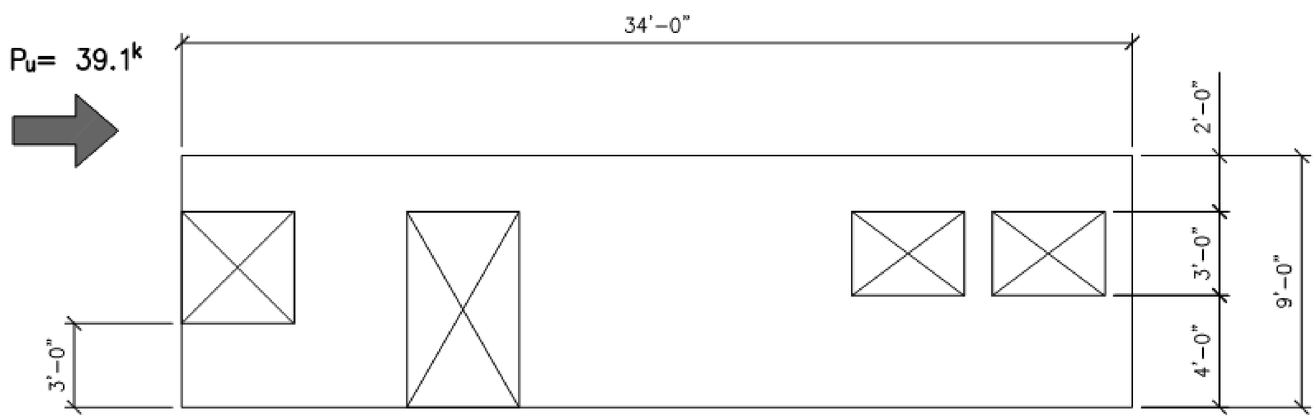
VERTICAL REINFORCING = #3 @ 12" OC MIN

SEISMIC P_u = 24 PSF

REINFORCING = #3 @ 12" OC EW MIN

IN-PLANE SHEAR DESIGN

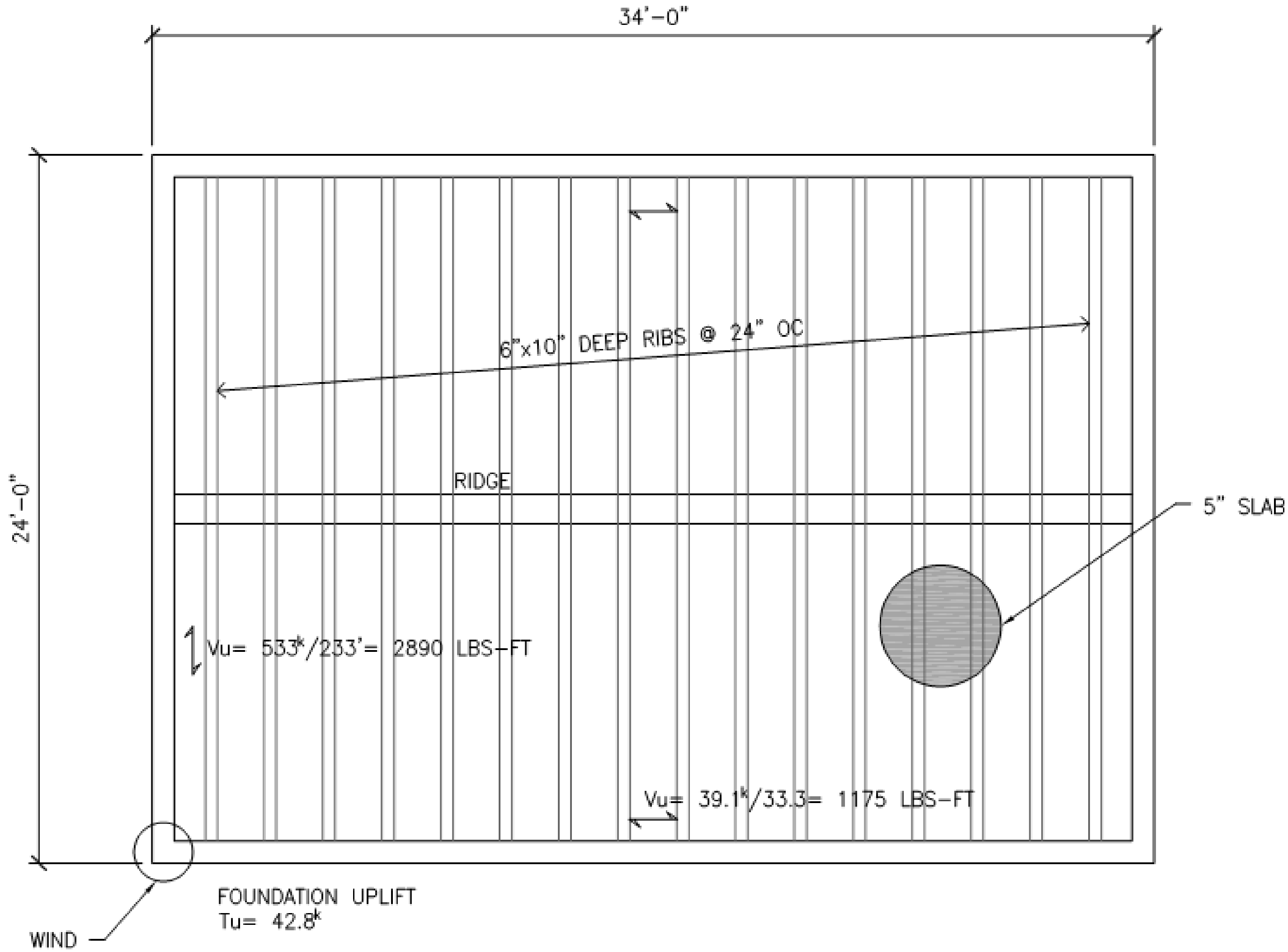
TORNADO (307 MPH) FORCE



FRONT SHEAR WALL (t=4")

HORIZONTAL REINFORCING = #3 @ 12" OC MIN

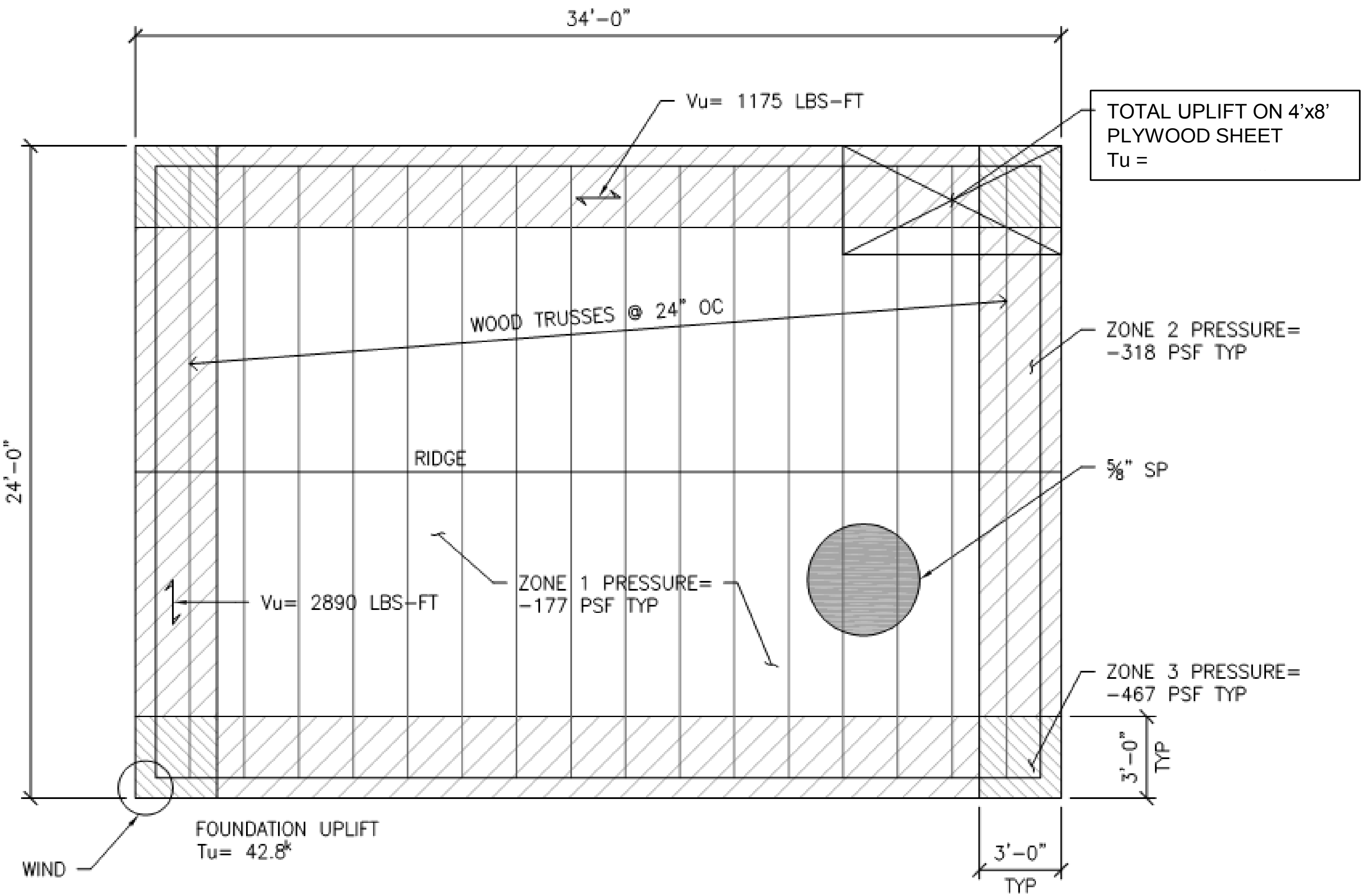
VERTICAL REINFORCING = #5 @ 12" OC



ICF CONCRETE SYSTEM

ROOF PLAN

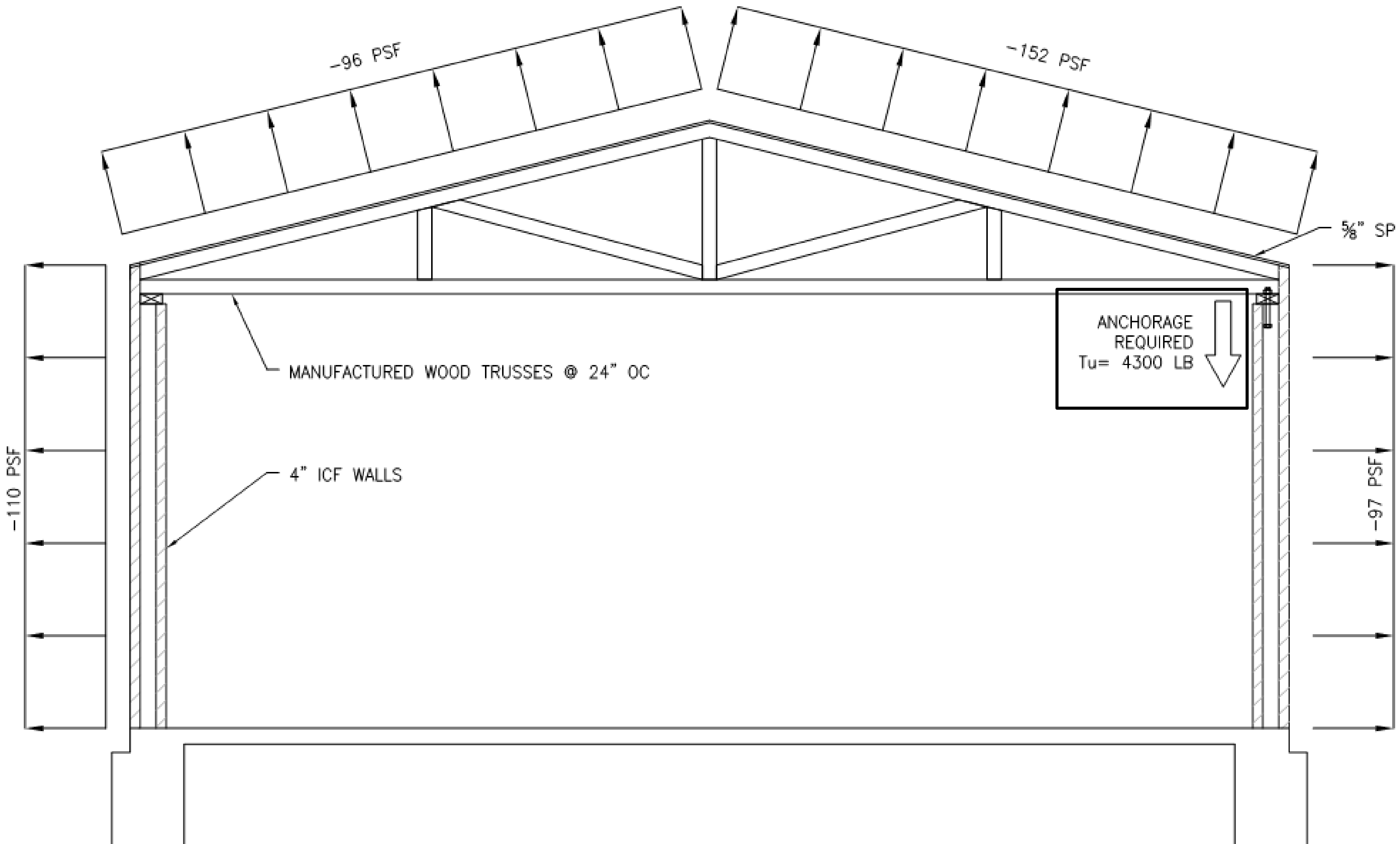
(VELOCITY = 307 MPH)



WOOD TRUSSES
ROOF PLAN

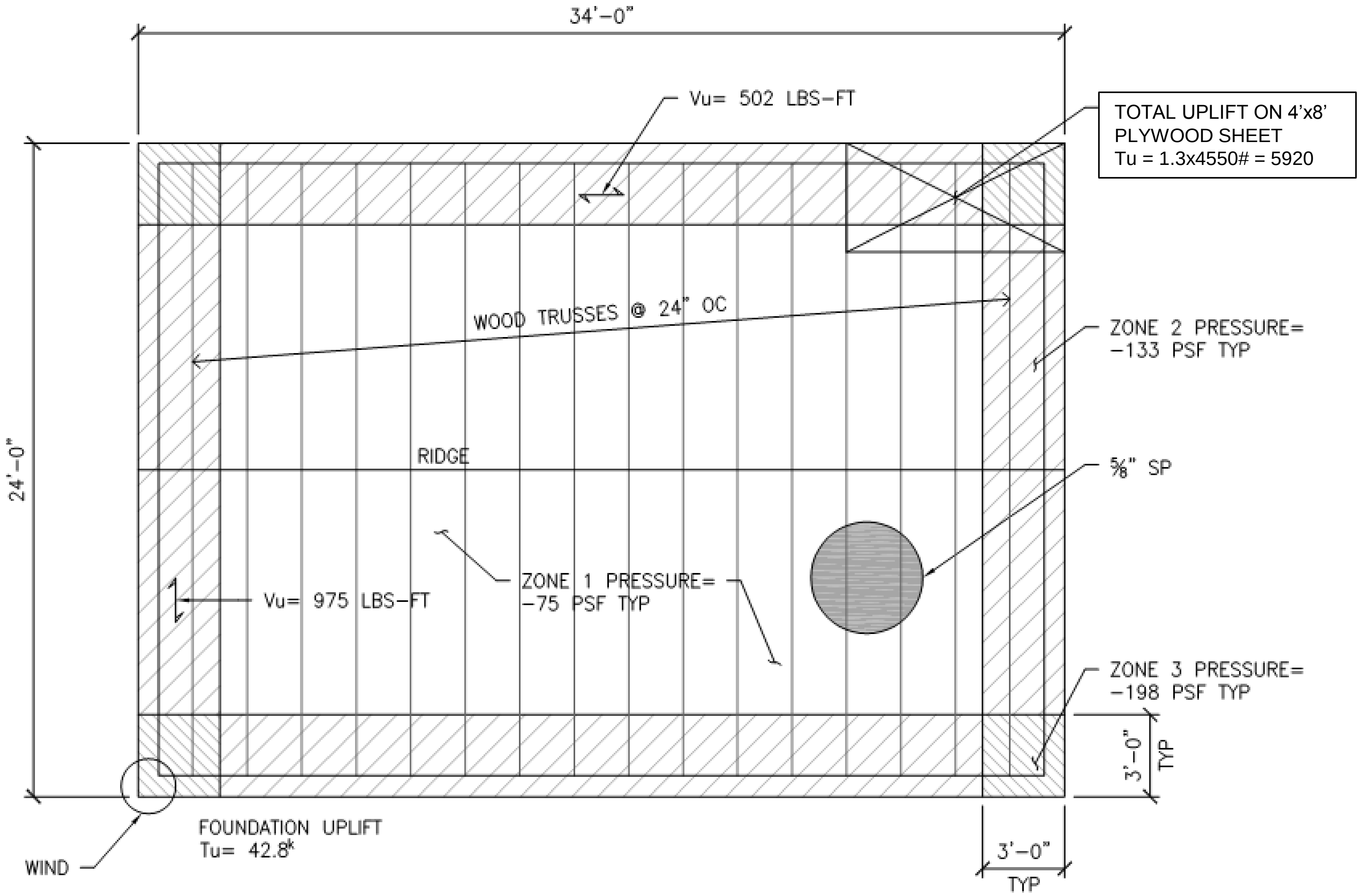
(VELOCITY = 307 MPH)

TORNADO WIND PRESSURES
(PARTIALLY ENCLOSED STRUCTURE ASSUMED)



LOAD CASE B WIND
(VELOCITY = 307 mph)

200 mph (approx. 228)



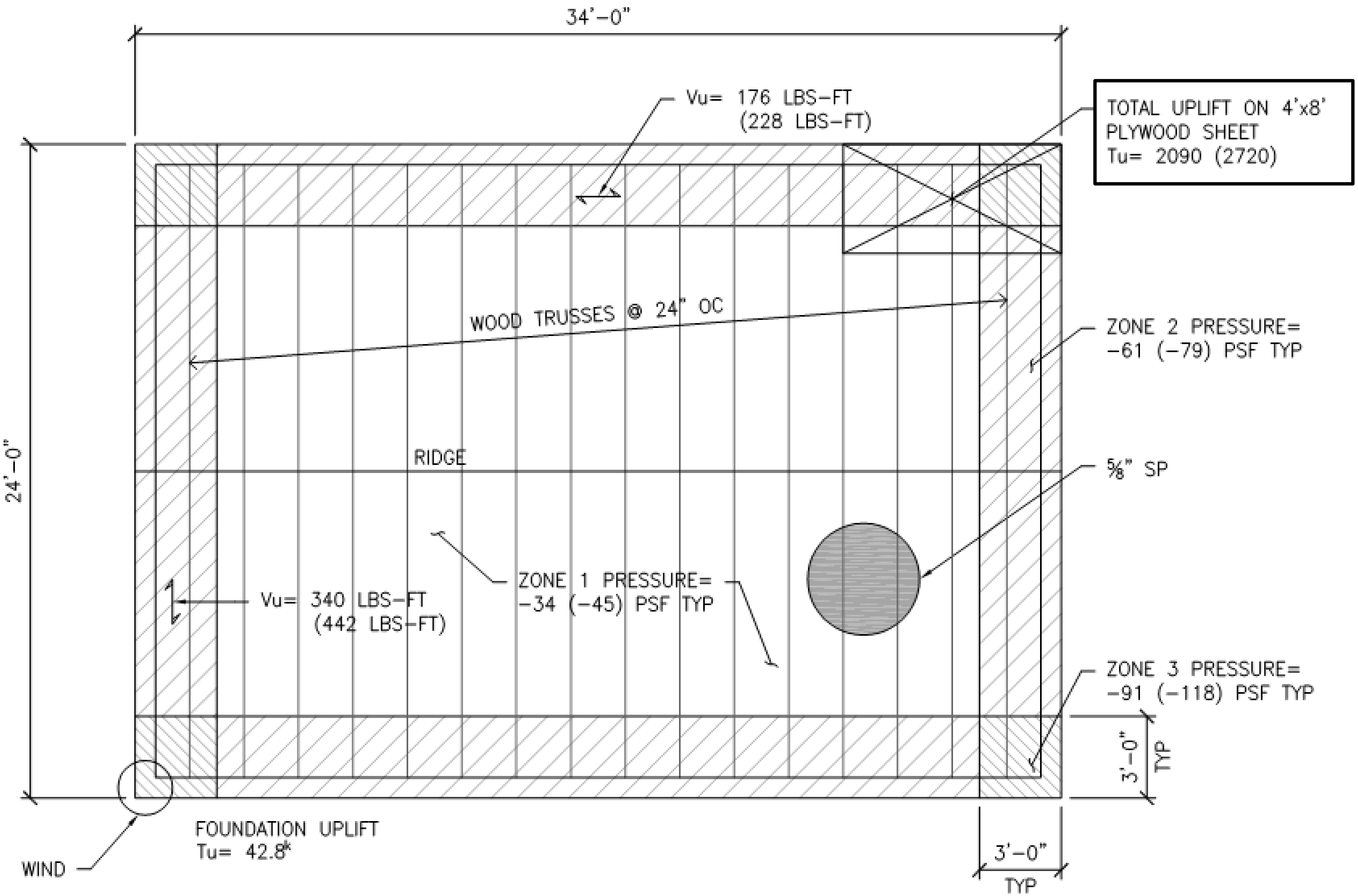
WOOD TRUSSES

ROOF PLAN

(VELOCITY = 200 MPH)

135 mph

Hurricane & Tornado



WOOD TRUSSES
ROOF PLAN

(VELOCITY = 135 MPH)

= HURRICANE PRESSURES
(##) = TORNADO PRESSURES (1.3xHURRICANE)

Here is the first all-concrete DRS single family house constructed in the world – on the island of Guam – 1963

GUAM – Where it Started

WHY GUAM?

GUAM IS THE WORLD'S

ONLY KNOWN

"DISASTER LABORATORY

FOR CONCRETE HOUSES"

WHERE IS GUAM?

INA
JAPAN
Seoul
SOUTH KOREA
Yellow Sea
Tokyo
Osaka
Yokohama
Pusan
Chengdu
Wuhan
Shanghai
Chongqing
East China Sea
Okinawa
RYUKYU ISLANDS (JAPAN)
NAMPO SHOTO (JAPAN)
Taipei
Marcus Island (JAPAN)
Taiwan
Hong Kong S.A.R.
Macau S.A.R.
Hanoi
Luzon Strait
LAOS
Gulf of Tonkin
Philippine Sea
Vientiane
Hainan Dao
Northern Mariana Islands (U.S.)
MARIANA TRENCH
PARACEL ISLANDS
THAILAND
VIETNAM
Manila
Saipan
Bangkok
South China Sea
Hagåtña
Guam (U.S.)
CAMBODIA
PHILIPPINES
Challenger Deep (world's greatest ocean depth, -10924 m)
Phnom Penh
Ho Chi Minh City
Gulf of Thailand
PHILIPPINE TRENCH
FEDERATED STATES OF MIC
SPRATLY ISLANDS
Koror
Bandar Seri Begawan
BRUNEI
PALAU
Kuala Lumpur
Medan
MALAYSIA
Celebes Sea
Singapore
SINGAPORE
INDONESIA
Bismarck Sea
PAPUA

GUAM
(Note Military Bases)

WHY STUDY GUAM?

- WESTERN PACIFIC REGION HAS A RECORD OF SOME OF THE MOST SEVERE EARTHQUAKES IN THE WORLD
- MARIANAS ISLANDS HAVE A RECORD OF SOME OF THE MOST INTENSE WIND STORMS IN THE WORLD
- GUAM HAS THE LARGEST AND OLDEST INVENTORY OF REINFORCED CONCRETE DISASTER-RESISTANT-SHELL (DRS) SINGLE FAMILY HOUSES *ON EARTH*
- IT IS LIKELY THAT THERE ARE MORE CONCRETE *BOX-FRAME* TRACT HOUSES ON THE ISLAND OF GUAM THAN EXIST ON THE ENTIRE NORTH AMERICAN CONTINENT

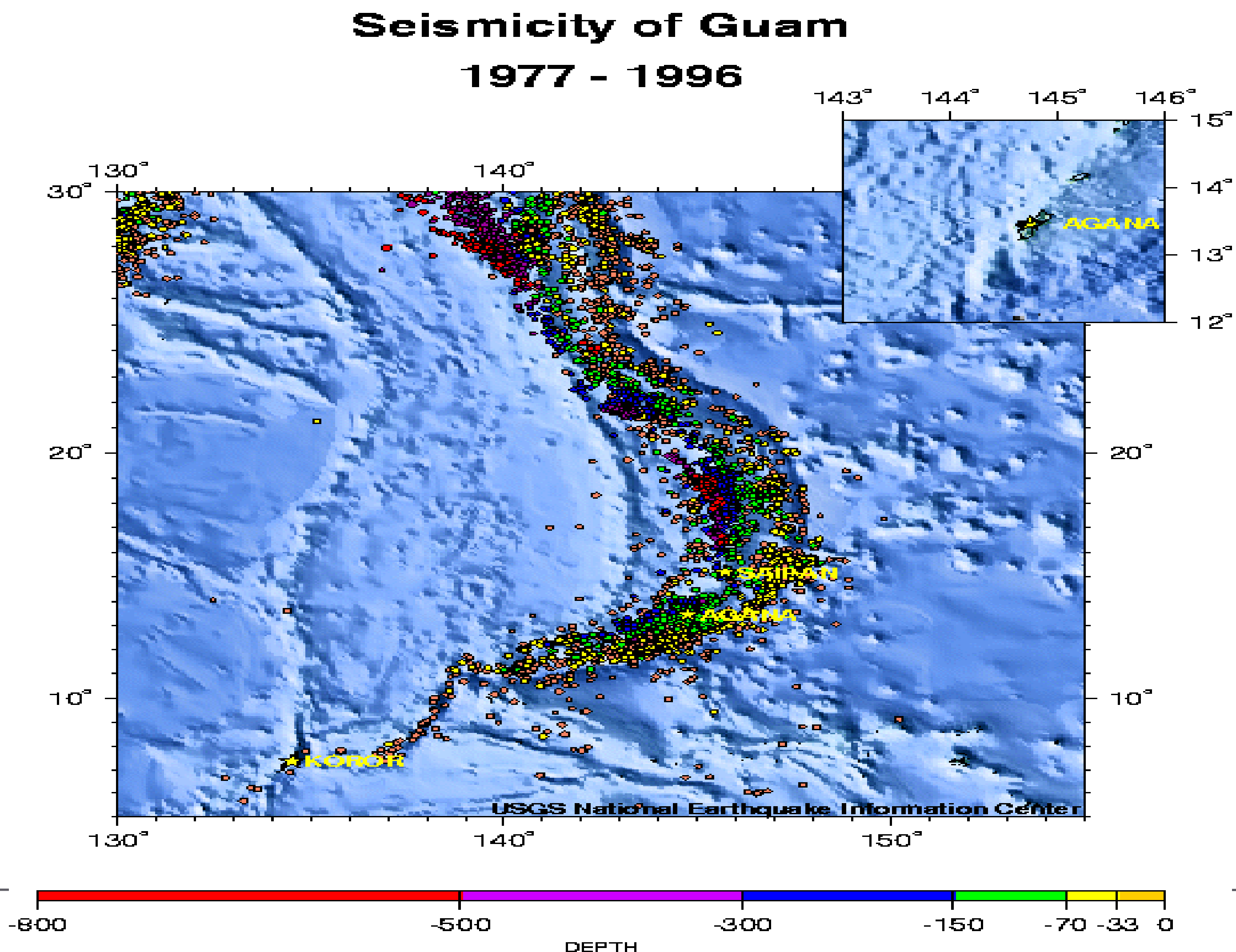
GUAM EARTHQUAKES

- “Earthquake risk in Guam is caused by the island’s proximity to the Mariana Trench, where the sub-duction of the Pacific Plate beneath the Philippine Plate occurs. This motion leads to earthquakes throughout the Mariana Island chain and north to Japan.”

Source: 1999-2009 Risk Management Solutions, Inc.

The following map is from the U.S. Geological Survey.
Shown are earthquakes of the Mariana Trench region (including Guam and Saipan to the north).

Each flyspeck represents a seismic event



MEXICO CITY BIG ONE – 8.1

(For perspective)

From the EERI Report:

- "*On September 19, 1985, at 7:17 A.M., a Richter magnitude **8.1** earthquake occurred on the Pacific coast of Mexico. The damage was concentrated in a 25 km2 area of Mexico City, 350 km from the epicenter. Of a population of 18 million, an estimated 10,000 people were killed, and 50,000 were injured. In addition, 250,000 people lost their homes, and property damage amounted to $5 billion. Over 800 buildings crumbled, including hotels, hospitals, schools, and businesses. Communications between the Mexican capitol and the outside world were interrupted for many days.*"

GUAM BIG ONE – 8.1
(By comparison to Mexico City)

- Newspaper item:
- "*Guam Earthquake of August 8, 1993*" – **8.1**

Even though damage to some structures from the 1993 Guam Earthquake was severe, little human injury and no fatalities occurred. Hardest hit were the island's hotels, which had the same design weaknesses typical to many high-rise hotels damaged in earthquakes worldwide. "

- **No** **reported damage to Box-Frame concrete houses**

GUAM TYPHOONS

- **NEWS ITEM:**

"Typhoon alley" is a term not taken lightly by the citizens of Guam. Although the last two years have been relatively quiet, there are an average of 31 tropical storms in the western north Pacific every year with one or more affecting the Island. Guam has been impacted by 16 typhoons since 1970 and devastated by four since 1960.

- One, **TYHOON PAKA**, **1997**, was one of the most powerful ever recorded. Winds to 240 mph -- This represents the velocity range of a Category F4 tornado.
- (Paka is well documented on the Internet)

COMPARING HURRICANE (TYPHOON) PEAK WIND VELOCITIES

(Related to U. S. Saffir-Simpson Hurricane Categories)

MAINLAND USA EST. PEAK WINDS			
HURRICANE NAME	YEAR	CAT.*	PEAK WIND Mph
Ike	2008	4	145
Katrina	2005	3	140
Rita	2005	5	180
Charlie	2004	4	150
Frances	2004	3	145
Ivan	2004	4	165
Opal	1995	4	150
Andrew	1992	5	175
Hugo	1989	4	160
Camille	1969	5	190
* At point of Landfall			

GUAM ESTIMATED PEAK WINDS				
TYPHOON NAME	YEAR	S-S CAT.*	PEAK WIND Mph	TORNADO FUJITA CAT. Mph
Pongsana	2008	4	150	F2
Paka	**1997**	**Int 8**	**240**	**F4**
Omar	1992	4	150	F2
Yuri	**1991**	**Int 6**	**175**	F3
Roy	**1988**	**Int 6**	**175**	F3
Pamela	1976	5	160	F2
Olive	**1963**	**Int 7**	**185**	F3
Karen	**1963**	**Int 7**	**185**	F3
*** Saffir-Simpson Hurricane Scale**				
Int = Interpolated extension Saffir-Simpson				

TYPHOON PAKA
LARGEST EVER RECORDED

"On Tuesday December 16th 1997, with peak winds of **240 mph*** the highest wind speeds ever recorded over land, swept across the island of Guam."

***Wind velocity equivalent to a Category F4 tornado"**

"Approximately 1500 structures (most of them residential) were completely destroyed and another 10,000 were damaged leaving an estimated 5000 homeless. Damage estimates were around $645 million (2007)"

No known damage to the thousands of DRS reinforced concrete houses

PAKA RECORD

- **Typhoon Paka proved by <u>actual experience</u> that DRS reinforced concrete box frames could withstand wind velocities equivalent to a Category EF4 tornado without structural damage**
- **The high winds of Paka were present for about six hours – as compared to a tornado which passes through a given location in only a few minutes**

HISTORY OF THE DEVELOPMENT OF DRS BOX FRAME HOUSES ON GUAM

TYPHOON KAREN

- One of the more intense typhoons to strike **Guam** was typhoon Karen, which passed over the southern part of the island in **1962**. Wind gusts estimated near 185 mph **destroyed 95% of all homes on the island**
- Guam governor appealed to President Kennedy for assistance
- JFK enlisted the help of Henry Kaiser and Kaiser Cement company
- With guidance from structural engineer Alfred A. Yee, Kaiser developed the prototype for a **DRS** house and began building in 1963

THIS IS THE FIRST DELIBERATELY DESIGNED DRS HOUSE IN THE WORLD – 1963 – ON THE ISLAND OF GUAM

THOUSANDS OF DRS CONCRETE HOUSES BUILT THIS WAY ON GUAM SINCE 1963

TYPICAL CONSTRUCTION OF CONCRETE HOUSES ON GUAM IN 1963

(NON-INSULATED)

GUAM HOUSE DETAILS

- Four inch thick tilt-up reinforced concrete walls
- Cast-in-place monolithic reinforced concrete flat roof
- Florida-style hurricane shutters
- Designed as "box-frame" with walls tied securely to the reinforced ribbed floor slab and to the roof slab
- Structural engineer Yee says: "You can almost imagine a giant picking these boxes up and dropping them on the ground with no damage"

- (Insulation was not considered necessary on Guam at that time - 1963)

Preparing for Ribbed Structural Concrete Floor Slab – On Grade

FORMS FOR FOUR INCH TILT-UP CONCRETE WALLS

FABRICATED TILT-UP WALL PANELS

RCF FORMS FOR CIP ROOF

CAST-IN-PLACE R/C ROOF

(NON-INSULATED)

2008 Comments by the Structural Engineer Alfred A. Yee

"The Dededo Houses have been in existence for 30 plus years and they have gone through many heavy typhoons that make Katrina look like only a rainstorm. " (They survived Typhoon Paka without damage)

"They have gone through earthquakes of Richter Scale 8.1, but the Dededo Houses did not even suffer any cracking"

"Of the thousands of (sic – DRS concrete shell) houses we built, not a single bit of damage was ever recorded from typhoons or seismic action"

CONTEMPORARY (2008) CAST-IN-PLACE CONCRETE DRS HOUSES ON GUAM

DRS HOUSES IN PROGRESS

MONOLITHIC ROOF COMPLETED

ROW OF COMPLETED DRS HOUSES

COMPLETED DRS HOUSE

HOME DEPOT HURRICANE SHUTTERS

CAST-IN-PLACE REINFORCED CONCRETE WALLS AND WOOD FRAME ROOFS

STRUCTURAL DISASTER RESISTANCE COMPARED

TYPE OF CONSTRUCTION	FIRE	CAT 5 H-CANE	RICHTER 8 E-QUAKE	CAT 3 -5 TORNADO
Total Wood Frame	None	None	Partial	None
R/C Walls & Frame Roof	None	Partial	Partial	Partial
R/C Walls & R/C Roof	Total	Total	Total	Total

ICF WALLS & WOOD FRAME ROOF – WISCONSIN F4 TORNADO

So what about an F5 Tornado?

- F5 tornado (261-318 mph)(classified as "Incredible")
  - In the absence of field information about the structural performance of concrete DRS houses in an F5 tornado, we made a comprehensive structural analysis of a hypothetical DRS house to see if four inch R/C walls would also work under F5 tornado winds
  - A small uncomplicated DRS house was studied (in order to reduce the analysis work)
  - An arbitrary 350 mph wind was selected for the calculations

FOUR INCH WALLS

CONCLUSION: FOUR INCH REINFORCED CONCRETE WALLS IN A DRS DESIGN WILL WORK FOR F5 TORNADOES --- WHEN THE ROOF IS A REINFORCED CONCRETE DIAPHRAGM INTIMATELTY CONNECTED BY REINFORCING BARS TO THE WALLS

(A separate structural engineering presentation about this analysis and related calculations is available upon request)

TWO GENERALLY ACCEPTED METHODS AVAILABLE FOR CONSTRUCTING DRS REINFORCED CONCRETE HOUSES:

CAST-IN-PLACE WALLS AND ROOFS

OR

TILT-UP OR FACTORY PRECAST WALLS WITH CIP ROOFS

INSULATION WAS NOT USED ON ORIGINAL GUAM DRS HOUSES

- **Because of its moderate temperatures, Guam construction practices did not call for insulation for their concrete houses 45 years ago**
- **Little demand for heat, much demand for A/C**
- **There are no energy resources on the island**
- **All energy must be imported, mostly by tanker**
- **Construction of reinforced concrete houses with stay-in-place ICF forms instead of removable concrete forms on Guam would likely:**
  - **Reduce energy demand per house by about half**
  - **Make the houses more comfortable**
  - **Reduce temperature change-related stresses In the concrete**

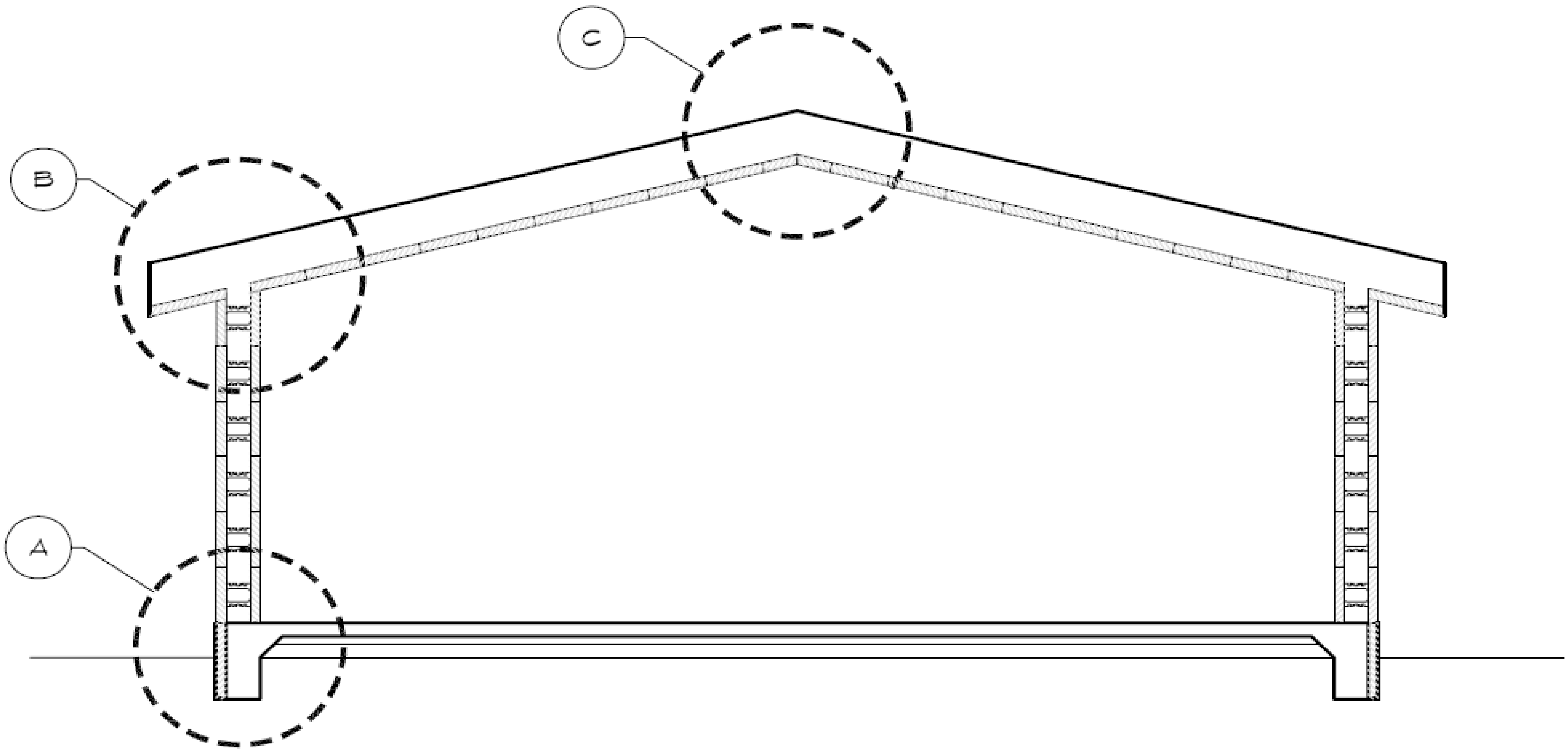
INSULATION IS IMPORTANT TODAY FOR ENERGY CONSERVATION AND COMFORT

- **FOR MOST REGIONS TODAY, INSULATION IS A NECESSITY FOR ENERGY CONSERVATION AND COMFORT**
- **UNTIL RECENT YEARS, (PRESENTER'S OPINION)THE LACK OF A PRACTICAL AND ECONOMICAL SYSTEM FOR INSULATING CONCRETE HOUSES *HAS POSSIBLY BEEN THE MOST IMPORTANT DETERRENT AGAINST THE GROWTH IN THE USE OF REINFORCED CONCRETE IN SINGLE FAMILY HOUSES***

INSULATING CONCRETE FORMS

EXAMPLES OF STAY-IN-PLACE ICFs FOR CONSTRUCTION OF CAST- IN-PLACE CONCRETE HOUSES

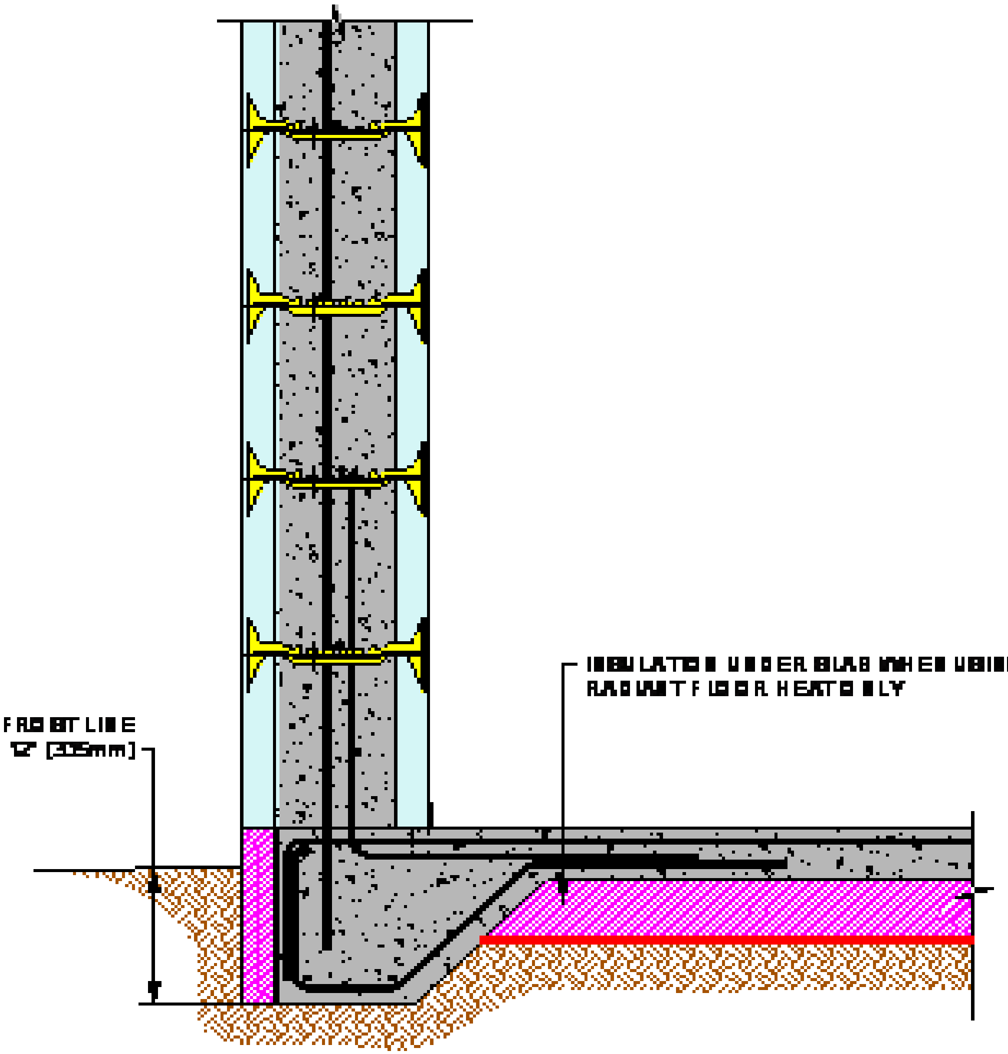
CROSS-SECTION DETAILS OF DISASTER-RESISTANT ICF SHELL



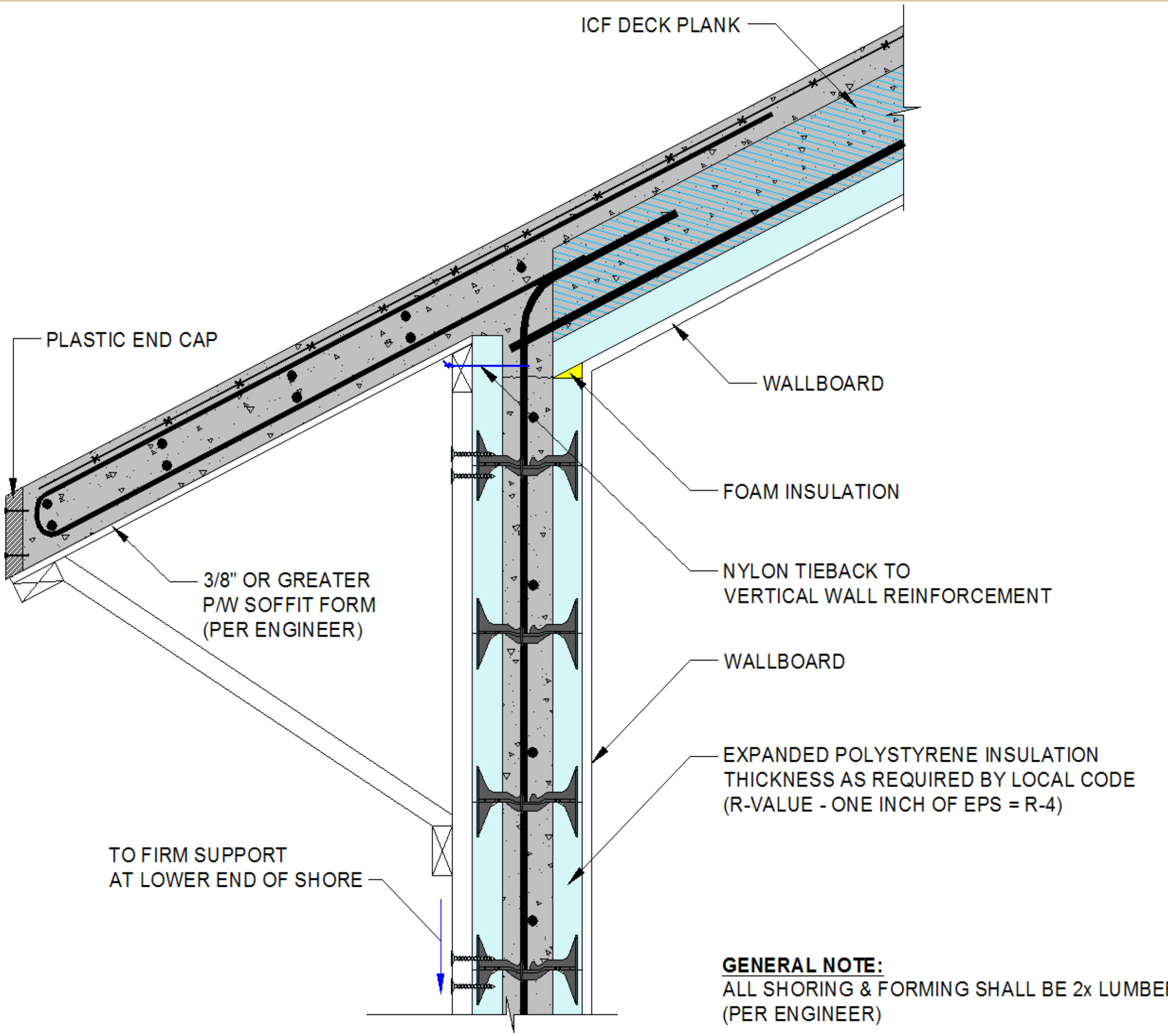
TRANSVERSE BUILDING SECTION

[One-Story House on Grade]

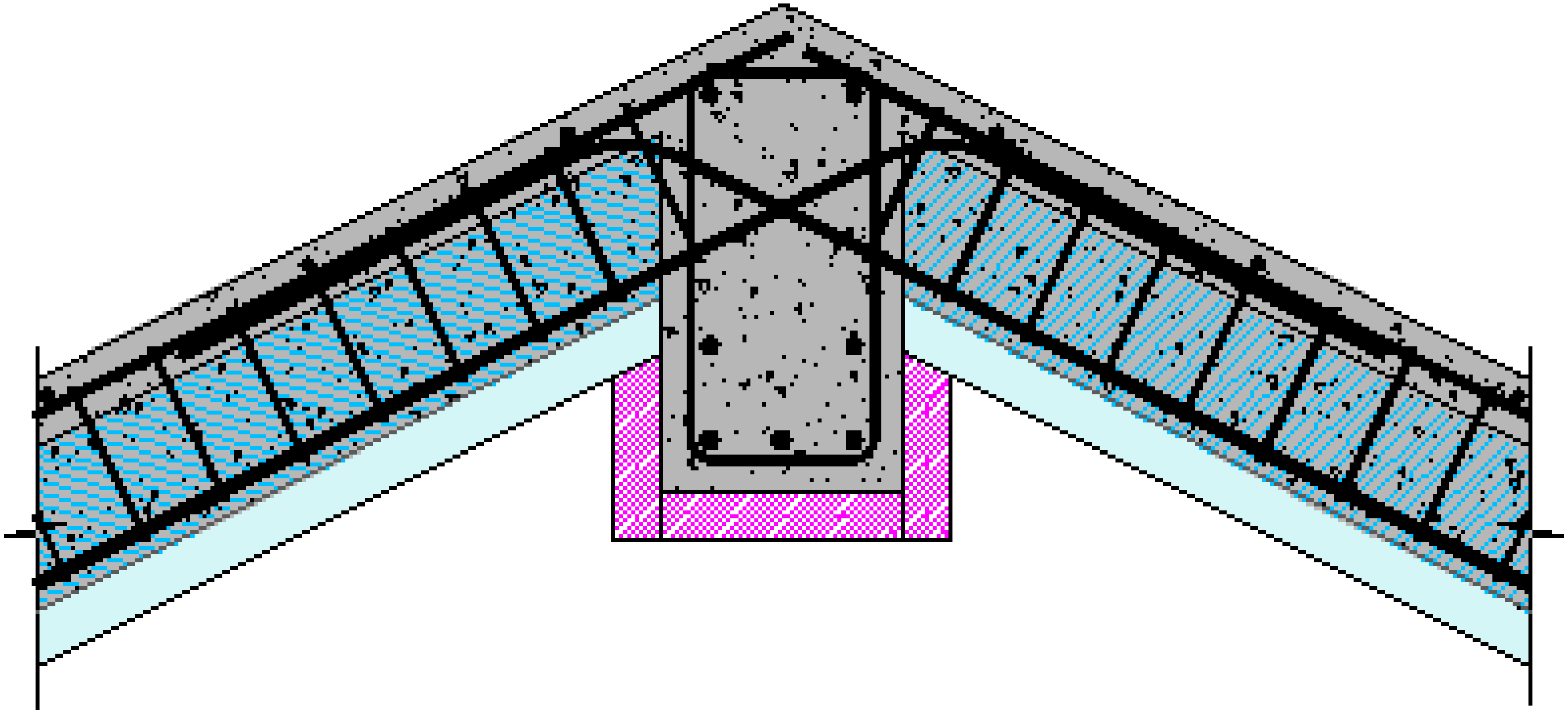
DETAIL A- DRS Floor-to-Wall Detail — Using ICF Wall Forms



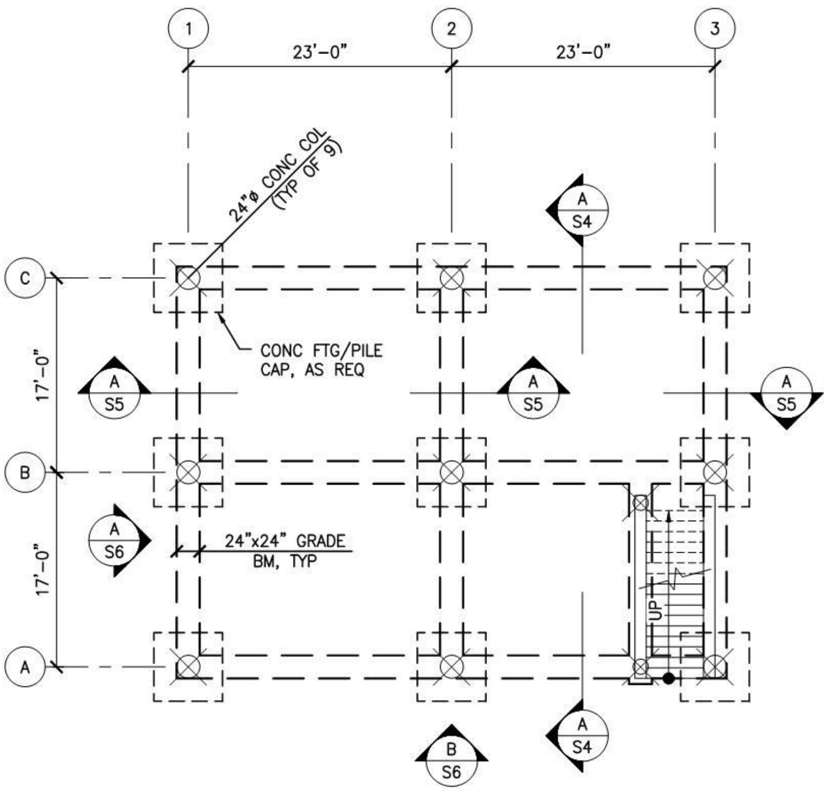
Detail B --- DRS Wall to Pitched Roof –- ICF CIP Wall Forms plus ICF Roof Plank Forms



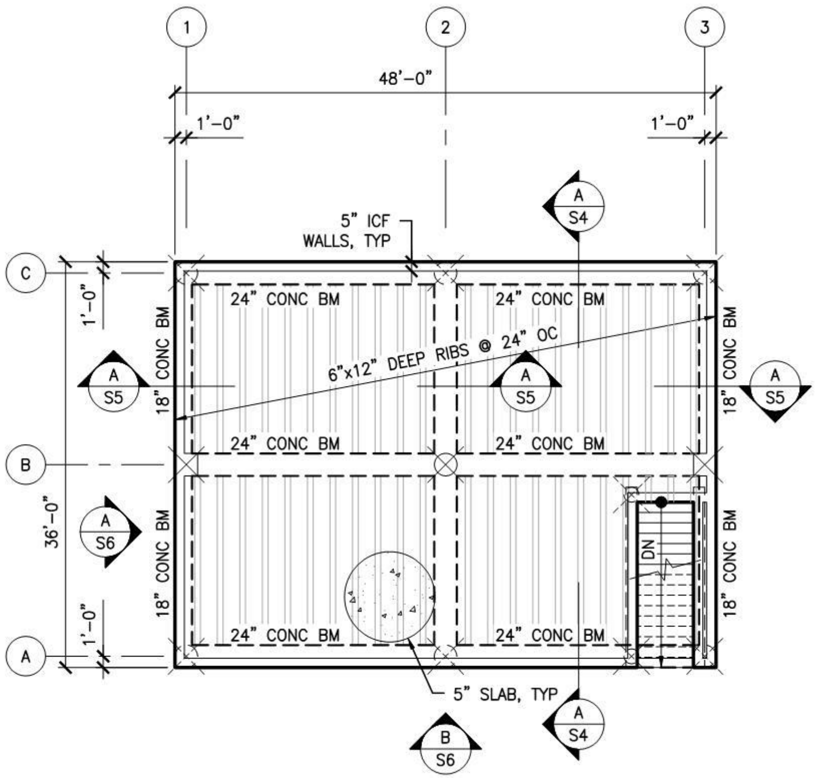
C - DRS Ridge (Deep Beam) Detail –ICF Roof Plank Forms



Structural Plans

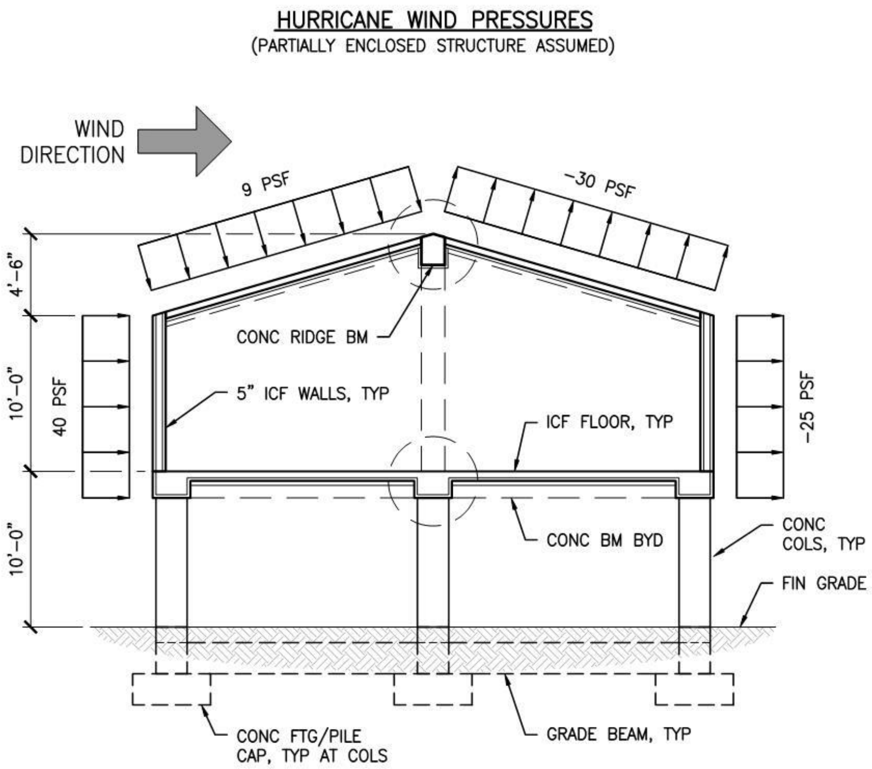


Foundation/Grade Beam Plan



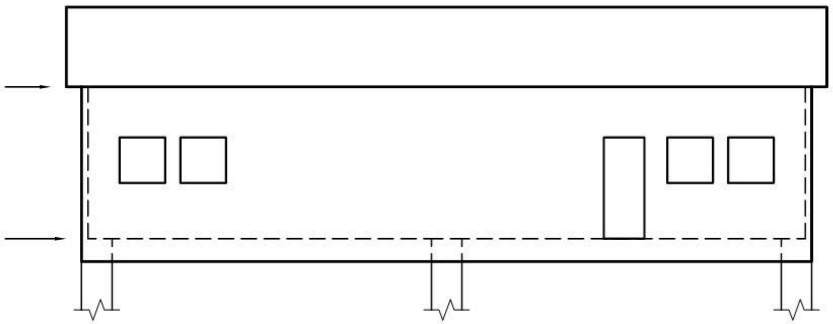
Floor Framing Plan

Structural Section & Elevation



Transverse Building Section

[One-Story House on Grade]



Longitudinal Elevation

Conclusions

- All-Concrete House can Resist Highest Tornado Winds
- Other “Hard-Shell” Structural Systems can Resist Tornados Too
- ICF System for an All-Concrete Building is Cost-Effective
- Wood Roof Systems Problematic, Even for EF-3 Tornados
- Wood Roof Anchorage to Walls Must be Addressed in the IRC

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Thank You!
Any Questions?

DISASTER RESISTANT HOUSING (DRH) WEBSITE ADDRESS:

http://www.tornadoproofhouses.com