Forensic Engineering = Detective Engineering

David W. Fowler
The University of Texas at Austin

Qualifications of Forensic Engineer

- Expert in subject under investigation
  - Formal education
  - Experience
  - Licensed engineer
  - Active in technical societies
- Fair, impartial, and ethical
  - Truthful
  - Objective
  - Avoid conflict of interest

- Must like to be a detective
  - Detective: “someone whose job is to discover information about crimes and find out who is responsible for them” (Cambridge Learner’s Dictionary)
  - You have to be able to think outside the box
  - You have to enjoy digging for the truth
- Must be a good communicator
  - Reports and presentations to clients and to judicial forums

So if you want to be an engineering Sherlock Holmes, let's go further……

Failure

- General Definitions
  - Inability of a component, structure or facility to perform its intended function
  - Note: Failure does not necessarily involve collapse or rupture

Concrete Floor Failure

Scientific Method of Determining Cause

- State the problem
- Perform observations
- Formulate hypotheses as to cause of problem
- Test the hypothesis by observation, analysis, physical test, etc.
- Analyze the results
- Make final conclusions

Forensic Engineer in Court

- Less than 10% of cases in U.S. go to trial
- Most cases settle after the lawyers make a lot of money
- For cases going to trial, the forensic engineer plays a major role

Let's look at some basics

- Volume change in materials is very important
- How does it affect cracking?

Cause of Concrete Cracks

- Concrete is very strong in compression
  - 28-day compressive strength ranges from about 3000 psi to over 10,000 psi
- But it is weak in tension
  - Tensile capacity is about 10% of its compressive strength

Source of Tension in Concrete

- External or “Structural” Sources
  - Gravity loads
  - Lateral loads
  - Loads from subgrade settlement or swelling
- “Internal” Mechanisms
  - Volume change restraint due to temperature changes or drying shrinkage
  - Expansion due to corrosion of reinforcing steel or deleterious chemical reactions

What Causes Volume Change?

- Temperature change
- Moisture change
- Chemical reactions
  - Reactive aggregates
  - Corrosion

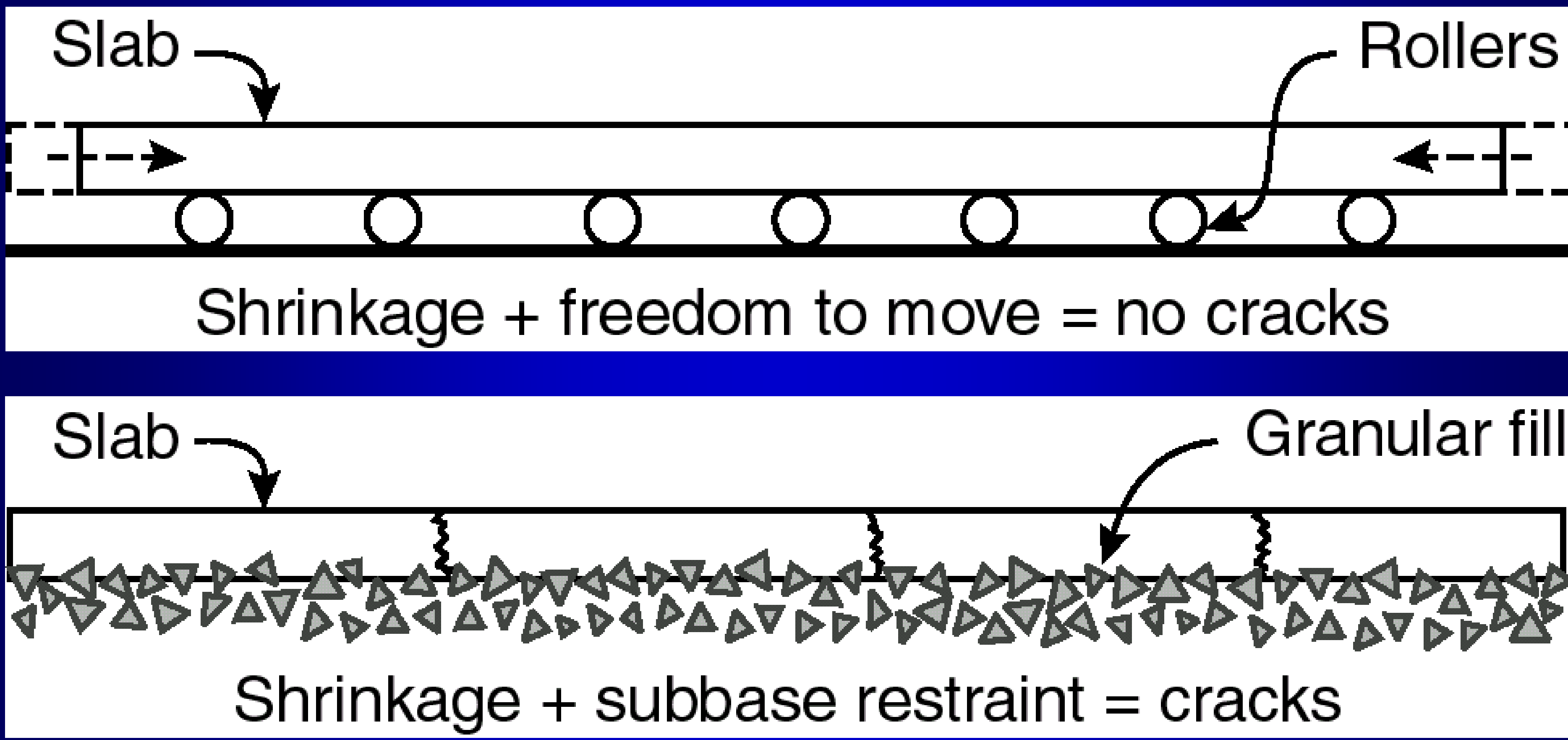
Do all volume changes cause cracking?

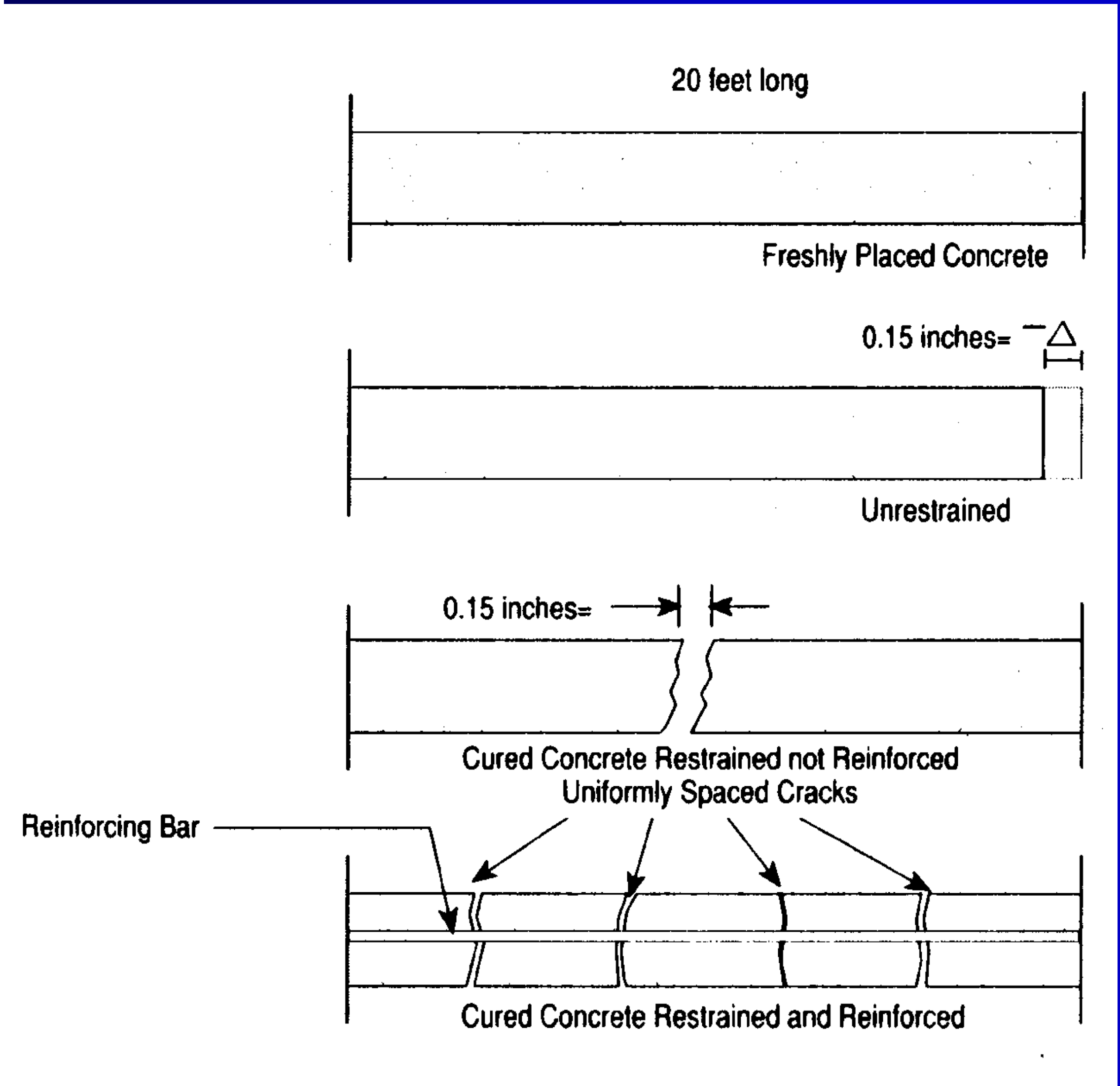
- When moisture or thermal effects cause a reduction in volume and there is restraint, cracking is likely
- When moisture or thermal effects cause increase in volume and there is restraint, spalling is possible
- When internal reactions, e.g. ASR or corrosion, occur, cracking is likely

Restraint is the key to cracking

- No restraint, no cracking

Effect of Restraint





Example of Drying Shrinkage

Slab length = 20 feet (6m)

Drying shrinkage = 600 microstrain

Shrinkage of slab = 0.0006 x 20’ x 12”/’ = 0.15 inches (6 mm)

Properly Designed Joints

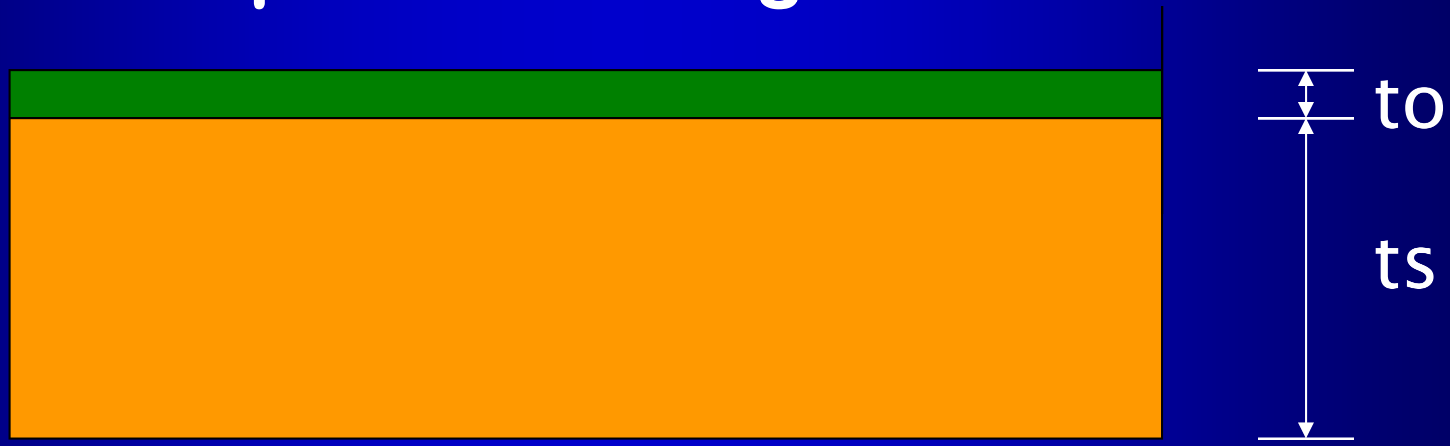
Crack at Control Joint

Stresses in overlays

- Again, no restraint, no cracking

Stress Condition

No temperature change = no stress

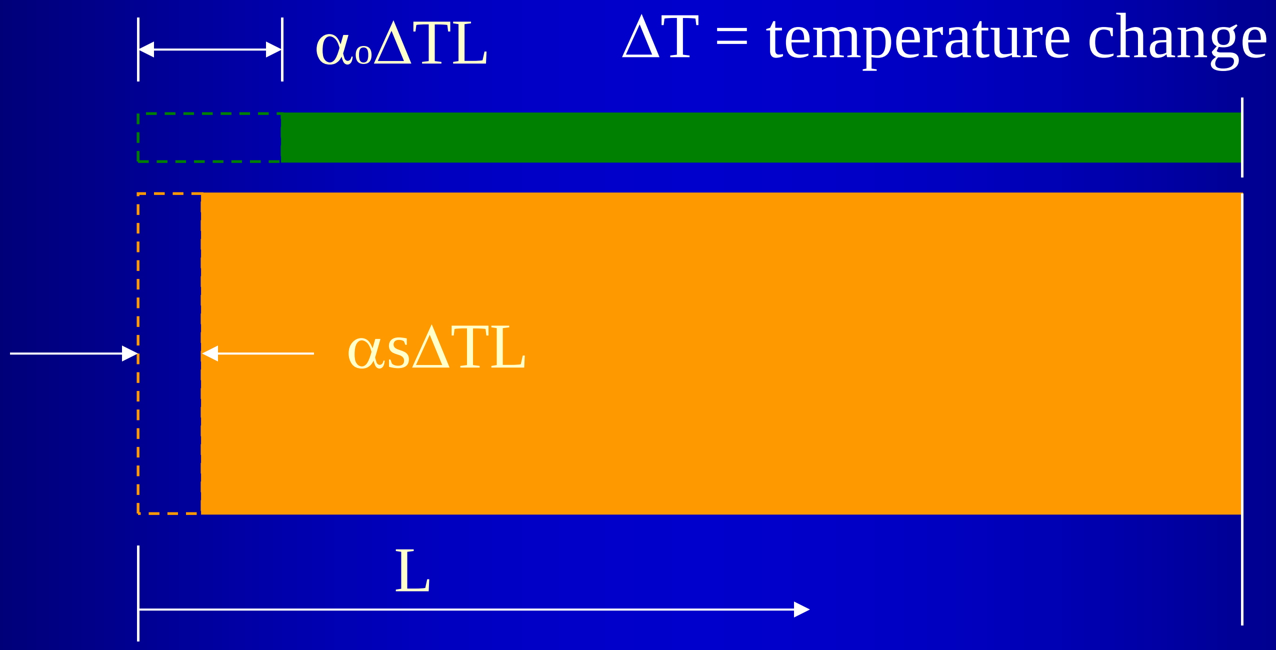


Overlay bonded to slab

$\alpha o > \alpha s$

Stress Condition

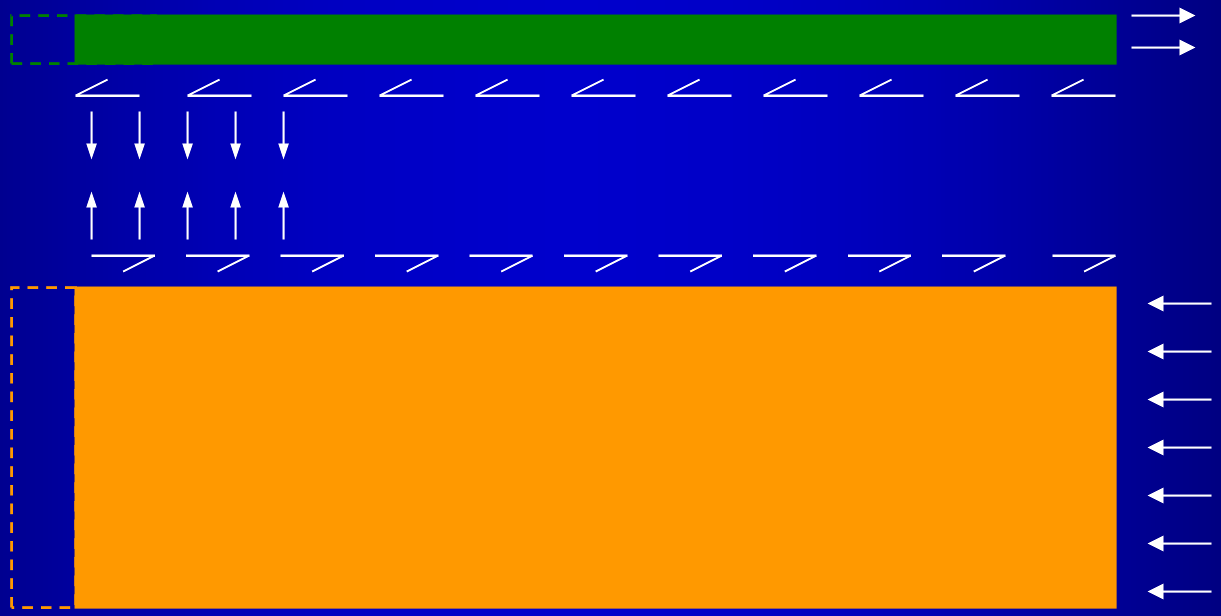
Temperature decrease – no bond



No restraint – no stress

Stress Condition

Temperature decrease – bond



Restraint due to bond results in stresses at interface and axial stresses

- An owner's worst nightmare!
- Delamination of a PC overlay
- Entire overlay was replaced
- Cause? An excessively thick bonding coat of resin which had a very high coefficient of thermal expansion.

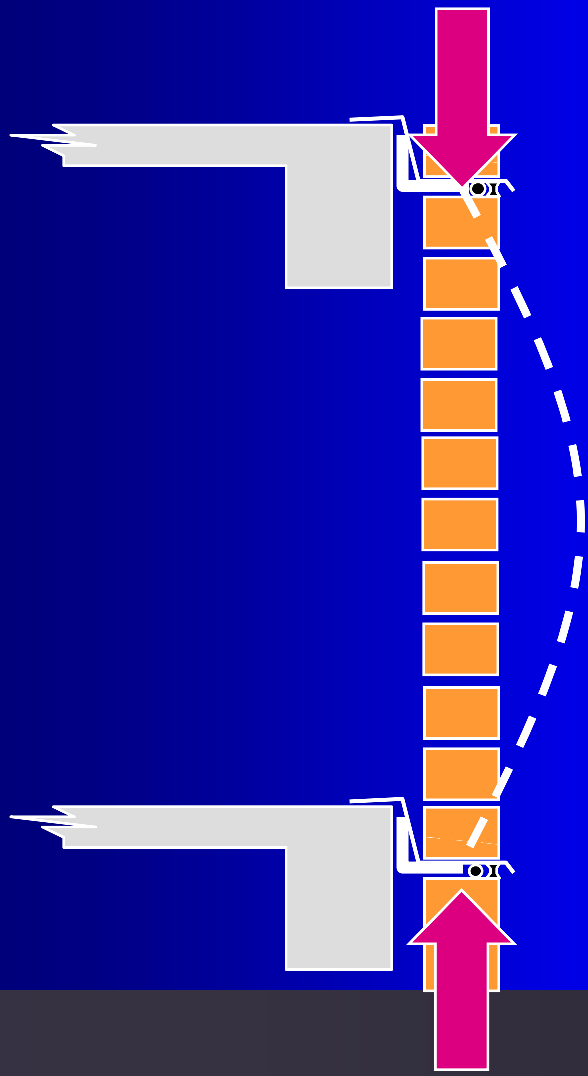
Spalling in concrete pavements—
thermal expansion and contraction

Why are jointed pavements used?

Masonry

- Brick masonry expands due to moisture
- Baked in kilns at over 2300F
- Absorbs moisture and expands
- Also expands due to thermal effects
- Concrete, on the other hand, shrinks from the time it comes out of the forms unless it is exposed to moisture.

Buckled Masonry

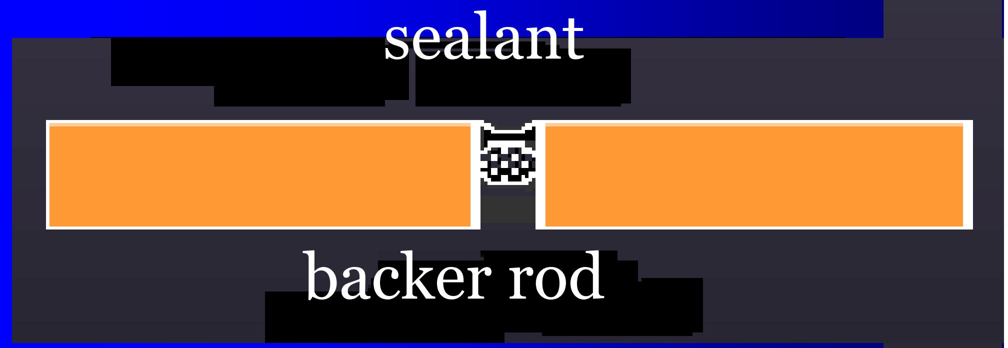


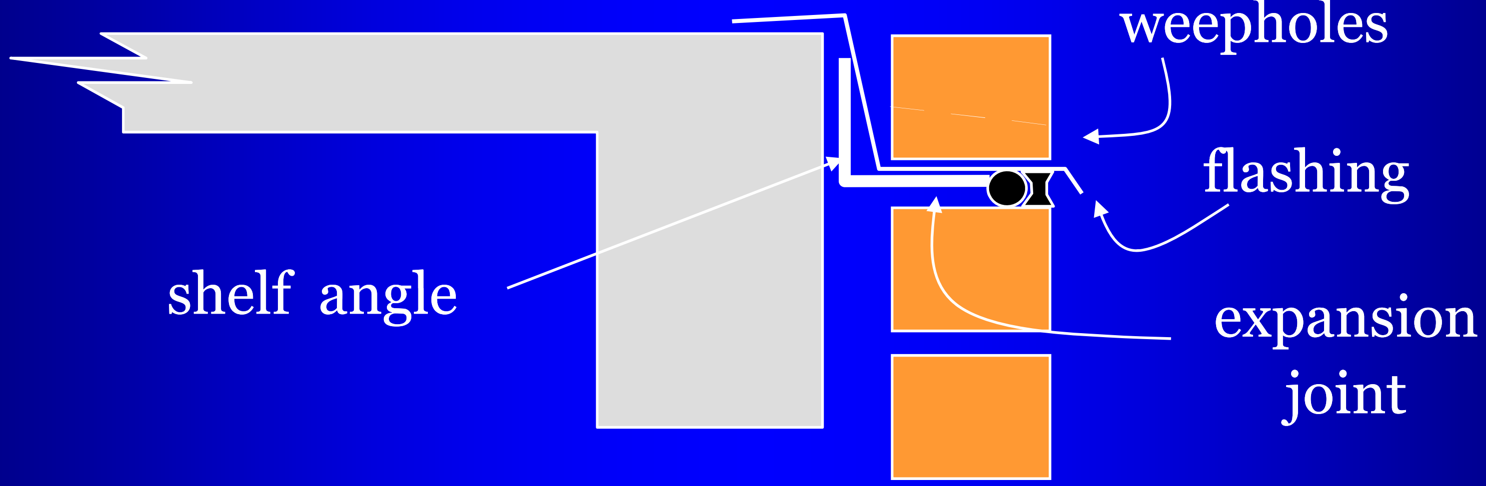
Absence of an expansion joint under shelf angle may cause compression of masonry that can lead to buckling, local spalling of masonry, and collapse of entire panel.

Clayford T Grimm PE Inc

Expansion Joints

Vertical expansion joint





Horizontal expansion joint under shelf angle

Expansion of Brick Masonry Spandrel

How To Prevent A Shear Crack

Expansion joint should have been placed here.

Absence of expansion joint caused shear crack.

Foundation Case Studies

Austin Residence

Shasta Gibbs

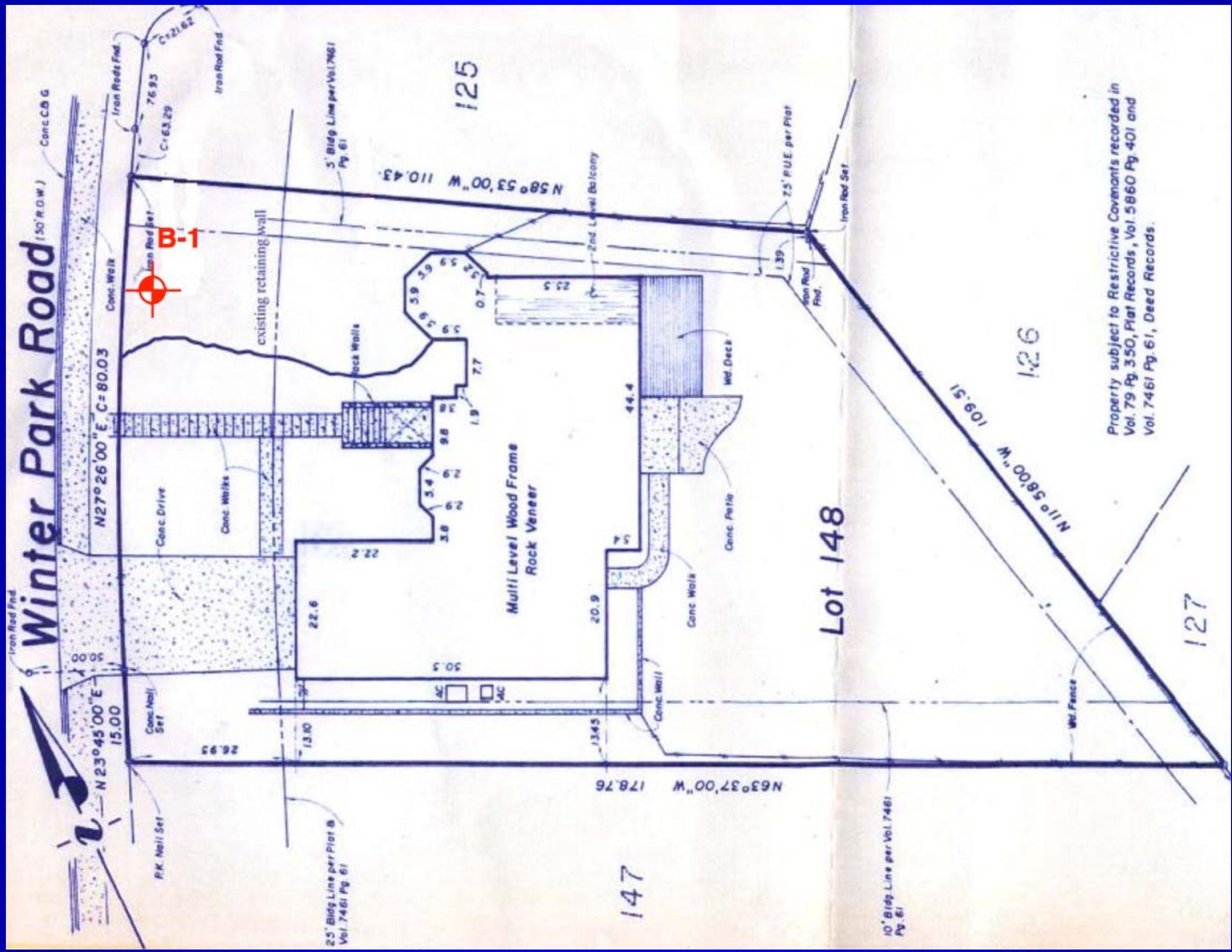
Final Project

Concrete Repair

Dr. David Fowler

8 May 2013

Site Plan



Sloping lot

Failed Foundation

*Original drilled piers
*Pressed Piles

Exterior

*Foundation cracks

Interior

*Cracks in slab
*Drywall separation
*Drywall shear cracks at window and door corners
*Relative floor elevation

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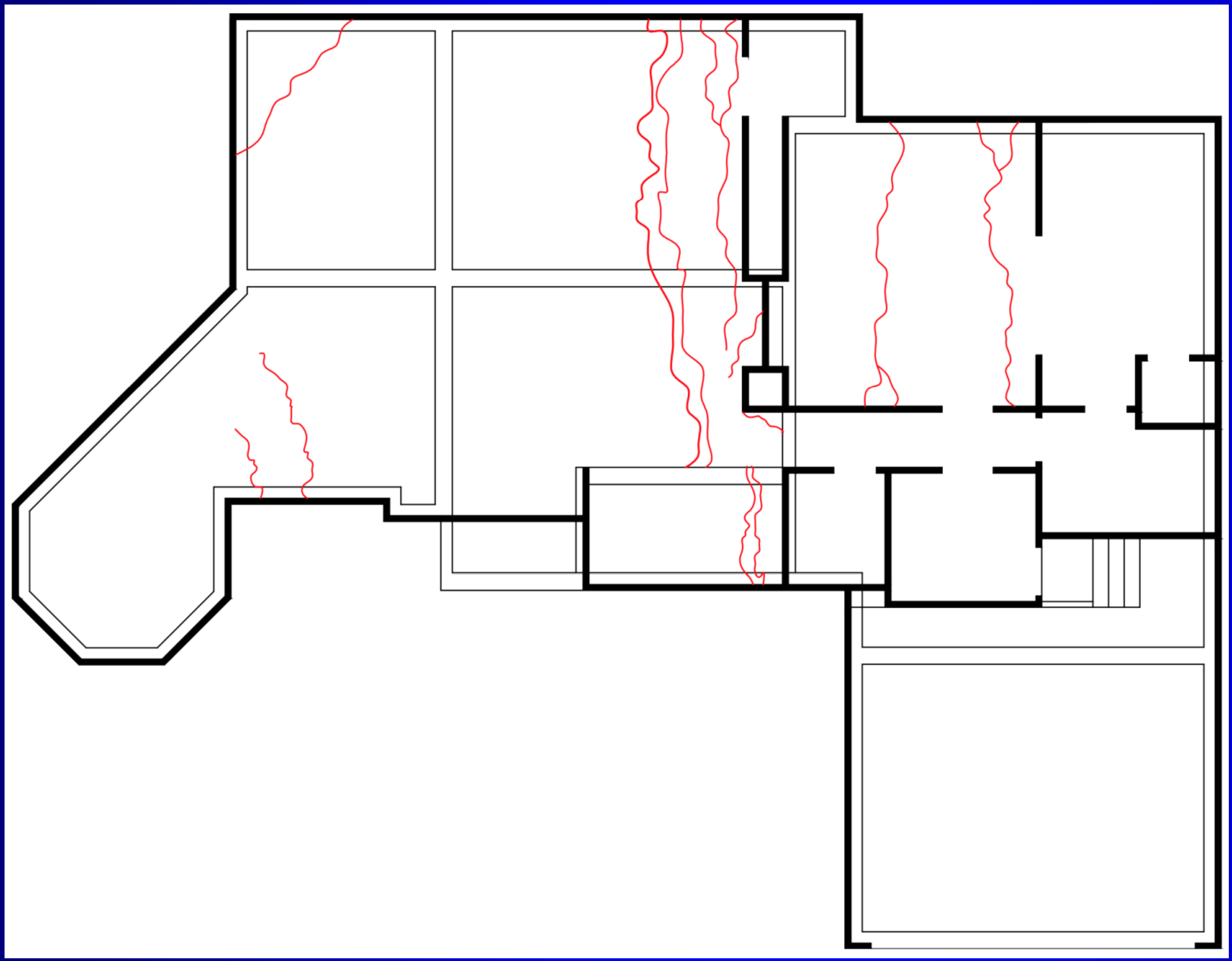

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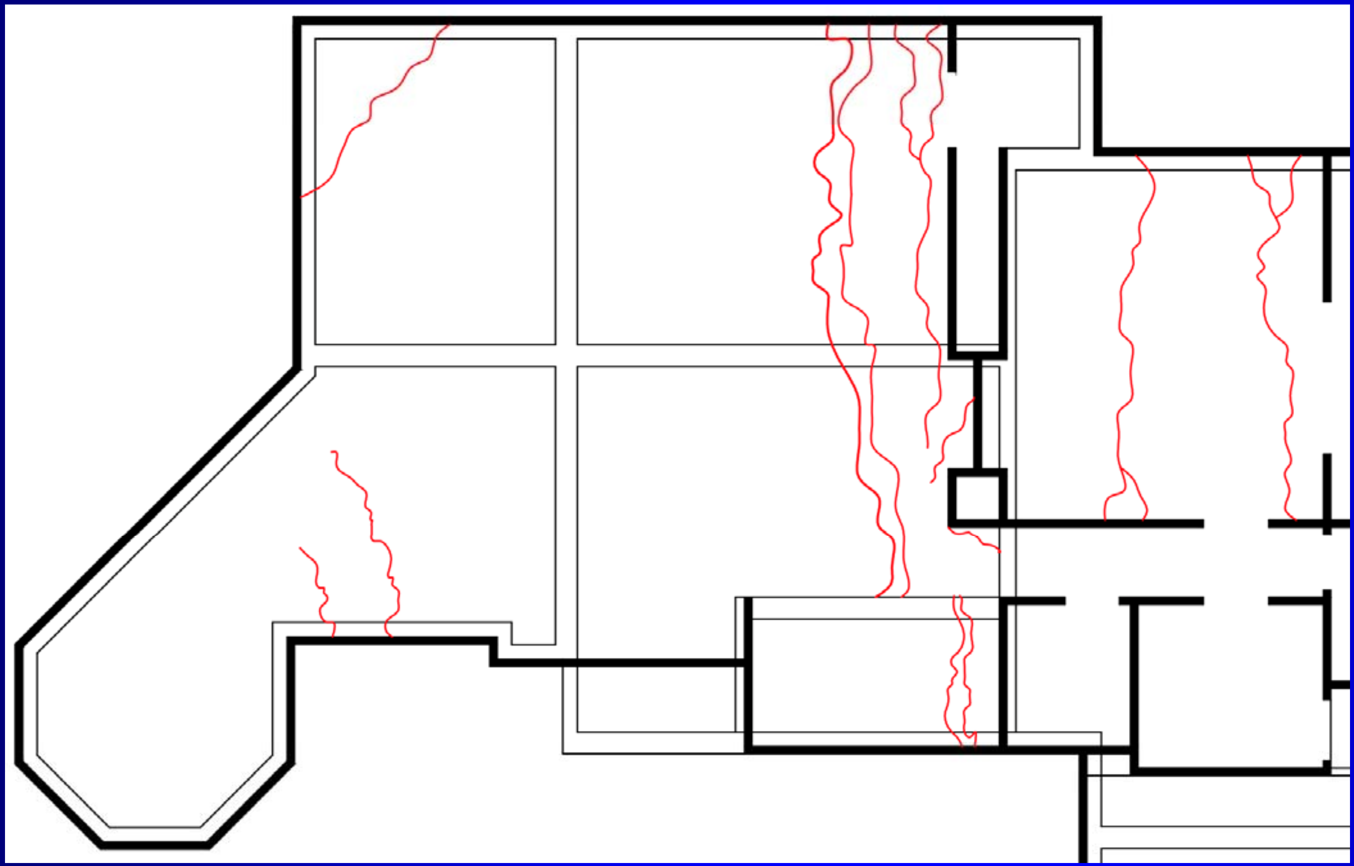

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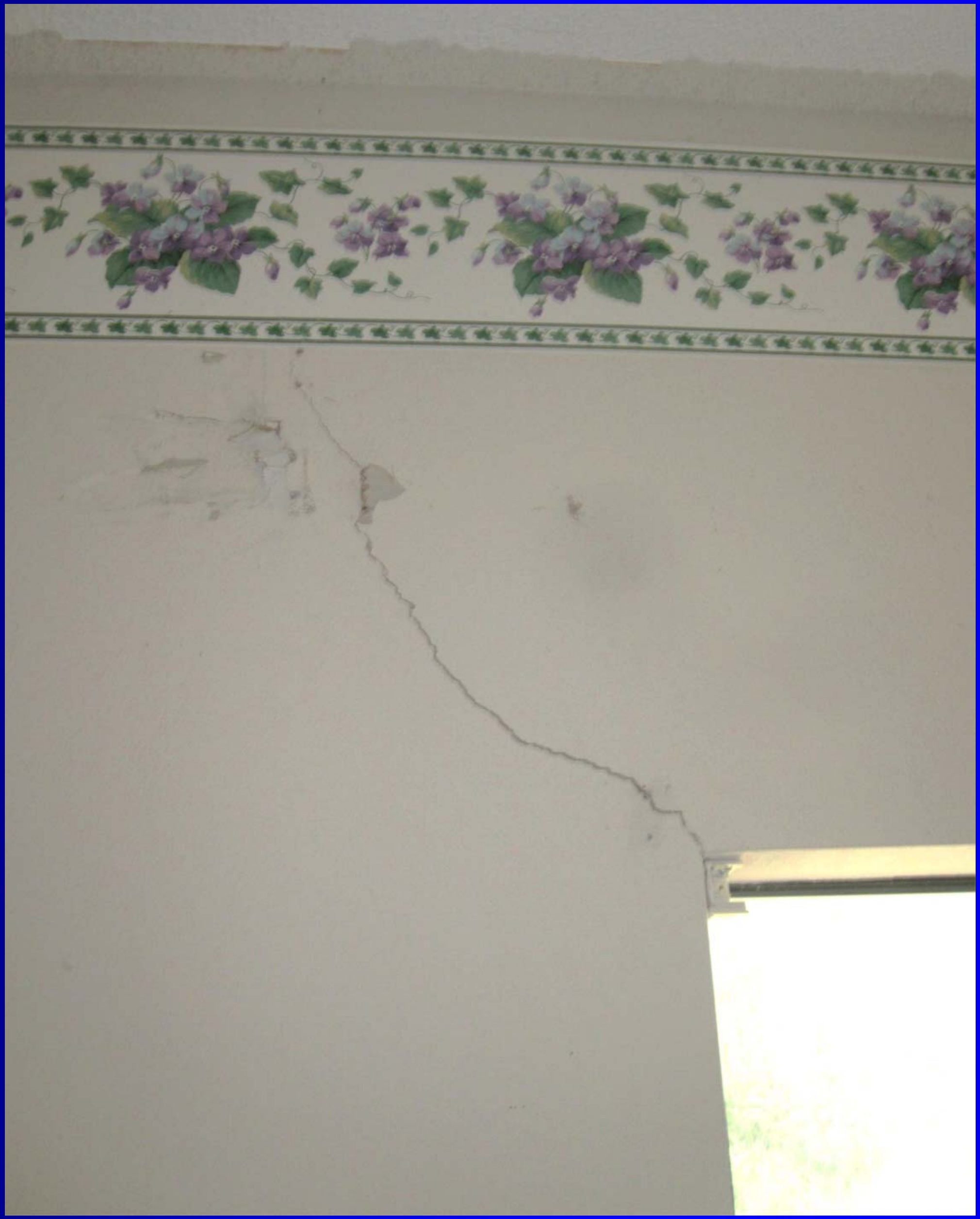

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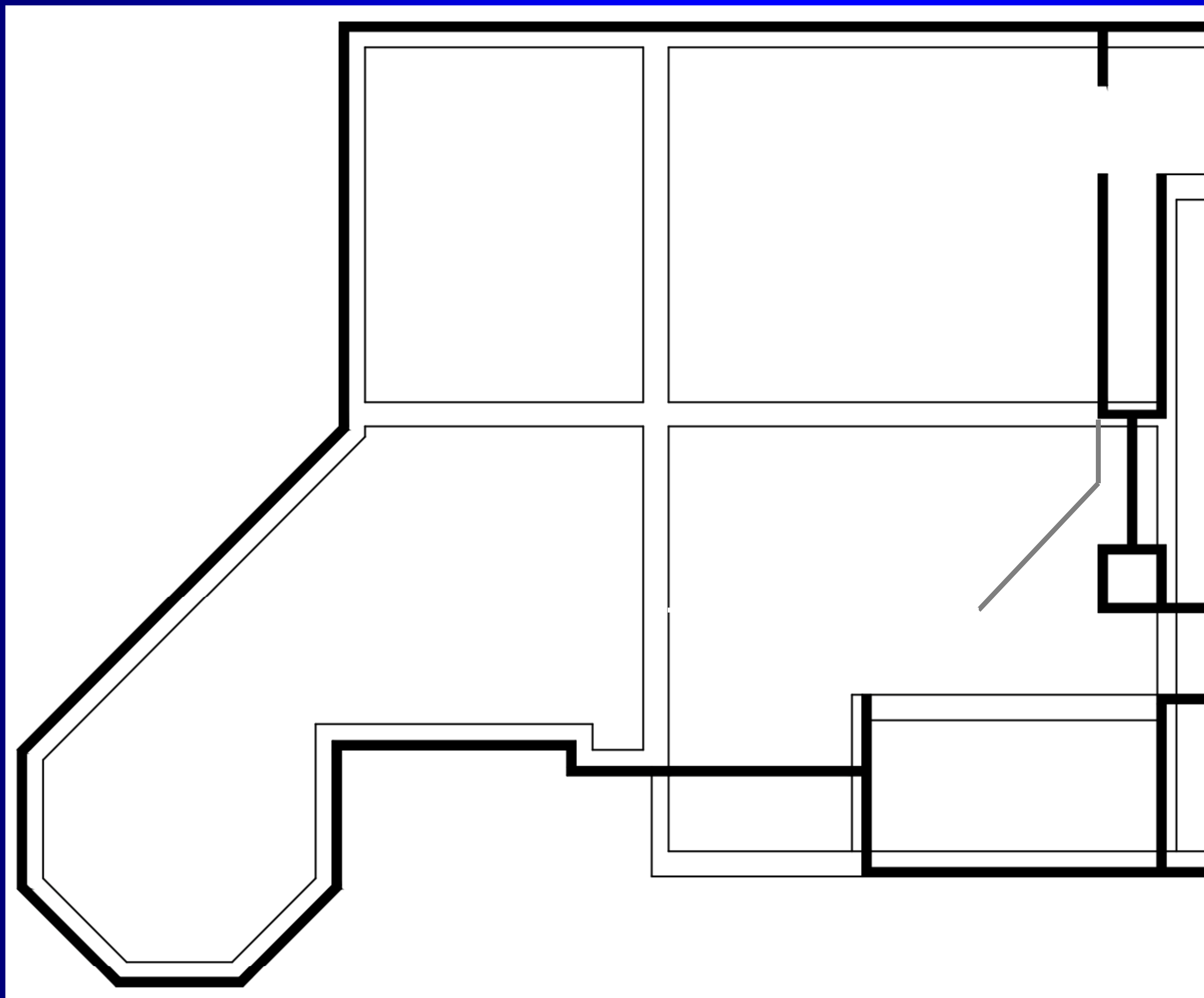

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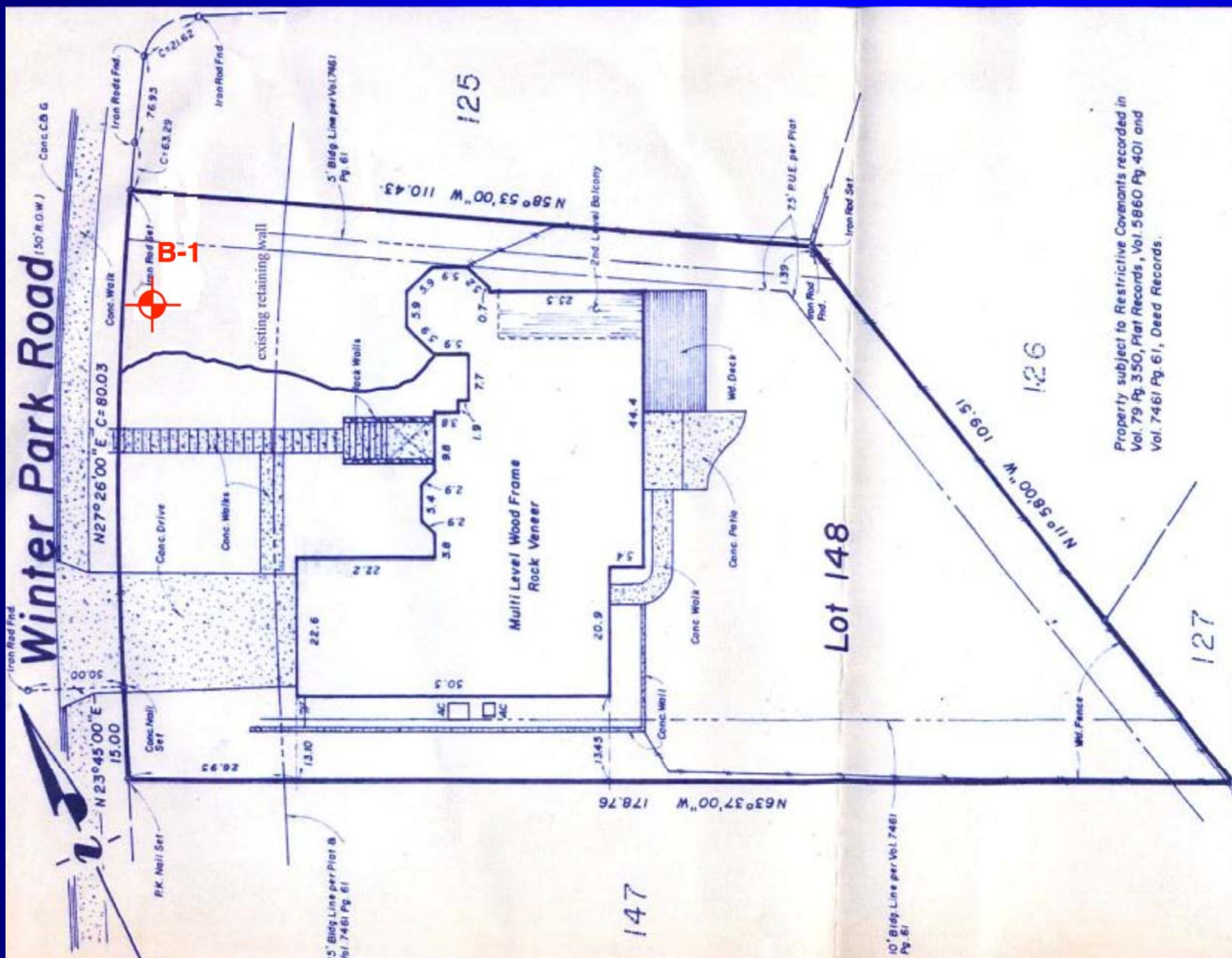
GEOTECHNICAL REPORT

Soil Boring

*Location
*Soil Profile
*Boring Log

Design

Recommendations
*Foundation System



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Description	Approximate Depth Range of Stratum (feet)	Material Encountered	Consistency/Density
Stratum I [1]	0 to 2	Brown Lean Clay (CL)	Medium Stiff
Stratum II [2]	2 to 25	Tan to Light Gray to Light Brown Fat Clay (CH)	Stiff to Hard

1. The Stratum I possible fill soils exhibited moderate shrink/swell potential as indicated by a measured plasticity index (PI) of about 19 percent. An in-situ moisture content was about 9 percent wet of the corresponding plastic limit. A pocket penetrometer value of about 0.5 tons per square foot (tsf) and a measured unconfined compressive strength of about 0.77 tsf were recorded for the stratum.
2. The Stratum II tan to light gray to light brown soils exhibited high shrink/swell potential as indicated by measured PI's of about 38 and 39 percent. In-situ moisture contents were about equivalent and 3 percent wet of the corresponding plastic limits. Pocket penetrometer values ranging from about 1.0 to 4.5 tsf and measured unconfined compressive strengths ranging from about 1.52 to 4.3 tsf were recorded for the stratum.

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BORING LOG NO. B-1

PROJECT: Kiguchi Residence Improvements

CLIENT: Dr. Koru Kiguchi, M.D., PhD
Austin, TX

SITE: 1805 Winter Park Road
Austin, Texas

LOCATION See Exhibit A-2

GRAPHIC LOG / DEPTH	Description	Depth (ft)	Field Test Results	Test Type	Compressive Strength	Strain (%)	Water Content (%)	Dry Unit Weight (pcf)	Atterberg Limits LL-PL-PI
	LEAN CLAY (CL) Medium stiff, brown (Possible Fill)		0.5 tsf (HP)	UC	0.77 (tsf)	9.5	24	107	34-15-19
2.0	**FAT CLAY (CH)** Stiff, tan to light gray to light brown, with trace calcareous nodules		1.0 tsf (HP)	UC	1.52 (tsf)	8.8	21	107	
	-very stiff to hard below 4 feet	5	3.0 tsf (HP)				20		58-20-38
			2.5 tsf (HP)	UC	1.89 (tsf)	9.6	23	103	
			4.5 tsf (HP)				20		
		10							
			4.5 tsf (HP)	UC	2.57 (tsf)	5	23	107	59-20-39
		15							
			4.5 tsf (HP)				22		
		20							
			4.5 tsf (HP)	UC	4.30 (tsf)	4.1	20	111	
25.0	***Boring Terminated at 25 Feet***	25							

Stratification lines are approximate. In-situ, the transition may be gradual.

Hammer Type: Automatic

Advancement Method:
Dry Augered 0 to 25 feet

Abandonment Method:

See Exhibit A-3 for description of field procedures.
See Appendix B for description of laboratory procedures and additional data, (if any).
See Appendix C for explanation of symbols and abbreviations.

Notes:

WATER LEVEL OBSERVATIONS
No free water observed

Terracon
5307 Industrial Oaks Blvd., Suite 160
Austin, Texas

Boring Started: 2/22/2012 | Boring Completed: 2/22/2012
Drill Rig: CME 75 | Driller: Core Tech Drilling, Inc.
Project No.: 96125026 | Exhibit A-4

TERRACON SMART LOG-HEADERS 96125026 BORING LOGS.GPJ TERRACON2012.GDT 3/20/12

Soil Boring

*Location
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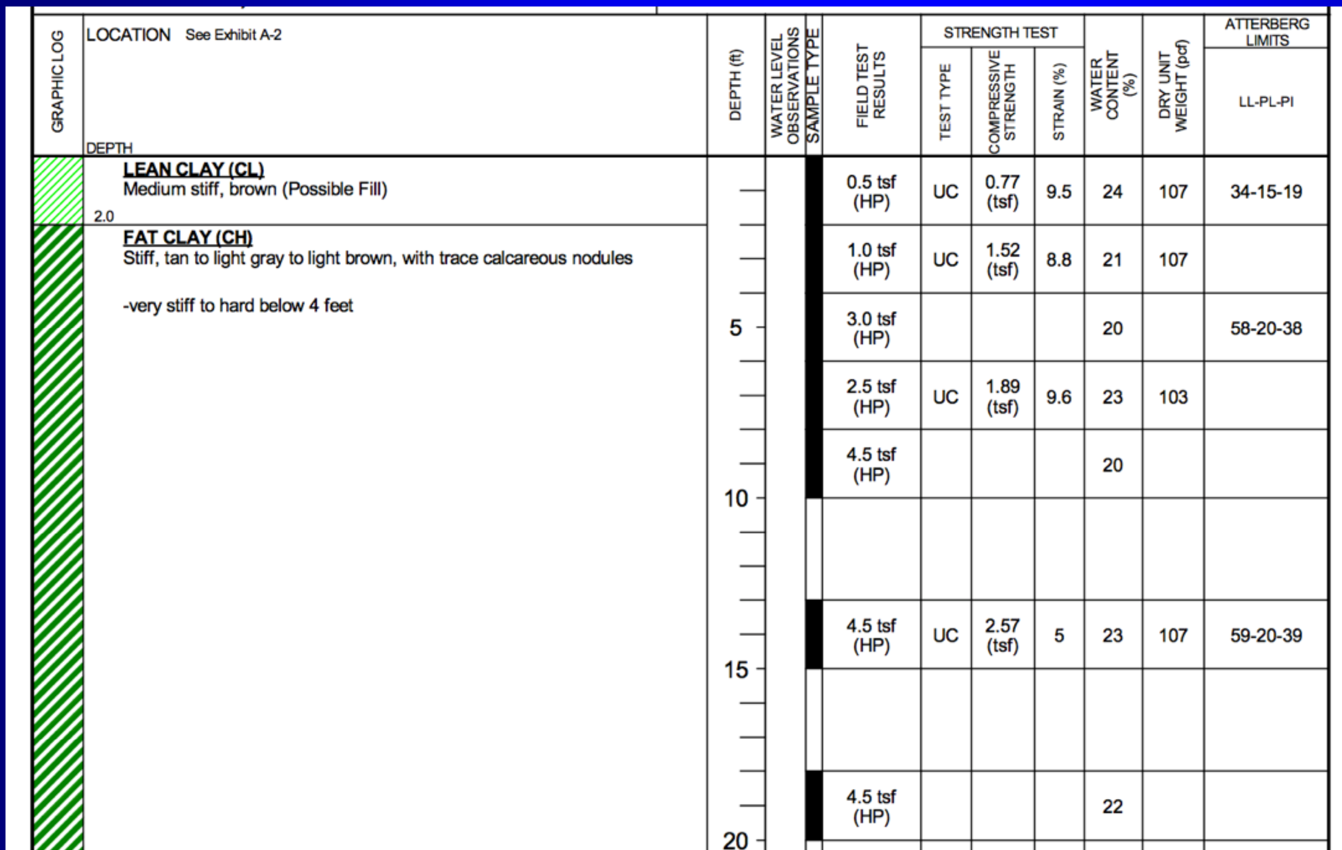
Recommendations
*Foundation System



GRAPHIC LOG	LOCATION See Exhibit A-2 / DEPTH	DEPTH (ft)	WATER LEVEL OBSERVATIONS	SAMPLE TYPE	FIELD TEST RESULTS	STRENGTH TEST: TEST TYPE	STRENGTH TEST: COMPRESSIVE STRENGTH	STRENGTH TEST: STRAIN (%)	WATER CONTENT (%)	DRY UNIT WEIGHT (pcf)	ATTERBERG LIMITS: LL-PL-PI
	LEAN CLAY (CL) Medium stiff, brown (Possible Fill)				0.5 tsf (HP)	UC	0.77 (tsf)	9.5	24	107	34-15-19
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		15									
					4.5 tsf (HP)				22		
		20									

Soil Boring

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4.2.1 Drilled and Underreamed Pier Foundation System

Description	Drilled and Underreamed Pier Design Parameter
Minimum embedment into bearing stratum [1]	18 feet below existing grades (natural grade at the time of our field program) and at least 15 feet below FFE, whichever is deeper
Bearing Pressures (allowable)[2]	Net dead plus sustained live load – 6,000 psf Net total load – 9,000 psf
Ratio of Underream Diameter to Shaft Diameter [3]	2:1 to 3:1
Estimated uplift force[4,5,6]	75*D
Minimum percentage of steel	0.5 percent
Approximate total settlement [7,8]	1 inch or less
Estimated differential settlement [7,8]	Approximately ½ to ¾ of total settlement

Soil Boring

*Location

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Design

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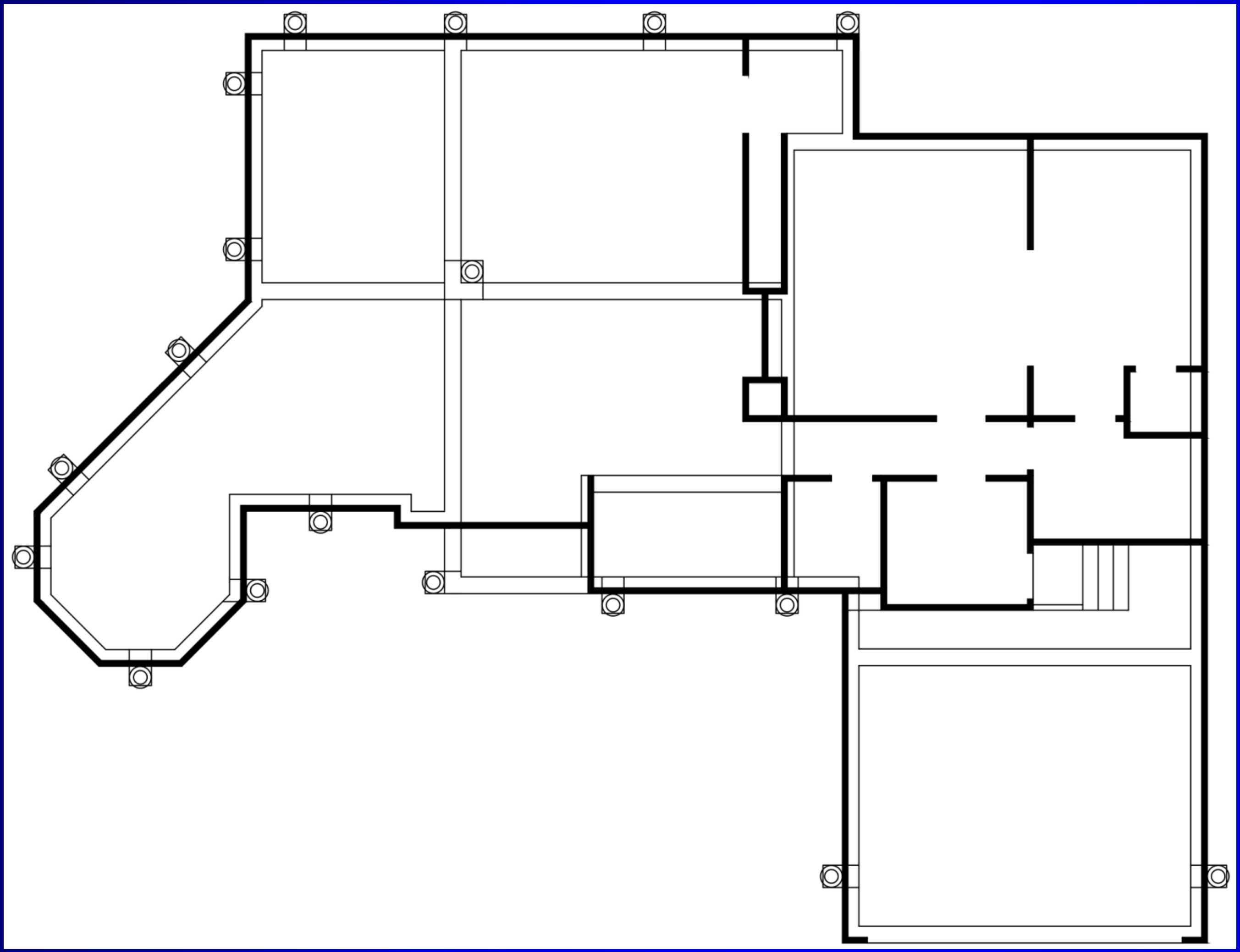
*Foundation System

REPAIR SOLUTION

Repair
Solution

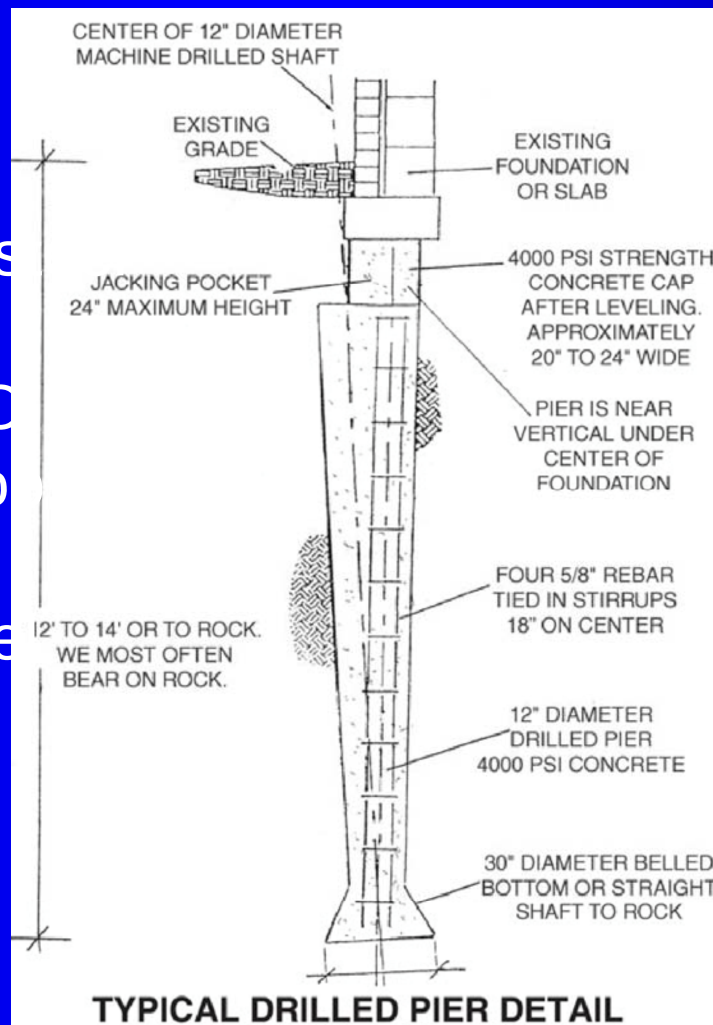
*Pier Design
*Additional Repairs
*Pier Construction



Repair Solution

*Pier Design
*Additional Repairs
*Pier Construction

- Rests 18 feet below grade, drilled at an angle
- 14” pier diameter
- 36” bell diameter
- 2’ bearing corbel
- (6) #5 longitudinal s bars
- #3 stirrups @ 12” O
  - (2) stirrups at to and bottom of longitudinal stee



Repair Solution

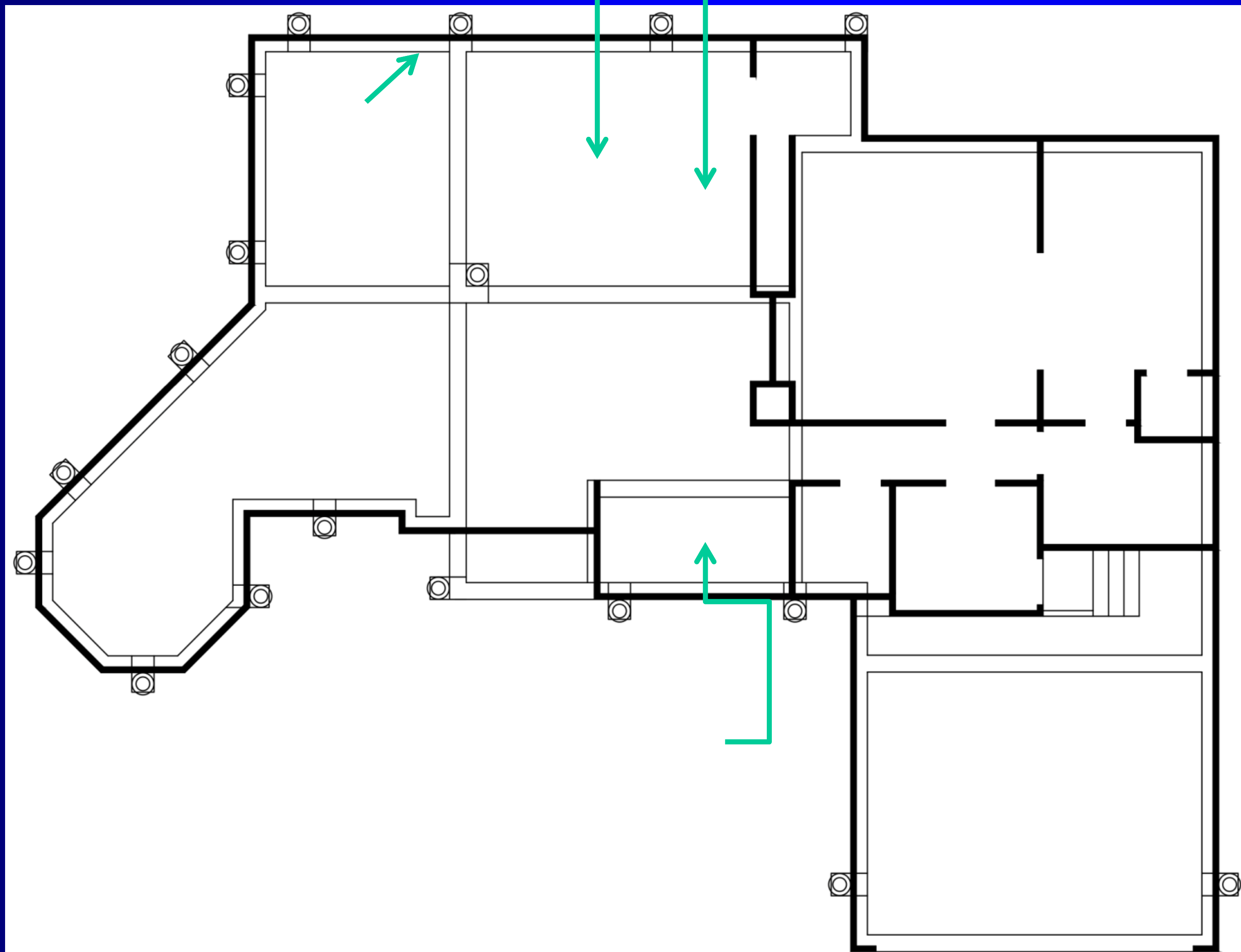
*Pier Design

*Additional Repairs

*Pier Construction

Level slab with flowable concrete after all piers have been installed and after jacking has been finished

Wood flooring platform with 2x6 @ 16” O.C. w/ ¾” plywood sheathing, glue and nail with 12d nails, 6” O.C. edge and 12” O.C. field



Repair Solution

*Pier Design

*Additional Repairs

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Repair Solution

*Pier Design
*Additional Repairs
*Pier Construction

Repair Solution

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Repair Solution

*Pier Design
*Additional Repairs
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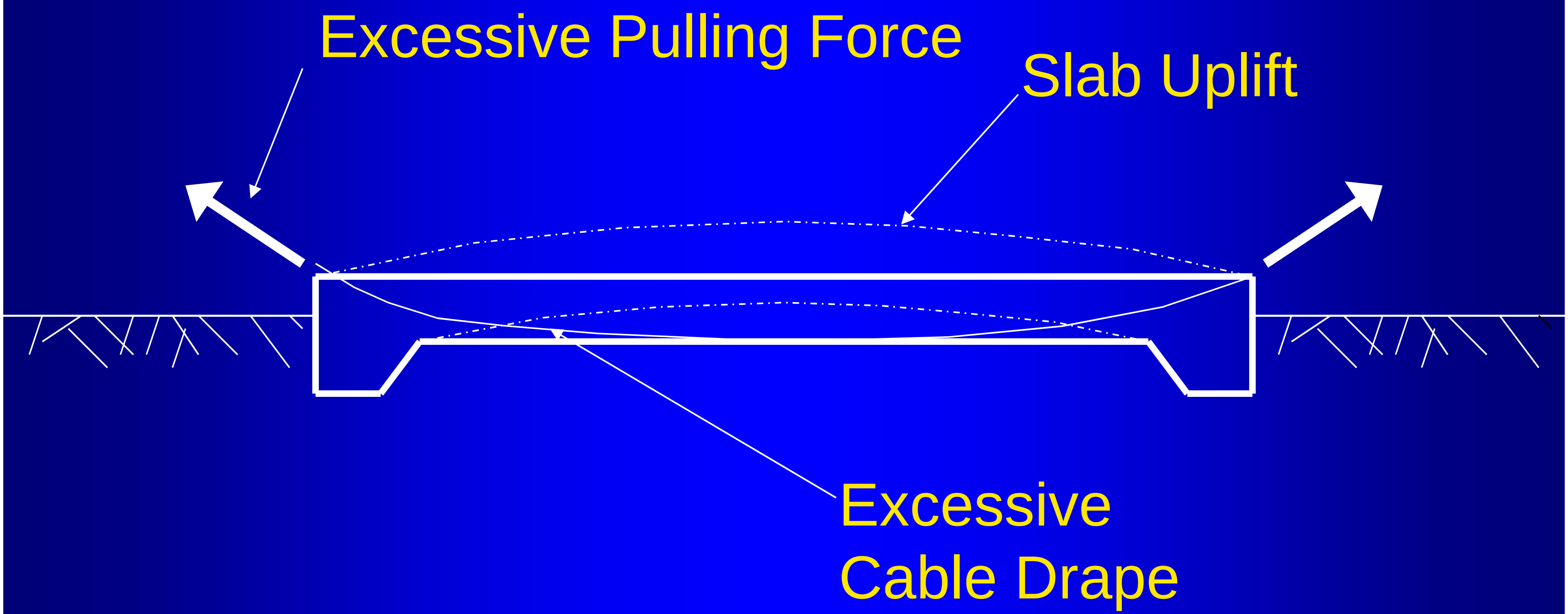
Apartment

- Two-story apartment rock veneered apartment
- Less than a year after it was repair with pressed piles it exhibited over 4 inches of settlement.
- The following photos show what they found when they exhumed the foundation.

Paper cup formed the tip

Other foundation failures…



Potential Problems with Post-tensioned Slabs

Exposed Cable—Poor Construction/Inspection

- Failure to maintain void beneath suspended slabs and beams
- Failure to provide adequate drainage around foundation

Test Pit #1: Two carton forms. Inside collapsed. Outside left 3.5” concrete in contact with clay.

Test Pit #3, no void, carton form collapsed.

Summary

- Many causes of concrete distress and foundation problems
- But not all is bad news
- This provides us with a life time annuity