# Some Lessons Learned Through 54 Years of Mistakes:
# HYDROCOMPRESSION SETTLEMENT OF DEEP EARTH FILLS

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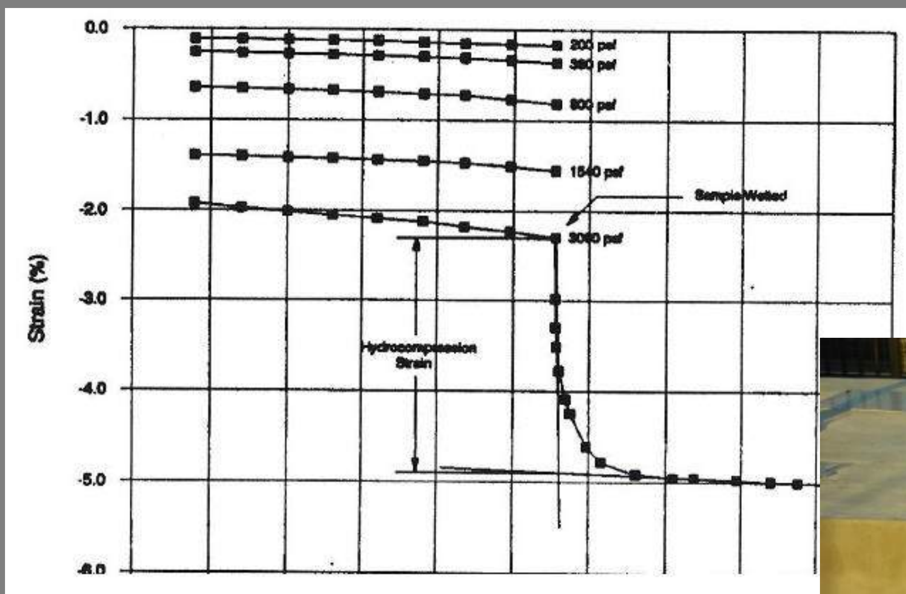


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# FOR YEARS I BELIEVED---

**"IF YOU COMPACT LEAN CLAY TO 95% STANDARD PROCTOR, YOU CAN BEAR ON IT FOREVER"**

# THEN THE COMPANY PRESIDENT TOLD ME—

**“ IF THE FILL IS MORE THAN ABOUT 20 FEET THICK AND IT GETS SATURATED, IT WILL COMPRESS 1 TO 2 PERCENT”**

# AND I THOUGHT--

## “UH-OH”

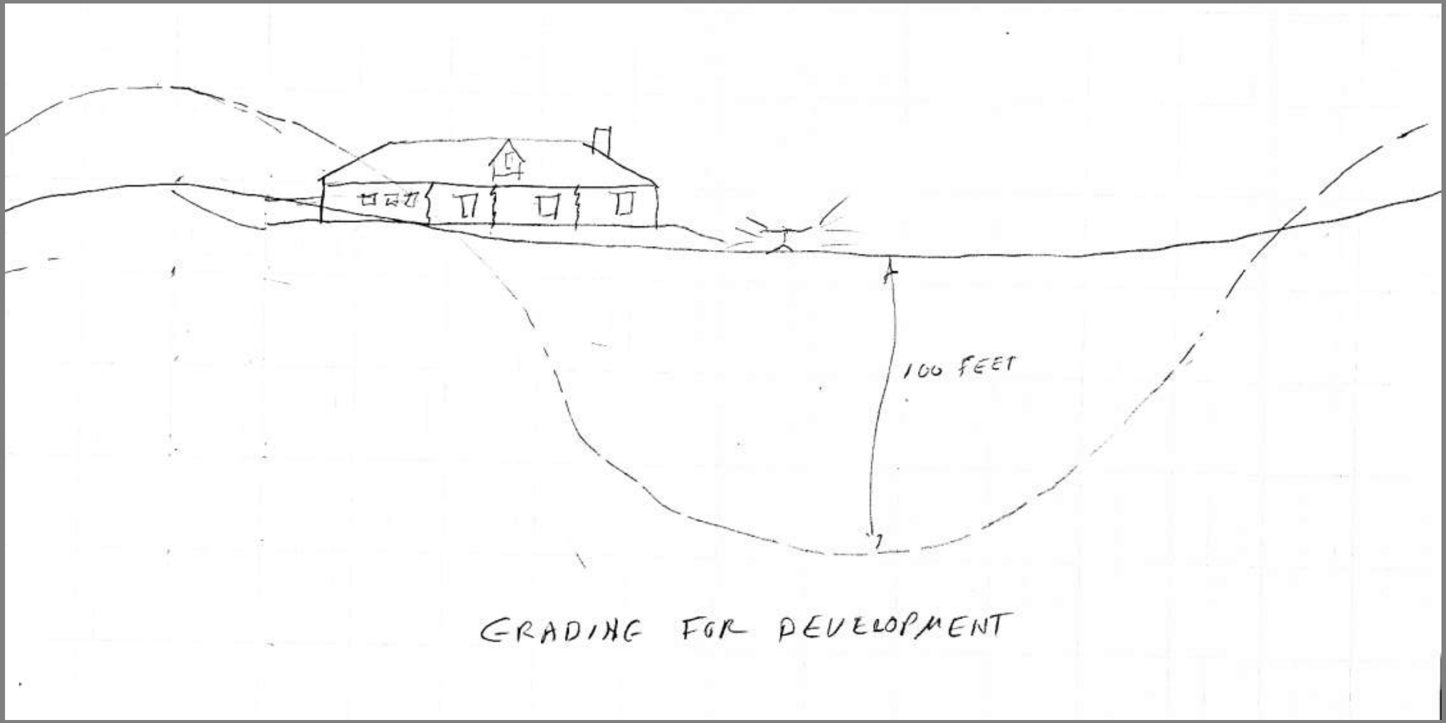
# BACKGROUND

- LARGE HILLS AND CANYONS IN SOUTHERN CALIFORNIA WERE GRADED TO DEVELOP HOUSING SITES
- OUR OFFICE IN SAN DIEGO PERFORMED GEOECHNICAL INVESTIGATIONS AND EARTHWORK INSPCTION
- FILLS WERE UP TO 100 FEET THICK
- THE SOIL WAS A CLAYEY SAND TO SANDY CLAY
- THE FILL WAS COMPACTED TO AT LEAST 90% MODIFIED PROCTOR
- WATER CONTENTS WERE NEAR OPTIMUM (ABOUT 11%)

- THIS PRACTICE WAS SUCCESSFUL FOR DECADES

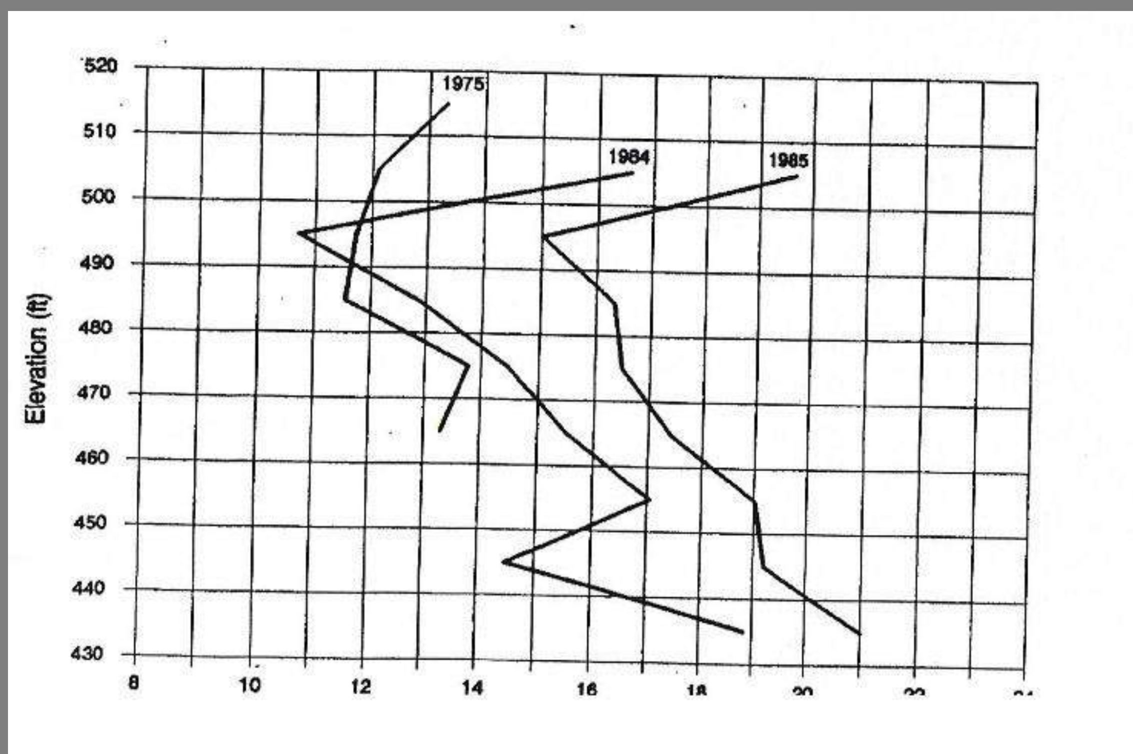
# BACKGROUND

- SETTLEMENTS WERE NOTICED IN MID-1970s IN HOUSING OVER 5 YEARS OLD.
- SETTLEMENTS UP TO 18 INCHES ULTIMATELY OCCURRED
- SOME HOUSES WERE DAMAGED



# WHAT CHANGED?

- HEAVY IRRIGATION OF LAWNS HAD BECOME COMMON
- EQUIVALENT ANNUAL RAINFALL INCREASED FROM 8 INCHES TO 70 INCHES PER YEAR!
- BORINGS SHOWED THAT WATER CONTENTS AT DEPTH HAD INCREASED TO 16 TO 21%



# INVESTIGATION

Brandon, Duncan, and Gardner, 1990

**HYDROCOMPRESSION SETTLEMENT OF DEEP FILLS**

**By Thomas L. Brandon,[1] Associate Member, ASCE, J. Michael Duncan,[2] Fellow, ASCE, and William S. Gardner,[3] Member, ASCE**

Journal of Geotechnical Engineering,
Vol. 116, No. 10, October 1990

# Another Reference

## CÒLLAPSE OF COMPACTED CLAYEY SAND

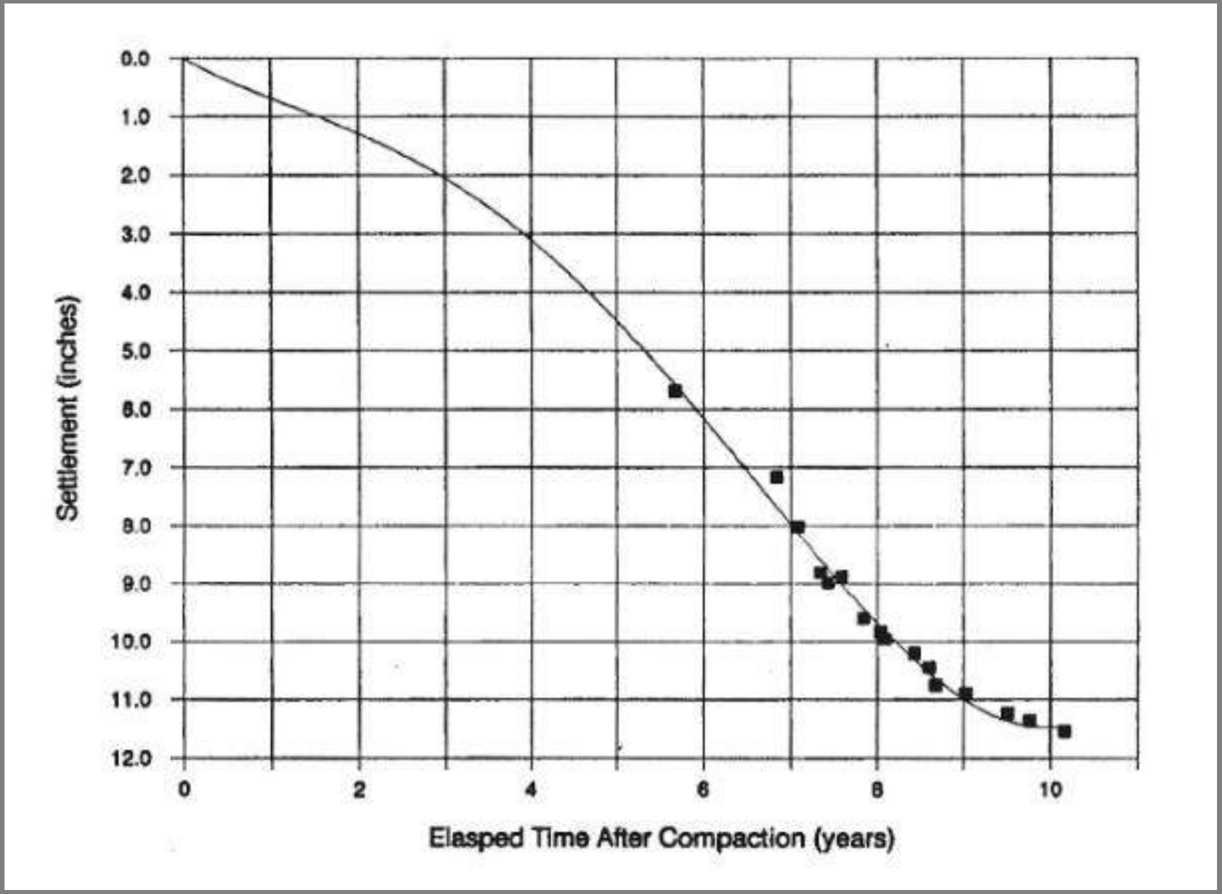
By Evert C. Lawton,[1] Richard J. Fragaszy,[2] and James H. Hardcastle,[3]
Members, ASCE

Journal of Geotechnical Engineering,
Vol. 115, No. 9, September 1989

# INVESTIGATION

## Brandon, Duncan, and Gardner, 1990

- AT ONE SITE, SETTLEMENT INCREASED FROM 6 INCHES IN 5 YEARS TO 11 INCHES IN 10 YEARS
- THE RATE OF SETTLEMENT WAS DECREASING



# INVESTIGATION
## Brandon, Duncan, and Gardner, 1990

- PLACEMENT COMPACTION AND DENSITY COMPLIED WITH SPECS AND WERE PRETTY UNIFORM

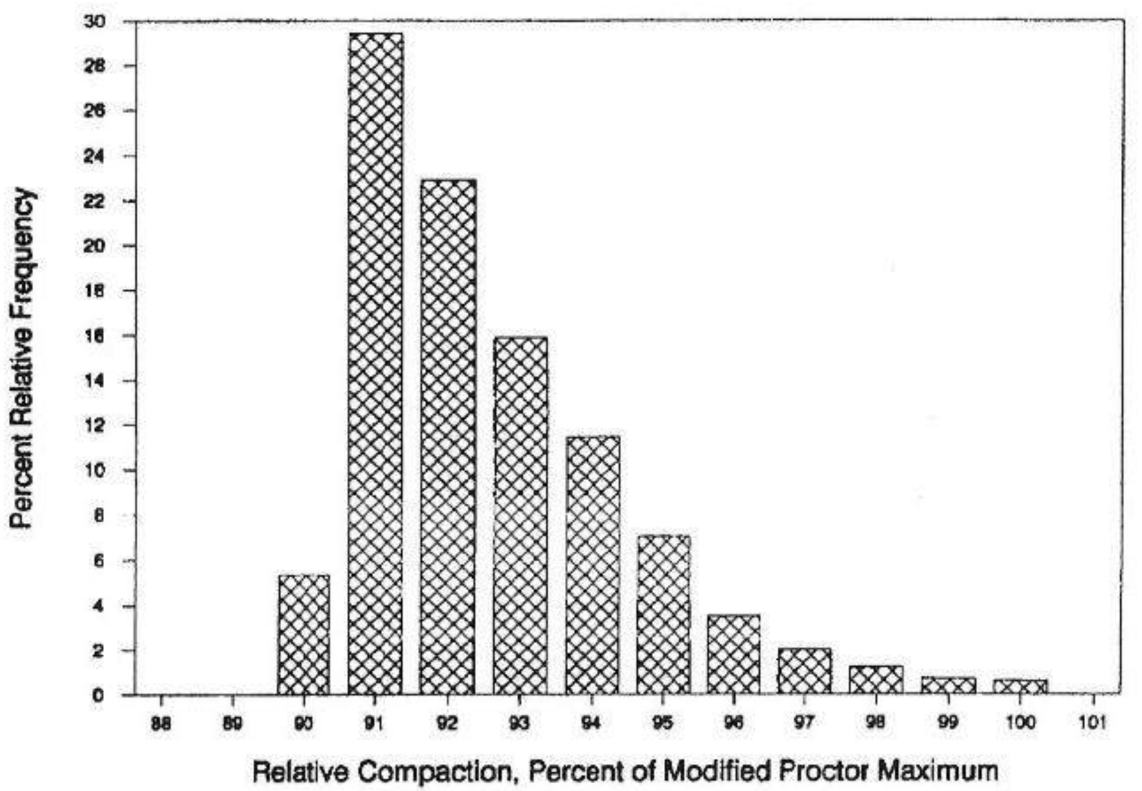



**FIG. 1. Relative Compaction (ASTM D-1557) Measured for Villa Martinique Development**

# INVESTIGATION

## Brandon, Duncan, and Gardner, 1990

- CONSOLIDATION SAMPLES COMPACTED AS SPECIFIED, LOADED TO MORE THAN 1000 PSF, AND WETTED COMPRESSED 0.3 TO 7 PERCENT

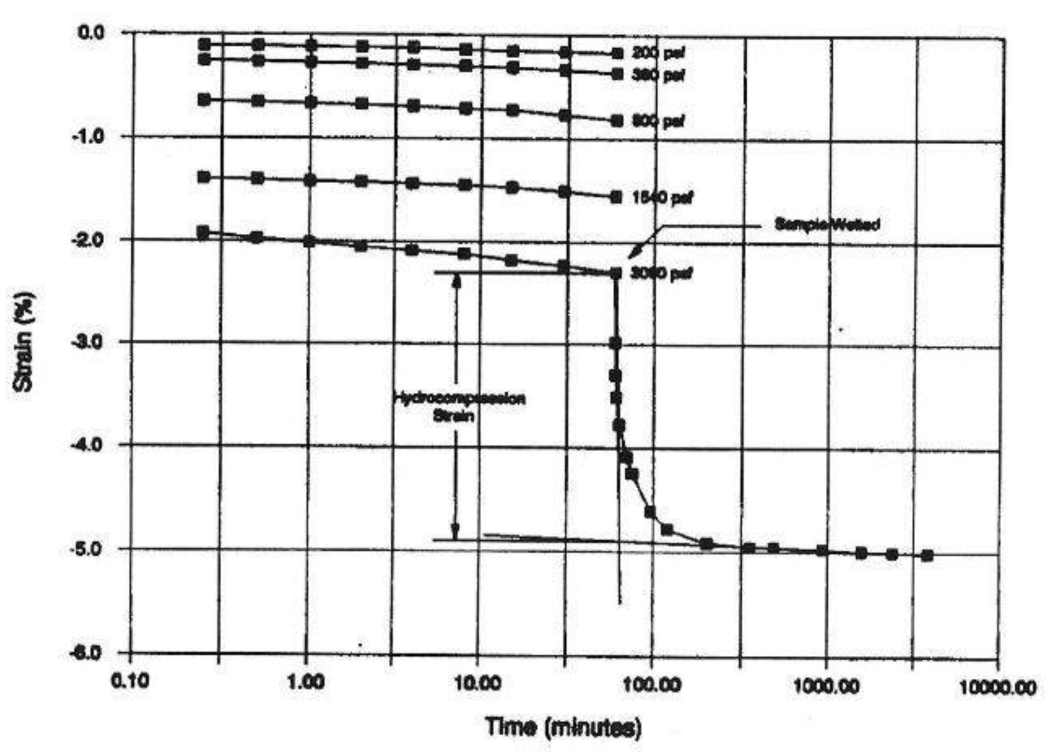
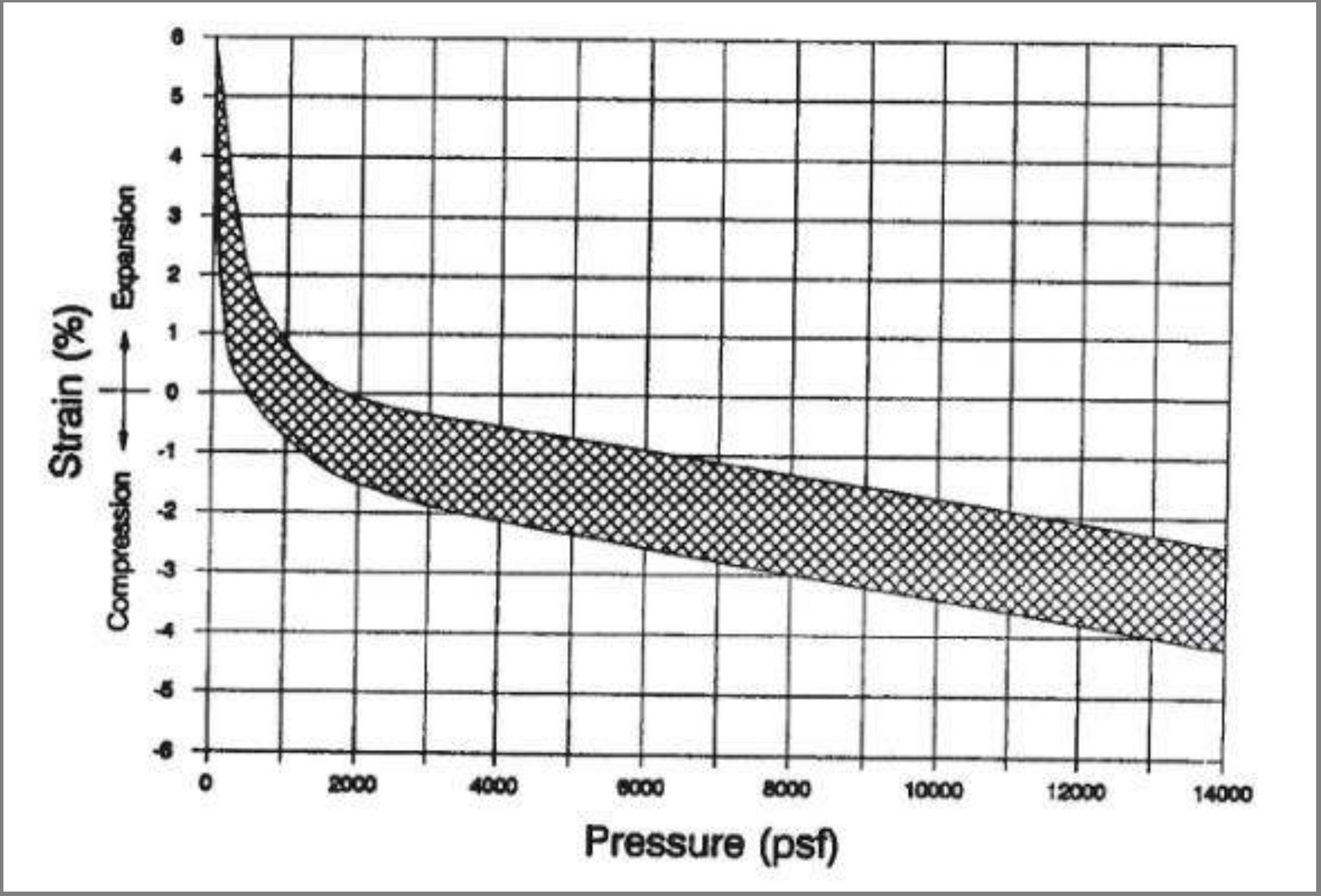



**FIG. 4. Results of Test to Measure Compression due to Wetting in Sandy Clay from Villa Trinidad**

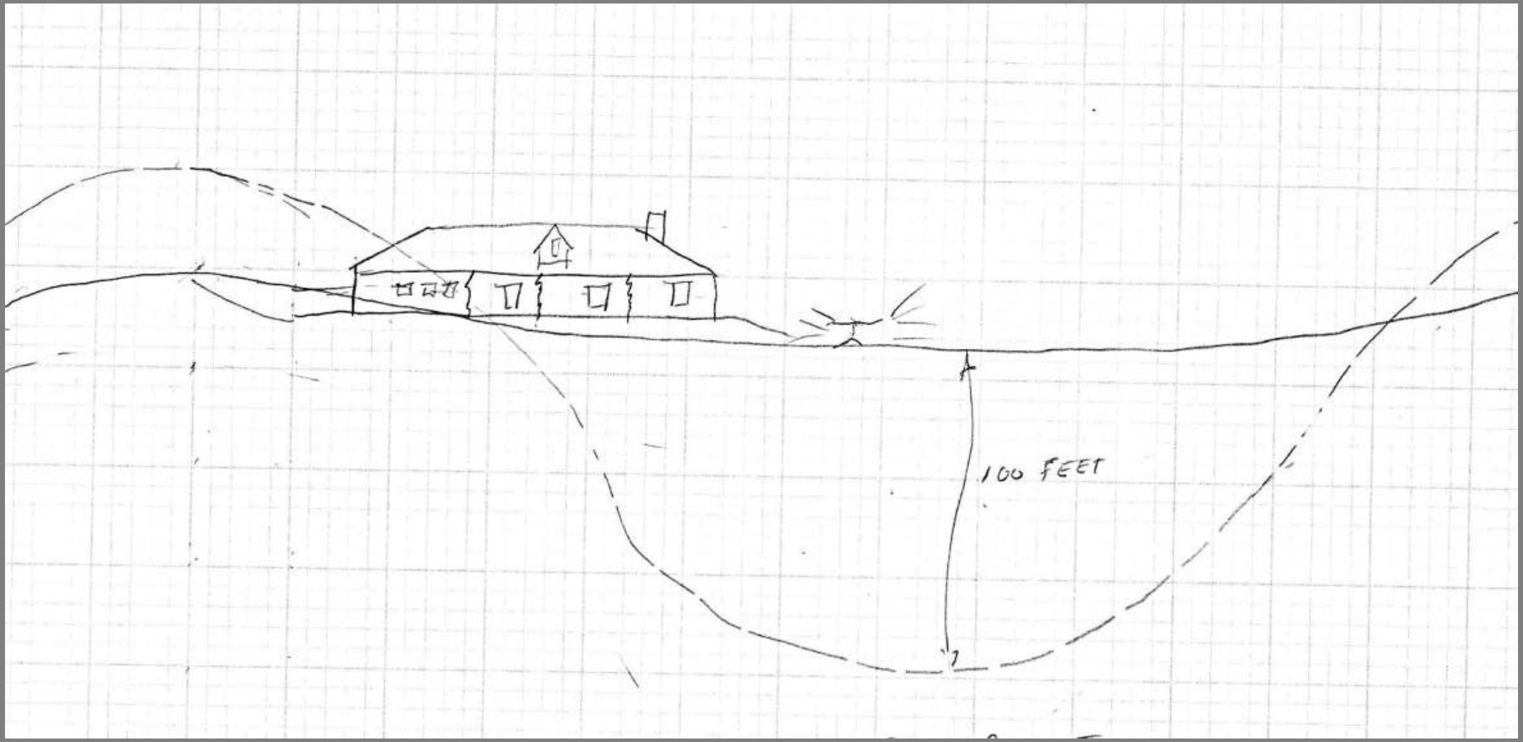
# INVESTIGATION
## Brandon, Duncan, and Gardner, 1990

- COMPRESSION UPON WETTING INCREASED WITH PRESSURE
- COMPRESSION DECREASED WITH INCREASED DENSITY AND PLACEMENT WATER CONTENT.



# INVESTIGATION
Brandon, Duncan, and Gardner, 1990

- BUILDING DAMAGE WAS GREATEST WHERE THE DEPTH OF FILL VARIED RAPIDLY ACROSS THE SITE



# TAKE-AWAY LESSON

## Doug Moorhouse, Woodward-Clyde Consultants

- “IF SOIL IS COMPACTED TO MINIMUM 90% MODIFIED PROCTOR NEAR OPTIMIUM, IT WILL COMPRESS ABOUT 1% TO 2% WHEN SATURATED”
- “MAYBE MORE” (Chuck Easton)

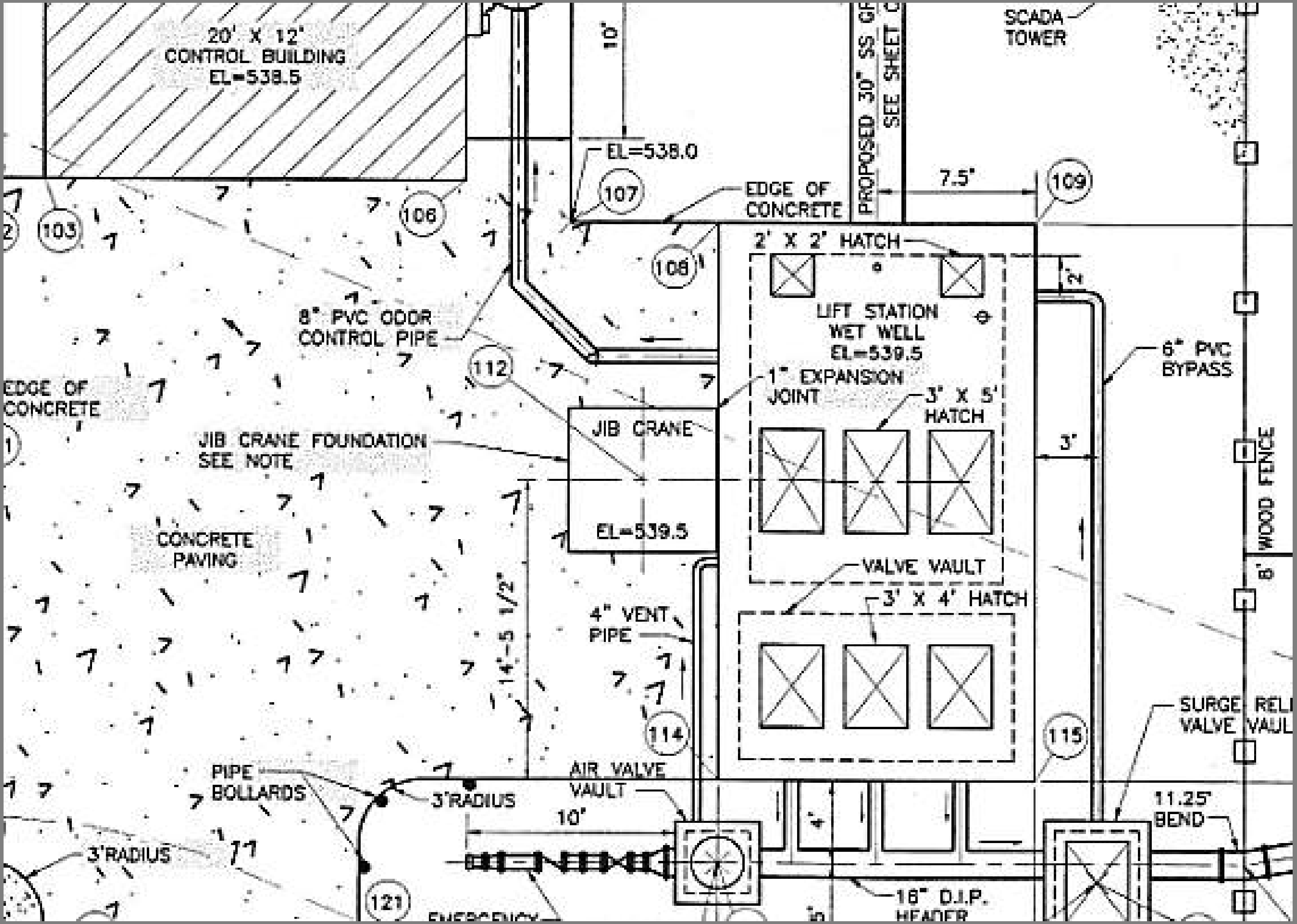
QUESTIONS?

# WHAT ABOUT OTHER SOILS?

- TEXAS EXPERIENCE
  - A.  SEWAGE LIFT STATION
  - B. DEEP BURIED SEWAGE PIPE

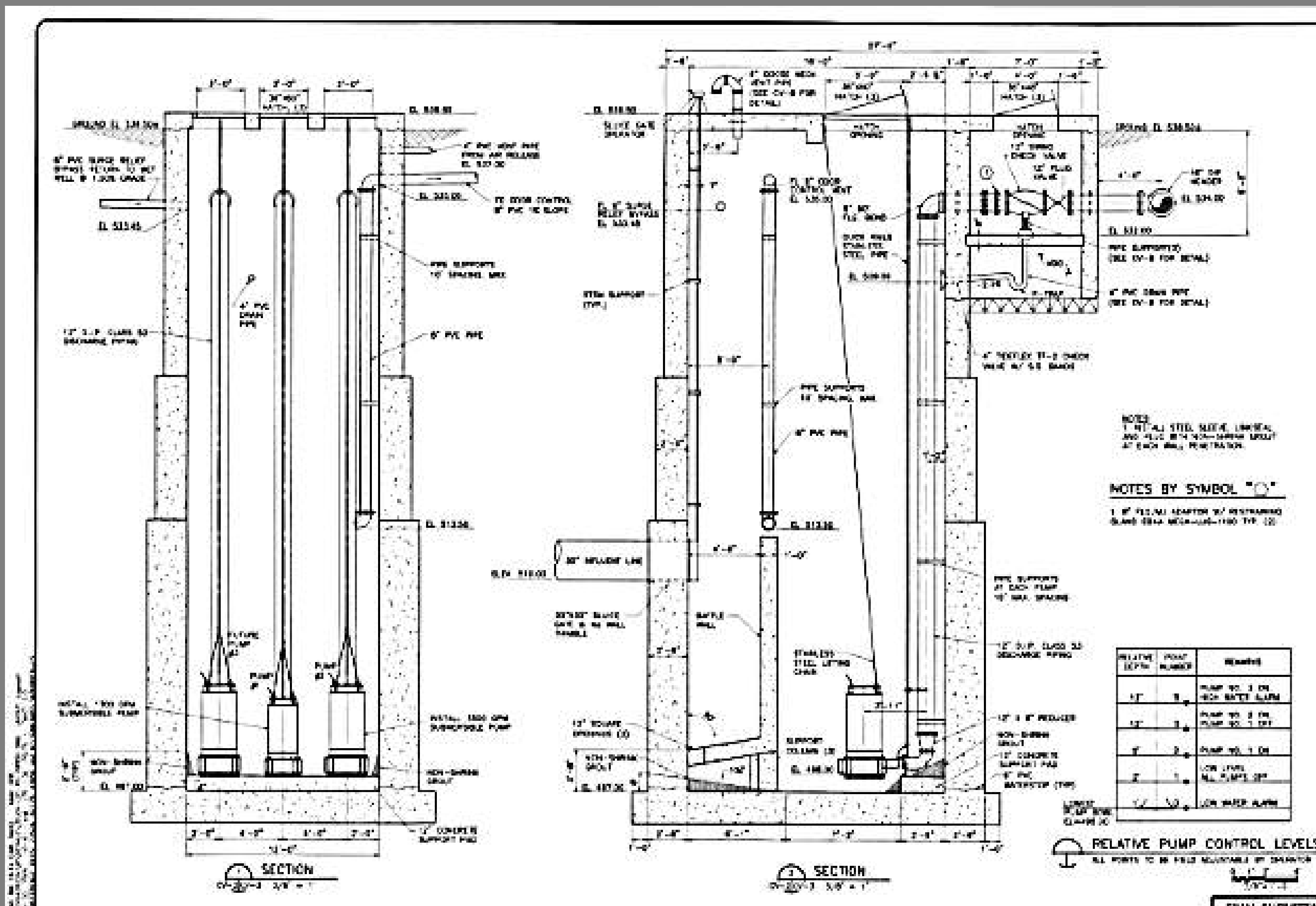
# SEWAGE LIFT STATION

- CONCRETE STRUCTURE ABOUT 19 BY 23 FEET IN PLAN,



# SEWAGE LIFT STATION

- EMBEDDED 43 FEET DEEP
- MAT FOUNDATION BEARING ON SHALE



# SEWAGE LIFT STATION

- EXCAVATED THROUGH ABOUT 29 FEET OF FAT CLAY AND INTO UNWEATHERED CLAY SHALE

# SEWAGE LIFT STATION

- BACKFILLED ABOUT HALFWAY WITH SELECT CLAYEY SAND
- THE RESTOF THE WAY WITH THE EXCAVATED FAT CLAY

# SEWAGE LIFT STATION

- COMPACTED WITH A VIBRATORY SHEEPSFOOT COMPACTOR

# COMPACTION TESTING

- ON DECEMBER 5, 2005, DENSITY TESTS WERE REPORTED AT 5, 7, AND 9 FEET ABOVE THE BOTTOM OF THE EXCAVATION
- ON DECEMBER 29, DENSITIES WERE REPORTED AT 12, 14, AND 16 FEET ABOVE THE BOTTOM OF THE EXCAVATION
- ON JANUARY 27, 3 TESTS TAKEN "15 FEET BELOW GRADE" WERE REPORTED
- I BELIEVE THESE TESTS WERE RUN ON SAMPLES OBTAINED WITH A DRILL RIG

# SEWAGE LIFT STATION

- A BLOCK FOOTING TO SUPPORT A JIB CRANE WAS CONSTRUCTED ON THE BACKFILL, ADJACENT TO THE LIFT STATION, ON AUGUST 14, 2006

# SEWAGE LIFT STATION

- BY SEPTEMBER 25, THE FOOTING HAD SETTLED ONE-HALF INCH

# SEWAGE LIFT STATION

BY JANUARY 10, IT HAD SETTLED 5-1/2 TO 9 INCHES, AND THE RATE OF SETTLEMENT APPEARED TO BE INCREASING

# SEWAGE LIFT STATION

- 9 INCHES OF SETTLEMENT IN A 43-FOOT FILL IS AN AVERAGE COMPRESSION OF 1.7 PERCENT
- THE OWNER ELECTED TO RETURN THE JIB CRANE FOR CREDIT

- Questions?

# DEEP BURIED WASTEWATER PIPE

- AN 8-FOOT DIAMETER INLET PIPE TO A 50-FOOT-DEEP STORAGE BASIN WAS INSTALLED BETWEEN TWO ROWS OF SHEET PILES

# DEEP BURIED SEWAGE PIPE

- THE PIPE WAS ENCASED IN CONCRETE; THEN THE TRENCH WAS BACKFILLED WITH HIGHLY-PLASTIC CLAY

# DEEP BURIED SEWAGE PIPE

- THE BACKFILL WAS COMPACTED BEGINNING WITH A WALK-BEHIND VIBRATORY SHEEPSFOOT ROLLER, LATER WITH A MEDIUM-SIZED RIDE-ON VIBRATORY SHEEPSFOOT ROLLER
- THE FILL WAS TESTED AT ABOUT 15-INCH INTERVALS WITH A NUCLEAR DENSITY METER

# LARGE PIPE IN A DEEP TRENCH

- LEAKAGE OF A CONSTRUCTION DEWATERING PIPE SATURATED THE BACKFILL
- THE FULL WIDTH OF THE BACKFILL BETWEEN THE SHEET PILES SETTLED

# LARGE PIPE IN A DEEP TRENCH

- THE GAP BETWEEN THE DRAINAGE LAYER AND THE SLAB WAS GENERALLY ABOUT 12 INCHES HIGH, BUT IN SOME LOCATIONS ABOUT 18 INCHES

# LARGE PIPE IN A DEEP TRENCH

- THE SETTLEMENT WAS ABOUT 2 TO 4 PERCENT OF THE FILL THICKNESS.

# TAKE-AWAY LESSONS
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- WE NEED TO USE OUR BEST QC PROCEDURES FOR THICK FILLS
- EVEN IF THE COMPACTION IS DONE IN STRICT COMPLIANCE WITH THE SPECIFICATIONS, IT MAY COMPRESS SIGNIFICANTLY WHEN SATURATED
- SATURATION MAY OCCUR DUE TO UNEXPECTED CAUSES
- FAT CLAY FILL MAY COMPRESS MORE THAN 2% WHEN SATURATED

# SUGGESTIONS

- READ THE REFERENCES
- TEST THE LOCAL FILL MATERIALS FOR COMPRESSION UPON SATURATION
- CONSIDER UNDERDRAINS BENEATH DEEP FILLS TO PREVENT FULL SATURATION
- UNDER MOST COMMON CONDITIONS, ASSUME SATURATION WILL OCCUR
- DESIGN FOUNDATIONS ACCORDINGLY

# QUESTIONS?  COMMENTS?

FREESE AND NICHOLS

# Some Lessons Learned Through 54 Years of Mistakes:

# HYDROCOMPRESSION SETTLEMENT OF DEEP EARTH FILLS

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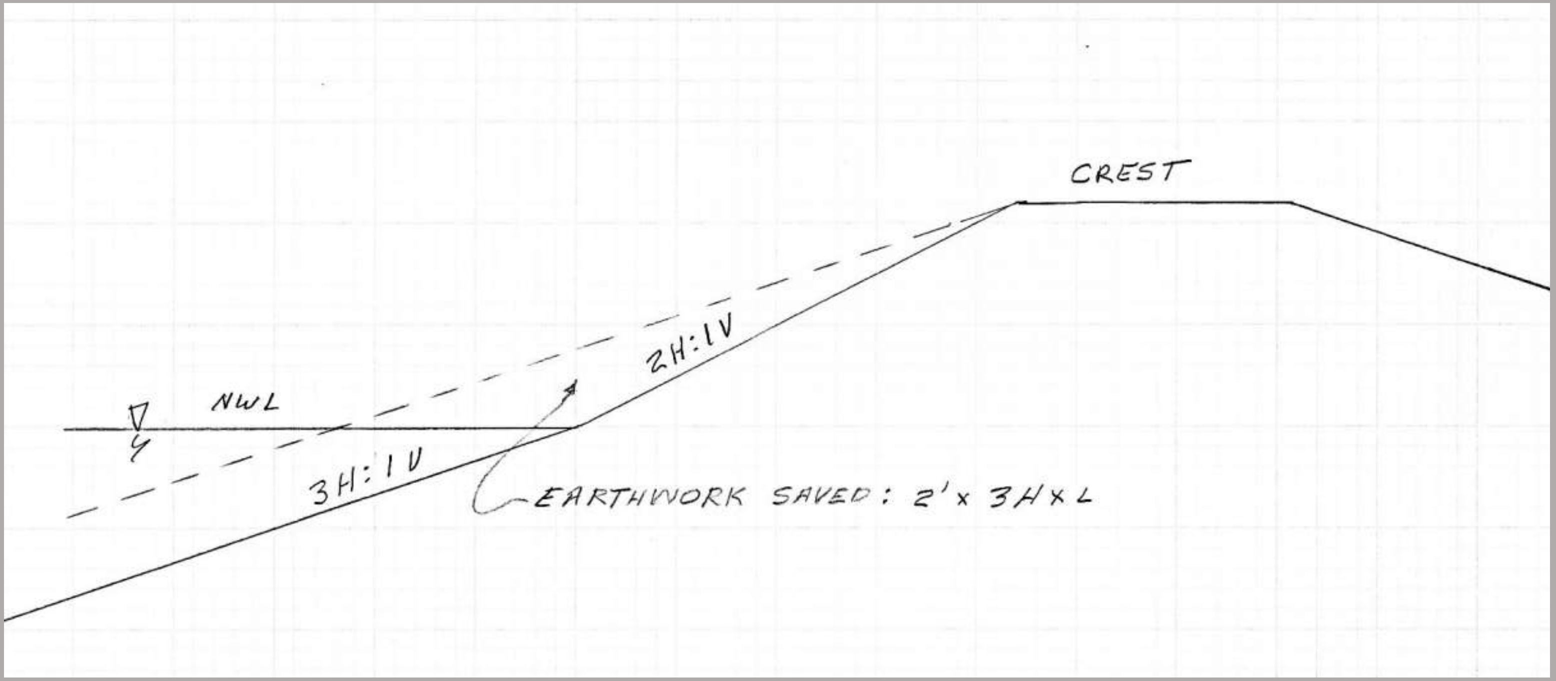
FREESE NICHOLS

# Some Lessons Learned Through 54 Years of Mistakes:

# HOLEY ROCKS CAN ROLL!

# HOLEY ROCKS CAN ROLL!




A 6O-FOOT-HIGH EARTH DAM WAS BUILT WITH A 3:1 UPSTREAM SLOPE BREAKING TO 2:1 AT THE NORMAL WATER LINE.
THIS SAVED CONSIDERABLE EARTHWORK VOLUME.

# HOLEY ROCKS CAN ROLL!

A HURRICANE PASSED BY ON THE EAST.
50 MPH WINDS FROM THE NORTH CAUSED 8-F00T WAVES.

# HOLEY ROCKS CAN ROLL!

RIPRAP AND BEDDING WERE REMOVED IN PATCHES.

# HOLEY ROCKS CAN ROLL!

THE WAVES TOOK AWAY THE RIPRAP AT THE WATERLINE,
THEN ERODED THE BEDDING, AND THE ROCKS ROLLED DOWN.

# HOLEY ROCKS CAN ROLL!

HERE'S ANOTHER EXAMPLE..

# HOLEY ROCKS CAN ROLL!

THE CLAY EMBANKMENT WAS ONLY SLIGHTLY DISTURBED

# HOLEY ROCKS CAN ROLL!

THE LIMESTONE RIPRAP HAD BECOME POCKED WITH
HOLES BY SELECTIVE DISSOLUTION.
THIS SIGNIFICANTLY REDUCED THE WEIGHT OF THE ROCKS.

# LESSONS

- DO RESEARCH BEFORE DEPARTING FROM STANDARD PRACTICE
- IF YOU STEEPEN THE SLOPE, INCREASE THE ROCK SIZE
- CHECK THE HISTORICAL PERFORMANCE OF A ROCK SOURCE
- CONSIDER A PETROGRAPHIC ANALYSIS
- IF POSSIBLE, USE CLAY EMBANKMENT IN AREAS THAT MAY BECOME EXPOSED

# Some Lessons Learned Through 54 Years of Mistakes:

# HOLEY ROCKS CAN ROLL!

QUESTIONS?

COMMENTS?

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# Some Lessons Learned Through 54 Years of Mistakes:
# LEONARD PUMP STATION ROCK ANCHORS

Photo by Chuck Easton

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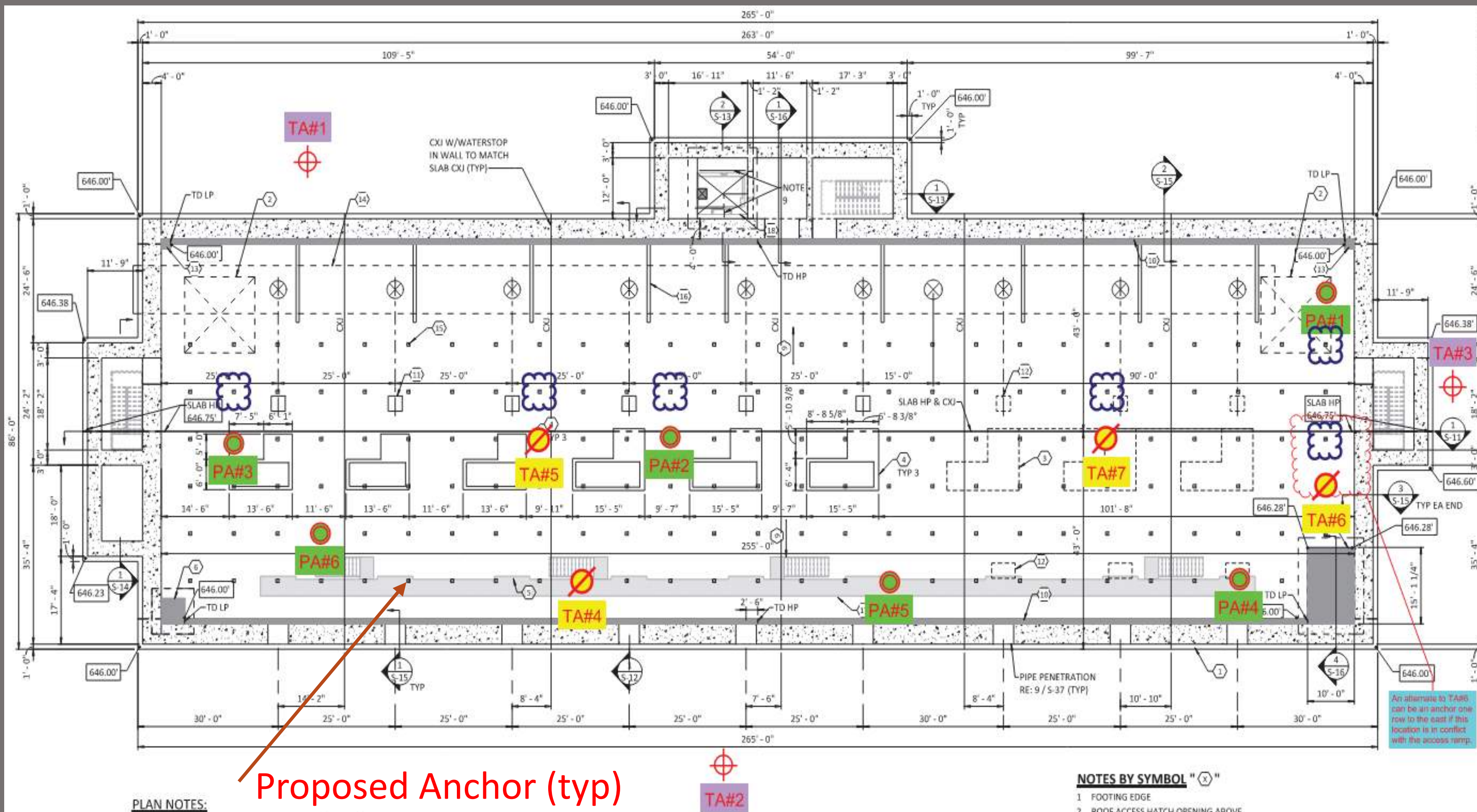
# Basement Floor Plan




Plan from North Texas Municipal Water District
Leonard Water Service Treatment Plant, Freese and Nichols, Inc.
Test anchor locations added by Garney

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# Passive Anchor Design

Length = 30 feet to engage sufficient weight of rock.

Design Load (DL) = 210 kips.

Tendon = 1-3/4-inch diameter Grade 150 threadbars, epoxy coated.

Allowable grout-to-rock bond stress = 40 psi (implies ultimate bond strength of 80 psi).

Borehole diameter = 5 inches.

# Pre-construction Testing

Three 10-foot-long Performance Test Anchors fully grouted in 10-foot boreholes

Allowable grout-to-rock bond stress = 40 psi

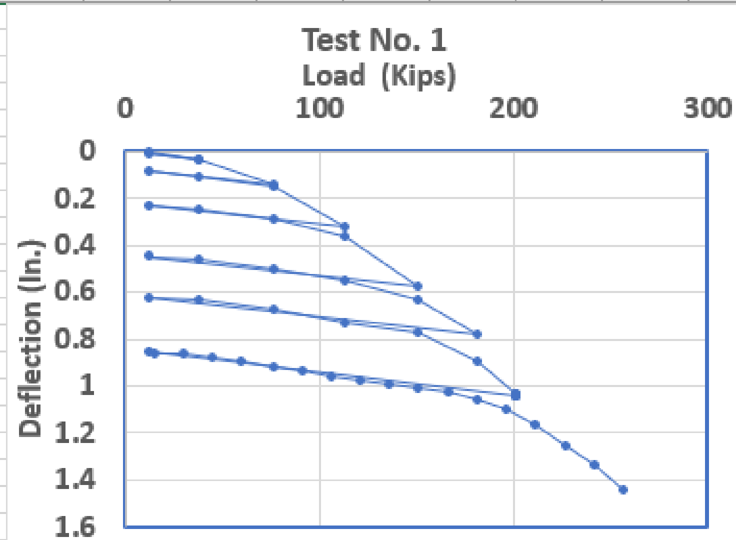
Borehole diameter = 6 inches

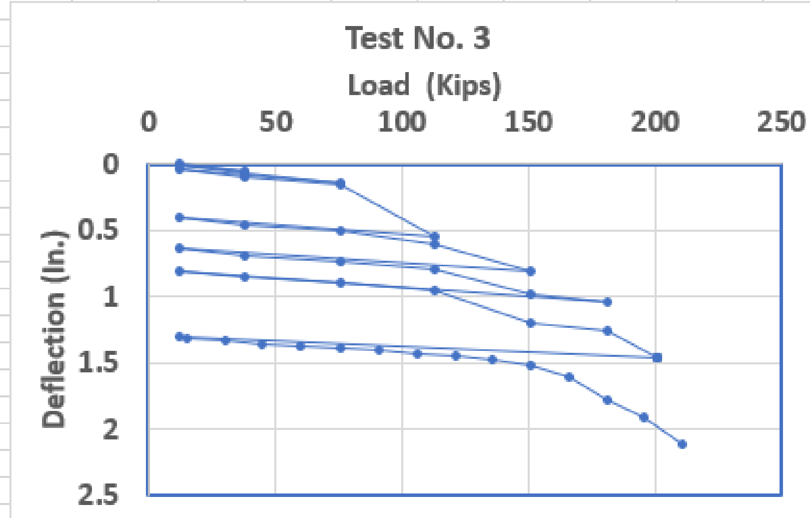
Design Load (DL) = 151 kips.

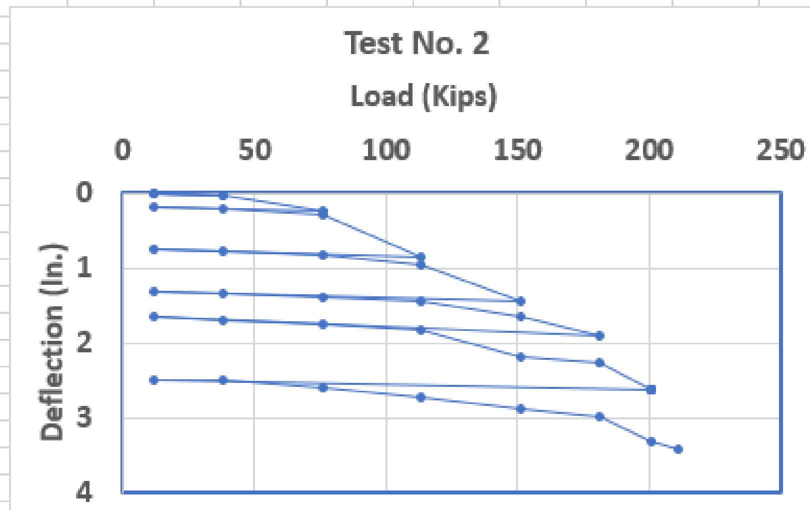
Maximum test load = 200 kips

Six 30-foot-long proof anchors were planned but not tested

# Pre-construction Testing Results




T:\4.0 CONSTRUCTION\4.10 Correspondence and Memos\4.12 Memos\GEO\HSPS Preconstruction Test Anchors (003) 12/9/2019

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# Boreholes Were Augered


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# Was the Drilling Method the Problem?

A 6-inch ordinary auger was used.

Each 10-foot hole required more than 2 hours to drill.

The cuttings were very fine.

We believe that the cuttings fell back around the auger and bogged down the auger.  The holes were lined with dust.

Similar anchors for an adjacent structure were drilled with a hollow auger and flushed with compressed air.  30-foot holes were drilled in 20 minutes each.

Those anchors showed excellent test results.

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# Second Anchor Test Program

The borings were drilled with a 6-inch drag bit flushing with air.

The performance test anchors had 10-foot bonded zones and 20-foot unbonded zones.

# Boreholes Were Drilled With Rotary and Air


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# A Drag Bit Was Used

# Performance Tests Were Run


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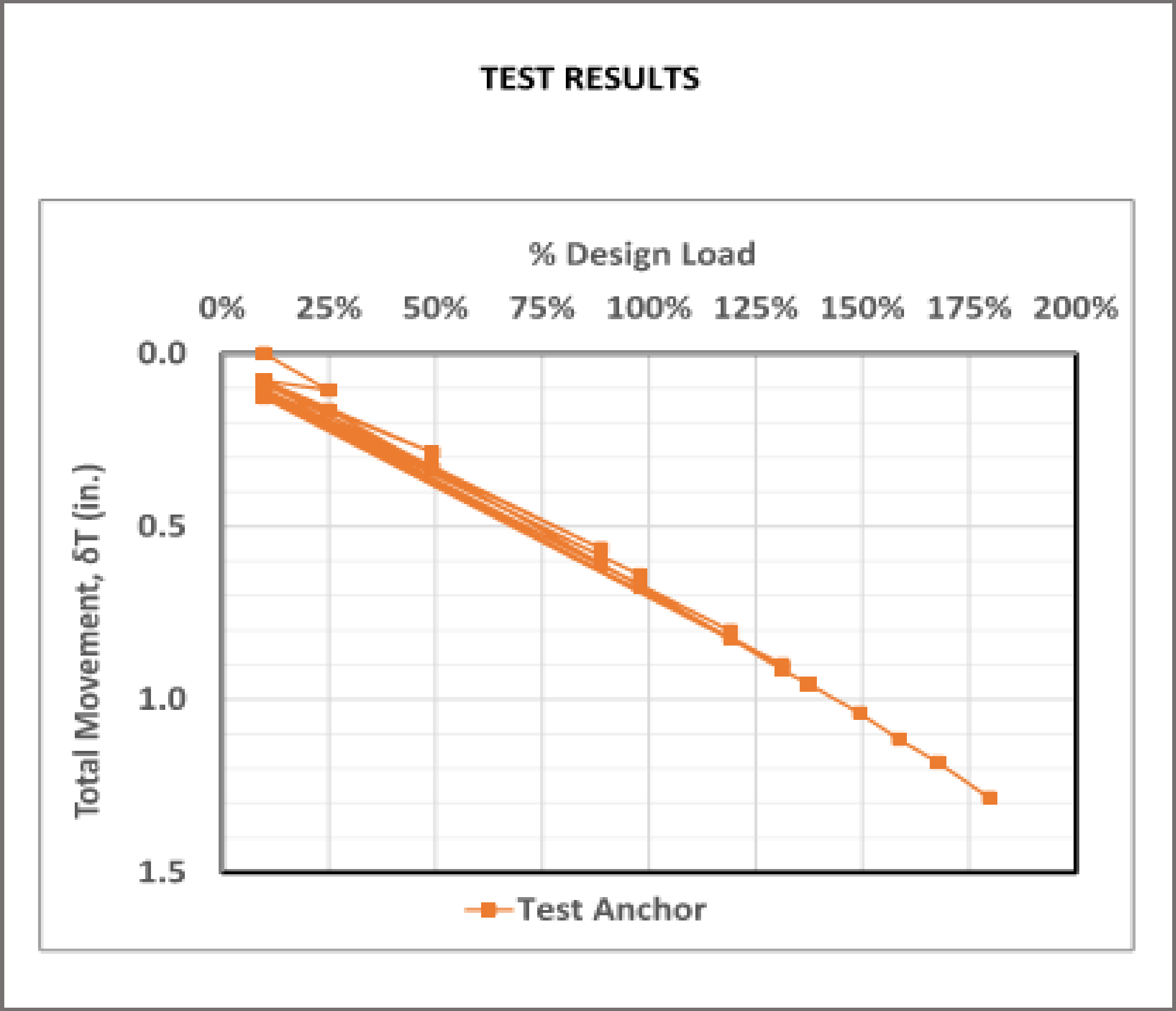
# Second Performance Anchor Testing Results




TA#4. Design Load = 151 kips. Max bond stress = 130 psi

# THE LESSON

The drilling method matters.

The walls of the holes must be clean.

# A SAFETY LESSON

# A Coupling and Rod Extension Were Added to Support the Dials

Photo by Chuck Easton

# The Coupling Failed

Photo by Chuck Easton

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# THE LESSON

Watch the work.

Don't stand too close.

# ANOTHER LESSON

# The Pump is Usually Connected to the Jack With Quick-Connect Couplings


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# THE LESSON

When there is a problem, don't take anything for granted; check everything.

Before you use the data, be sure it is right.

# Some Lessons Learned Through 54 Years of Mistakes
## Collapse of Tempering Cooler

- A STRUCTURAL ENGINEER CALLED
- THE CEO OF A PACKING COMPANY HAD CALLED HIM
- A PART OF THEIR PLANT HAD COLLAPSED
- "PLEASE COME AND BRING SOMEONE FROM WCC WITH YOU"

- WE WENT

- MANAGERS AND ENGINEERS LED US AROUND THE BUILDING
- HERE IS WHAT WE SAW:

Chuck Easton, P.E.
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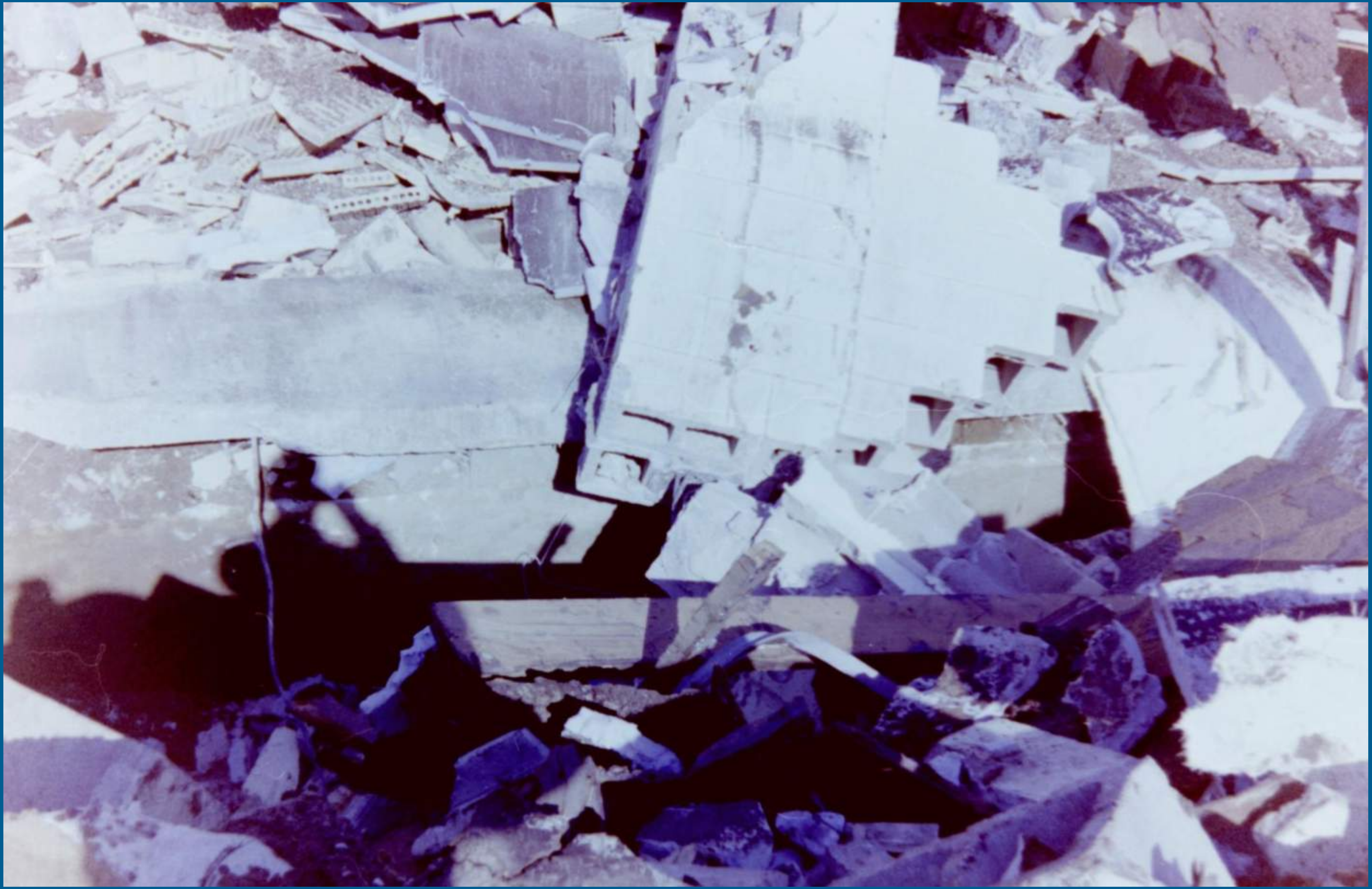
Fort Worth, Texas

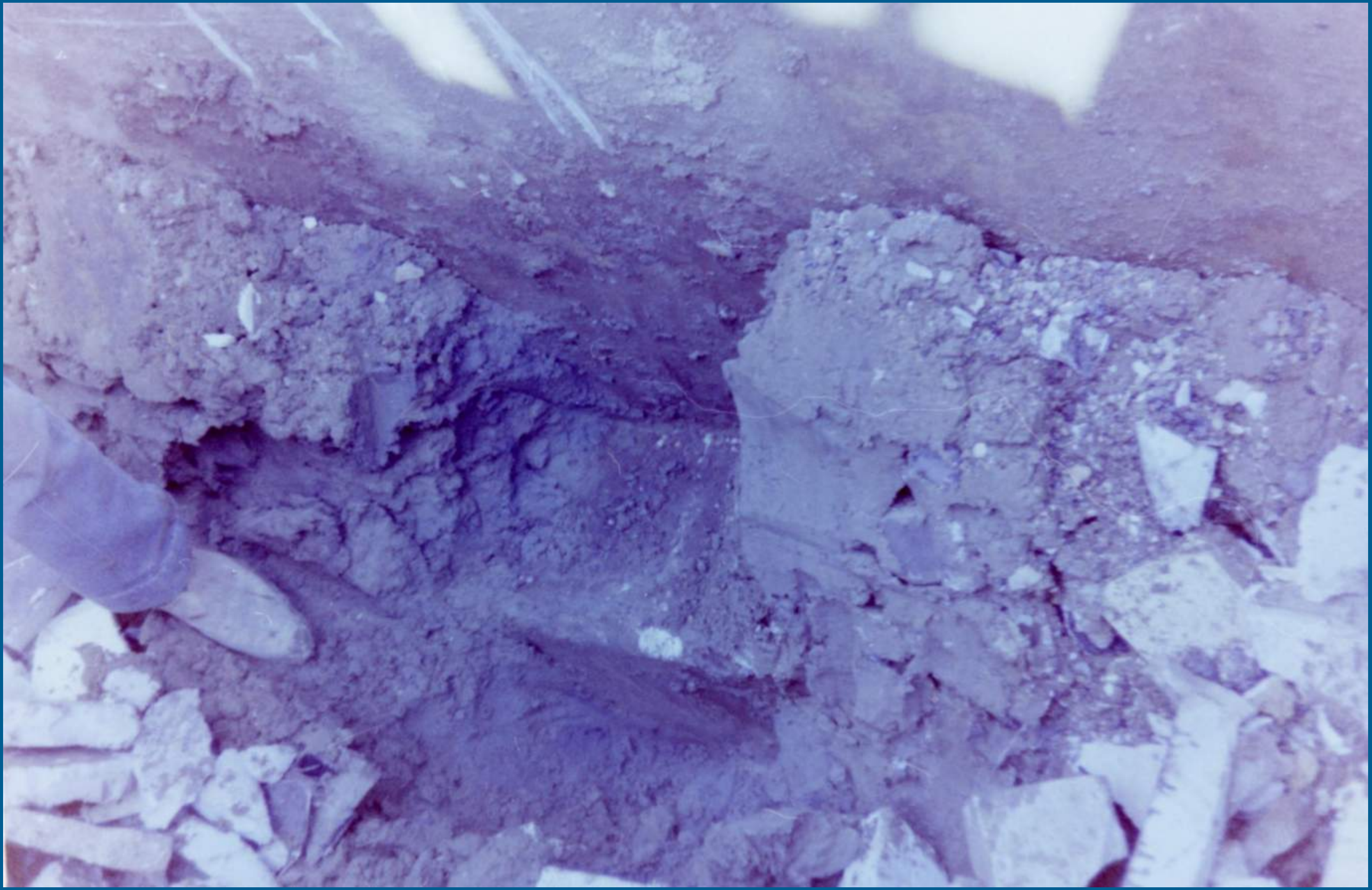
# Rubble of Tempering Cooler

# Unreinforced Masonry Wall



# Wall and Floor Slab Collapsed Into Excavation

# Wall Footing and Foundation Wall



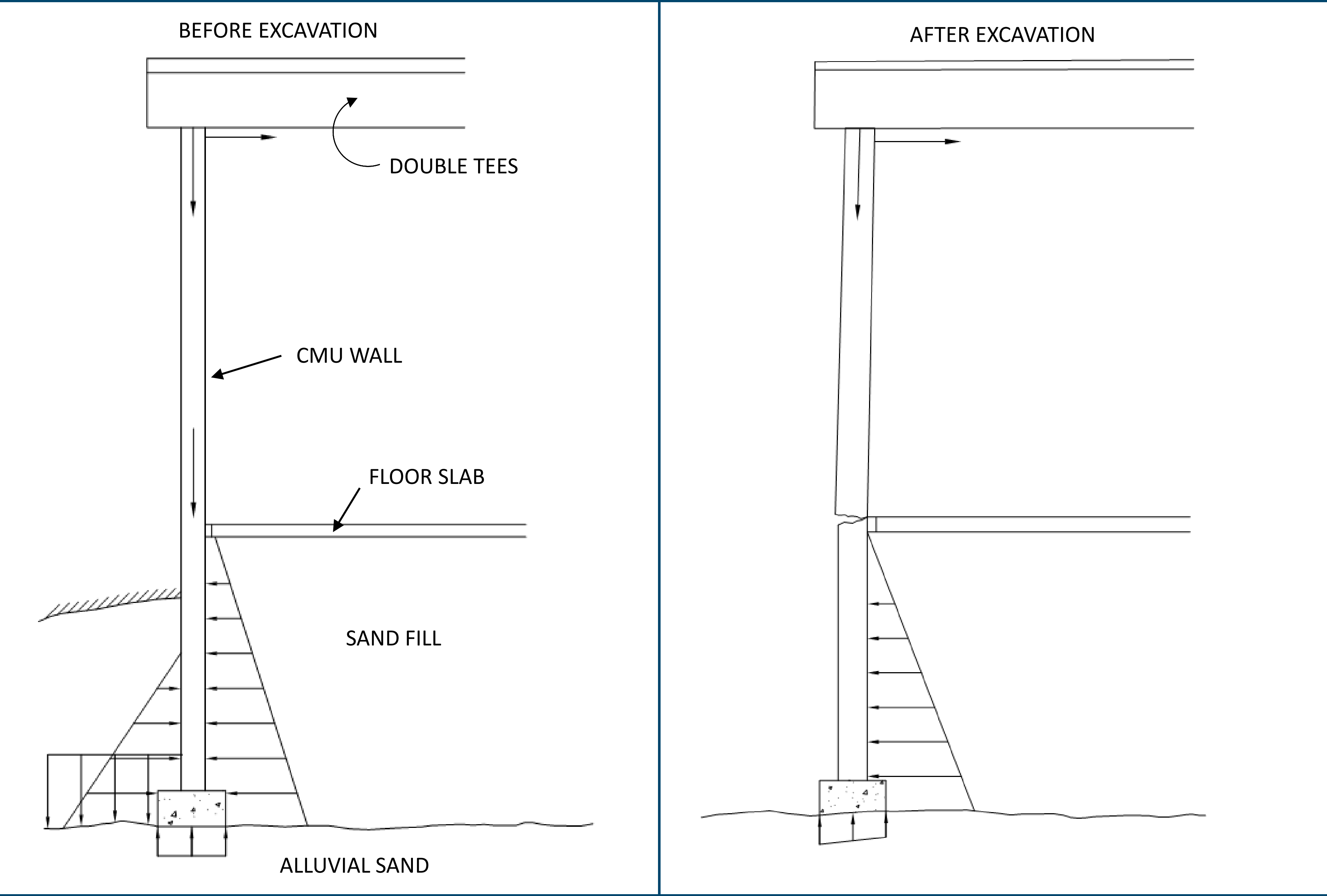
# Room North of Cooler That Did Not Collapse

# Collapse Stopped at Precast Column

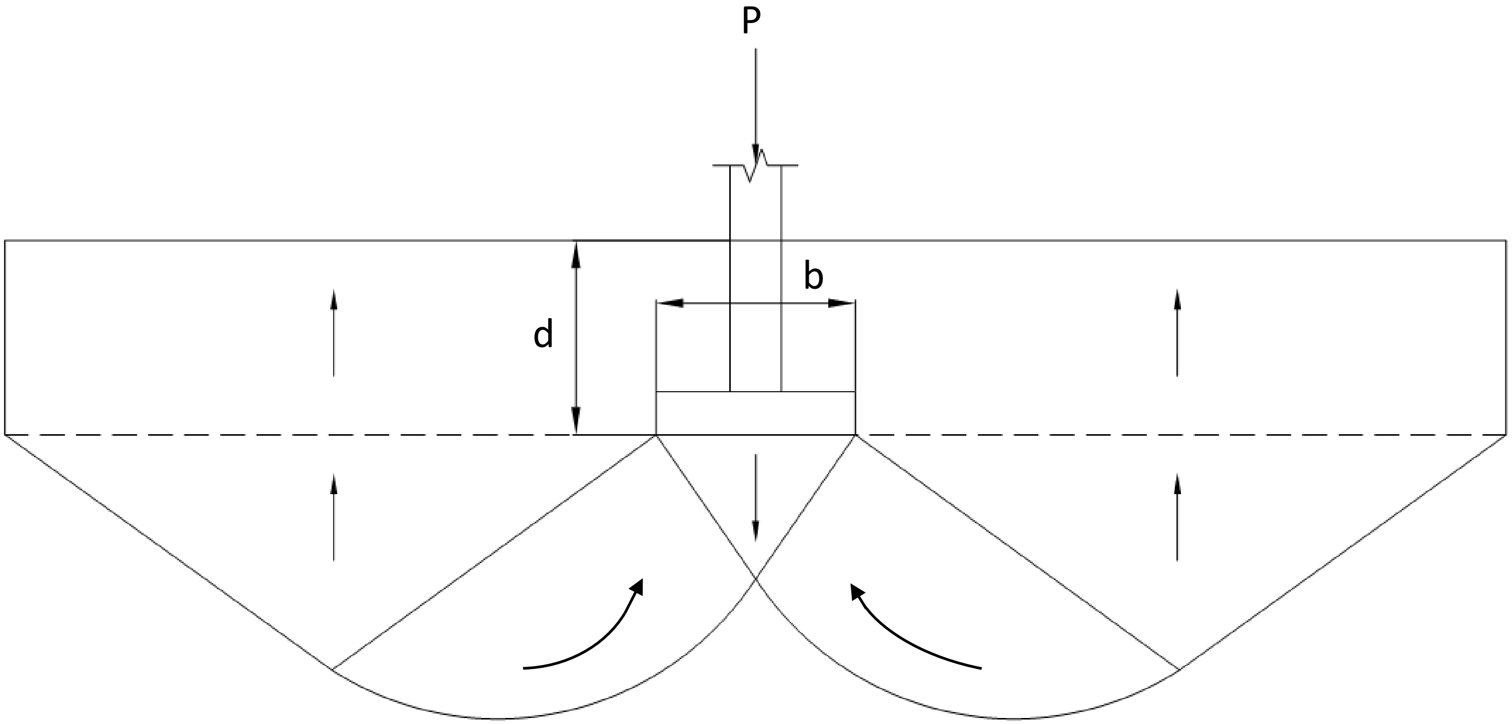
# Here’s the Good News!

- THE WORKFORCE WAS ON STRIKE
- THE PLANT WAS SHUT DOWN
- COOLER EMPTY
- REFRIGERATION REPAIR FINISHED
- CLEANING FINISHED
- COLLAPSE OCCURRED AT MIDNIGHT

# Section of the Wall That Failed



# FOUNDATION BEARING CAPACITY




**GENERAL BEARING CAPACITY EQUATION**

$$q_u = \frac{\gamma b}{2} N\gamma + CNc + \gamma d N_q$$

**$q_u$ = ULTIMATE BEARING PRESSURE, PSF**
**γ = SOIL UNIT WEIGHT, PCF**
**b & d IN FEET**

**C = SOIL COHESION, PSF**
**$N_\gamma$, $N_C$, $N_q$ FACTORS DEPEND ON SOIL FRICTION ANGLE, ϕ**

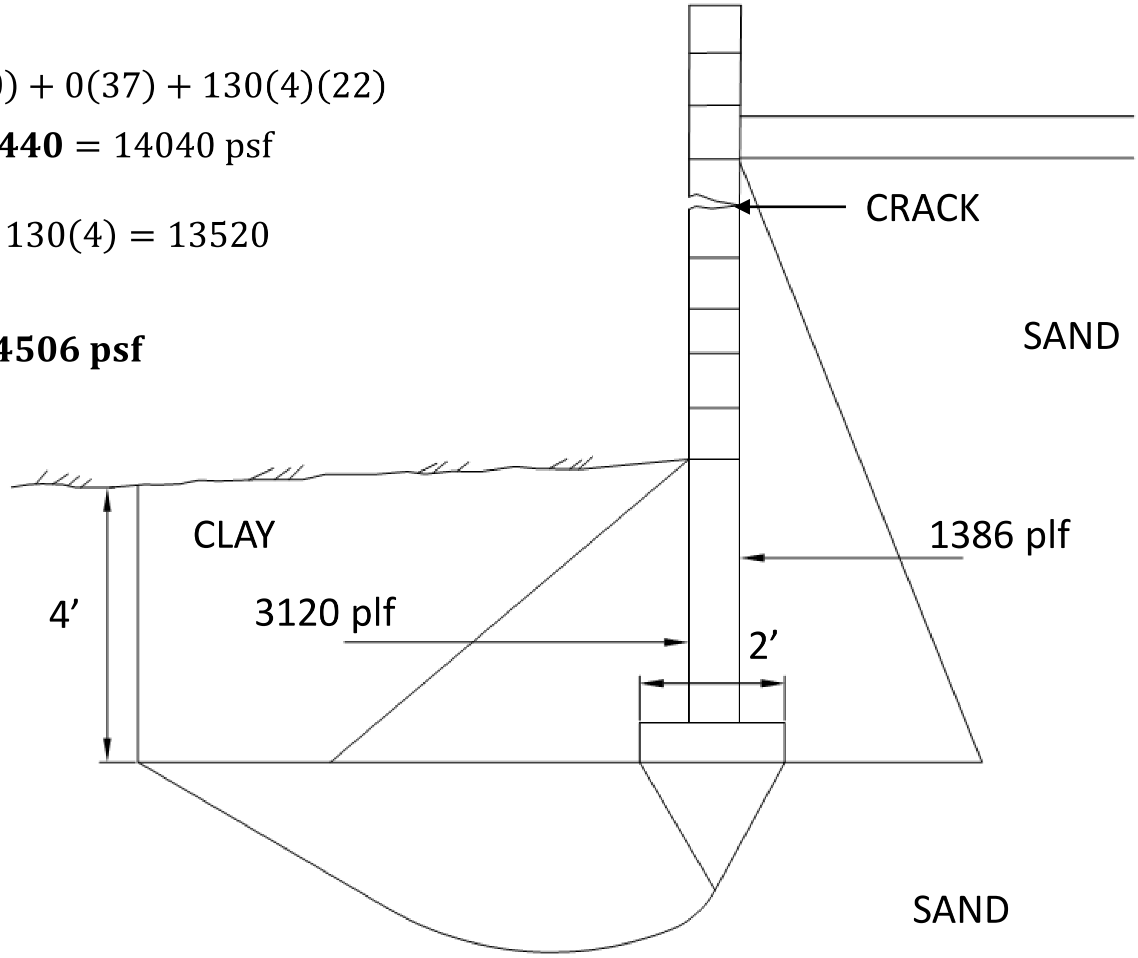
# BEARING CAPACITY BEFORE EXCAVATION

ASSUME $\phi = 30^{\circ}$, $C = 0$, $\gamma = 130$ pcf

$$q_u = \frac{130(2)}{2}(20) + 0(37) + 130(4)(22)$$
$$= 2600 + \mathbf{11440} = 14040 \text{ psf}$$

$$q_{net} = 14040 - 130(4) = 13520$$

$$q_{all} = \frac{13520}{3} = \mathbf{4506\ psf}$$

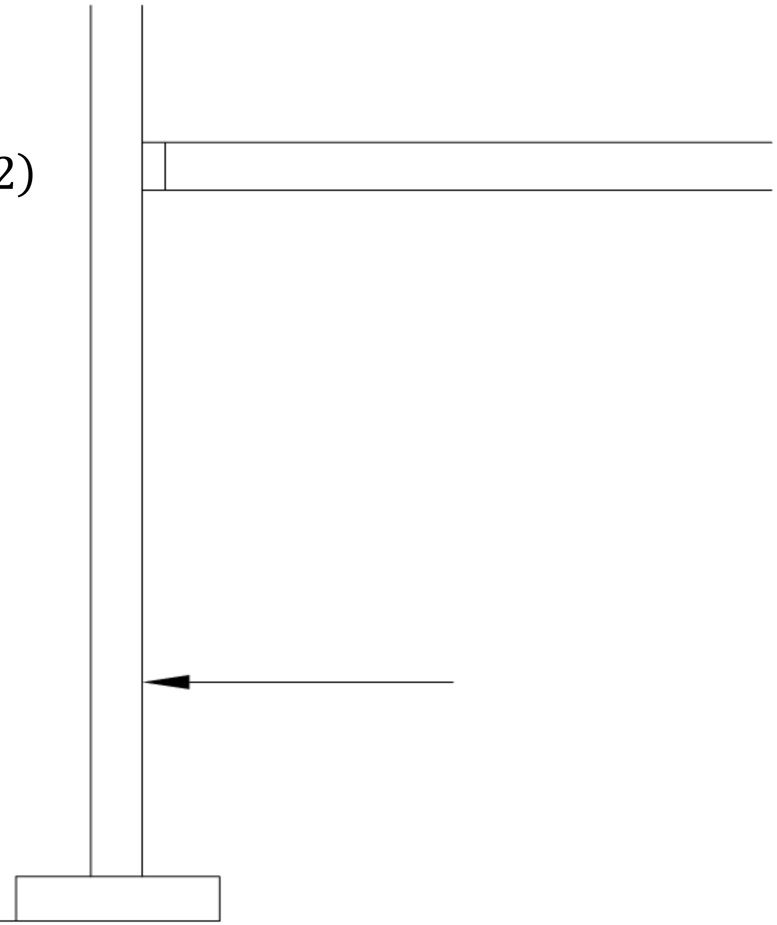


# BEARING CAPACITY AFTER EXCAVATION

$$q_u = \frac{130(2)}{2}(20) + 0(37) + 130(0)(22)$$
$$= \mathbf{2600\ psf}$$

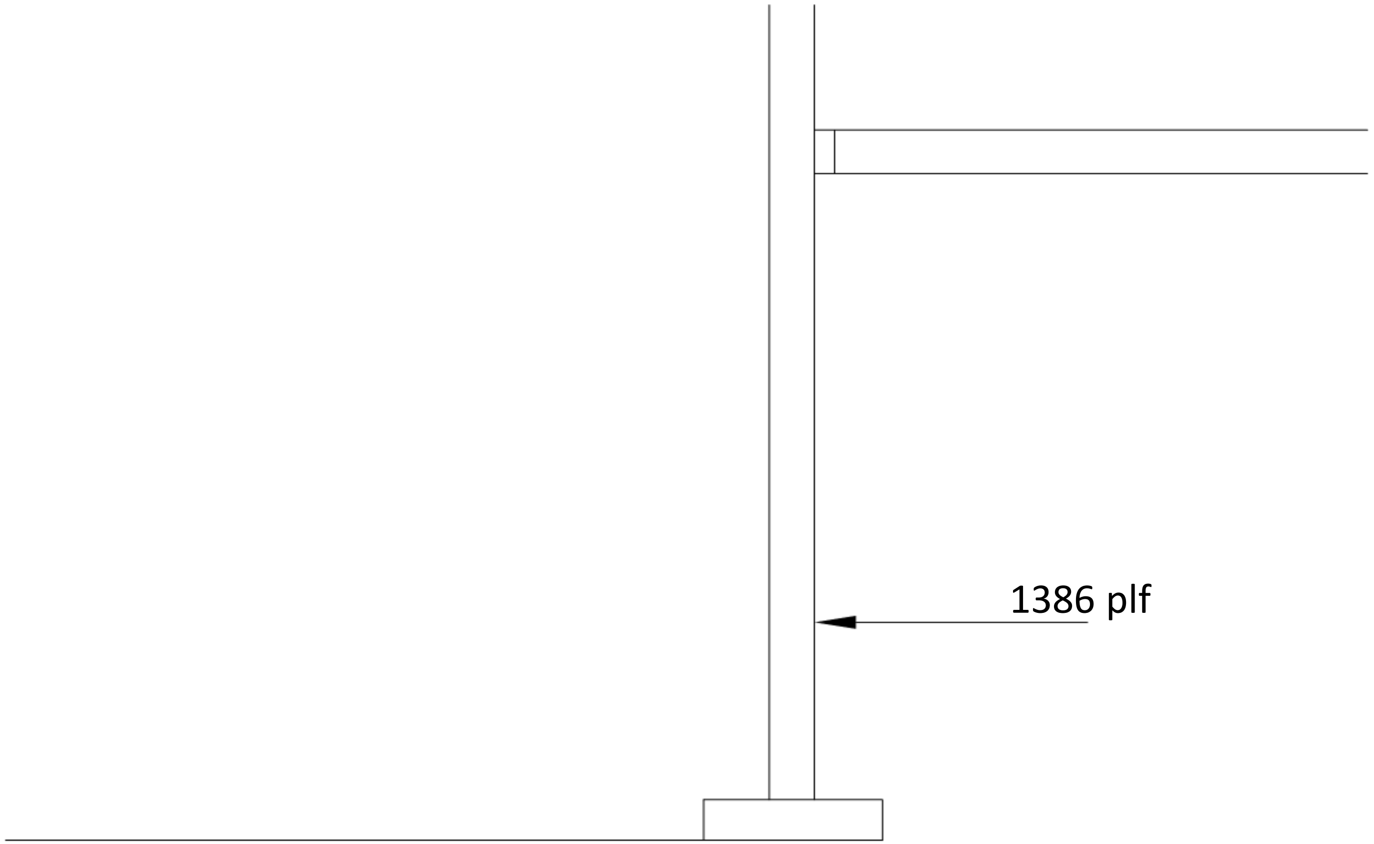
$q_{all}$ = 2600/3 = ***866 psf***

Sliding of the footing and flexural failure of the wall were also marginal.



SAND

# If the wall had not failed, the footing might have slid out



# MISTAKES

- The Contractor did not realize that exposing the foundation would reduce the bearing capacity and increase the bending stress in the wall

- Neither the plans nor the geotechnical report warned that excavation could result in failure.

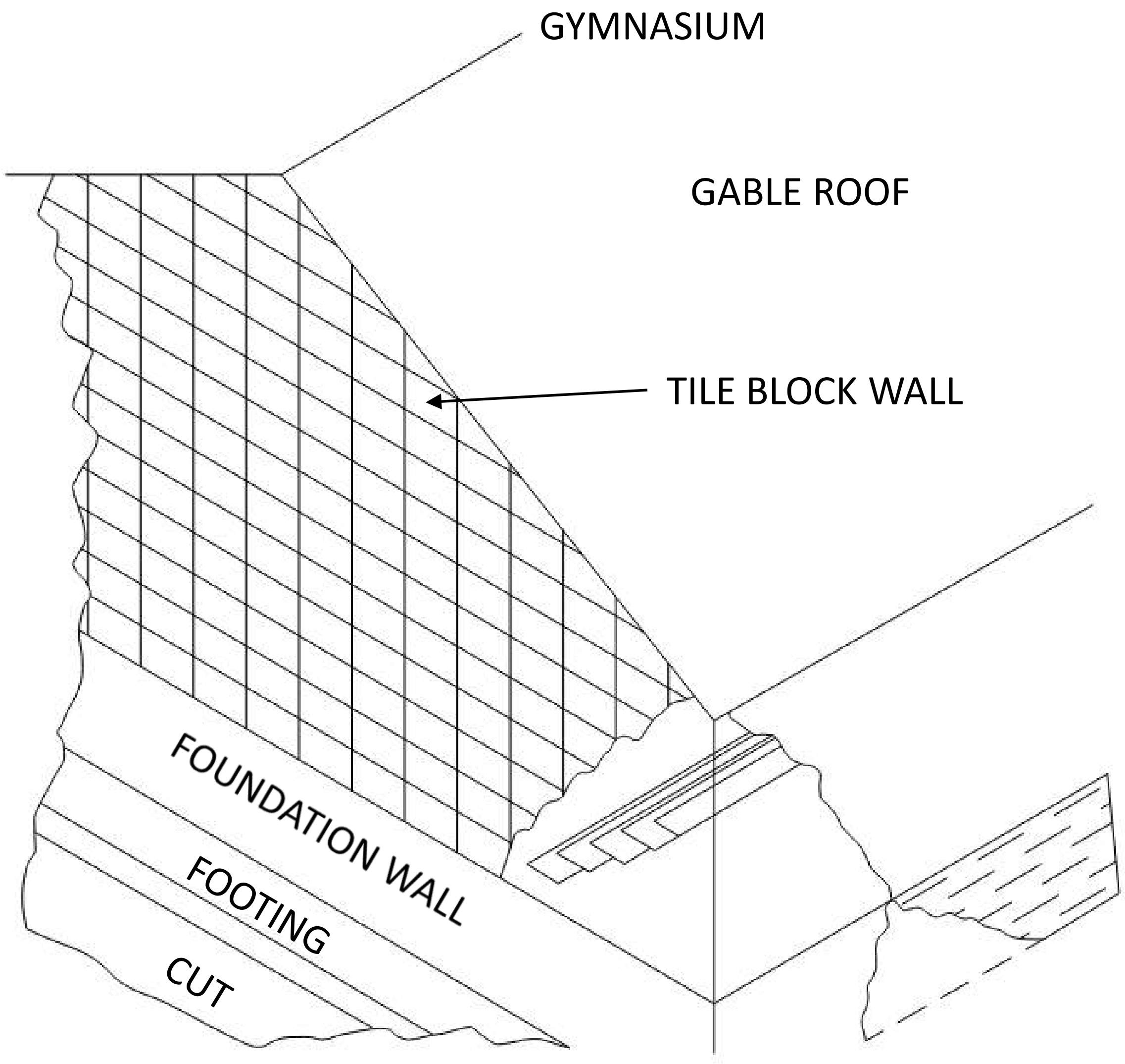
- Who bears the responsibility?

# HOW COULD THIS HAVE BEEN PREVENTED?

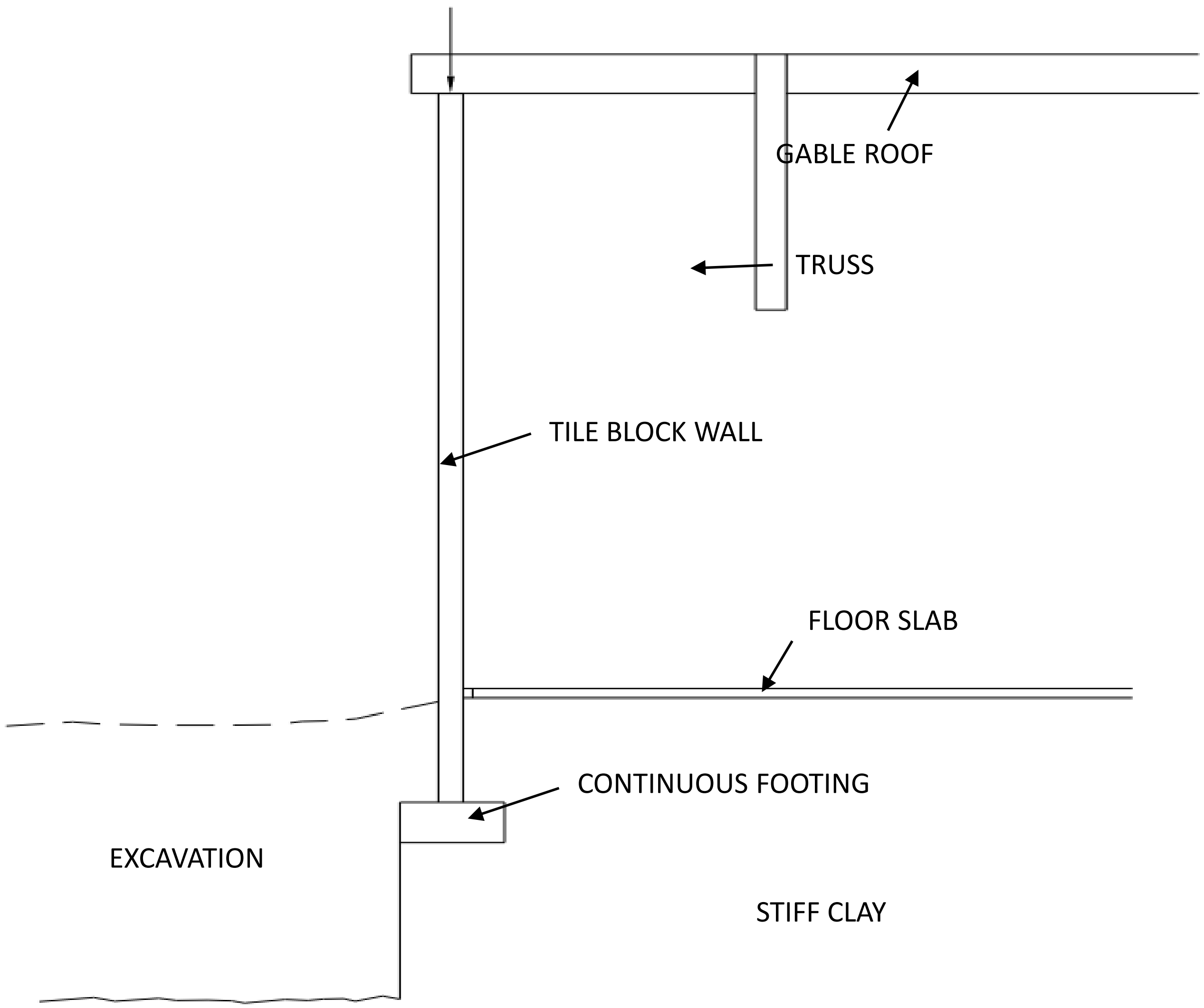
- Excavate and replace the soil in short segments
- Tie the wall to the opposite wall
- Shore the roof structure
- The footing might have failed anyway

# CHANGES TO ORIGINAL CONSTRUCTION TO FACILITATE EXPANSION

- Extend the site preparation
- Reinforce the wall and pilasters
- Size the footing to support another roof


GYMNASIUM
GABLE ROOF
TILE BLOCK WALL
FOUNDATION WALL
FOOTING
CUT

# SECTION THROUGH END WALL



IF WE EXCAVATE ALONGSIDE AND BELOW THE FOOTING:

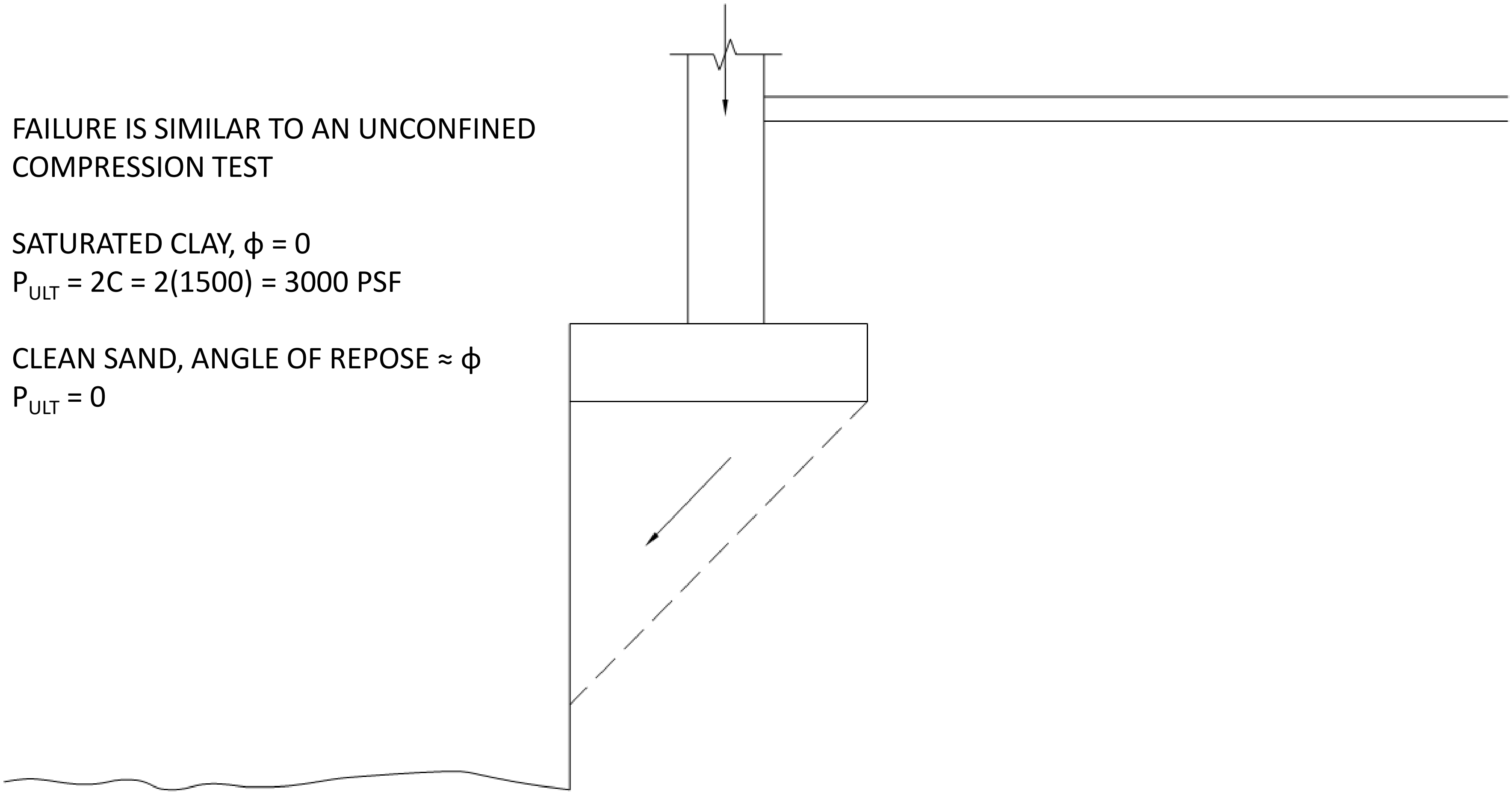
FAILURE IS SIMILAR TO AN UNCONFINED COMPRESSION TEST

SATURATED CLAY, $\phi = 0$

$P_{ULT} = 2C = 2(1500) = 3000$ PSF

CLEAN SAND, ANGLE OF REPOSE $\approx \phi$

$P_{ULT} = 0$



# THE MISTAKE

- Excavating below and beside a footing without professional guidance

# LESSON LEARNED

- Excavating safely below a footing requires analysis using knowledge of the bearing pressure and the soil strength parameters.

# FOR DISCUSSION

- If you walk onto the site and see an excavation alongside a footing, how can you determine whether it is dangerous?
- If your investigation indicates that it is dangerous, what should you do?
- If you can’t determine whether it is dangerous, what should you do?
- What should we put on the plans or in the specs to avoid this situation?

# Some Lessons Learned Through 54 Years of Mistakes

## Deterioration of a Deep Cut In Loess

From “Plattsmouth, Nebraska: A Forty Year Coal Line Project” by Gary Seymour, The BN Expediter, July 2021. Photo by David P. Oroszi


Chuck Easton, P.E.
Freese and Nichols, Inc.
Fort Worth, Texas

# Some Lessons Learned Through 54 Years of Mistakes

## Deterioration of a Deep Cut In Loess

# THE CUT SHORTLY AFTER CONSTRUCTION

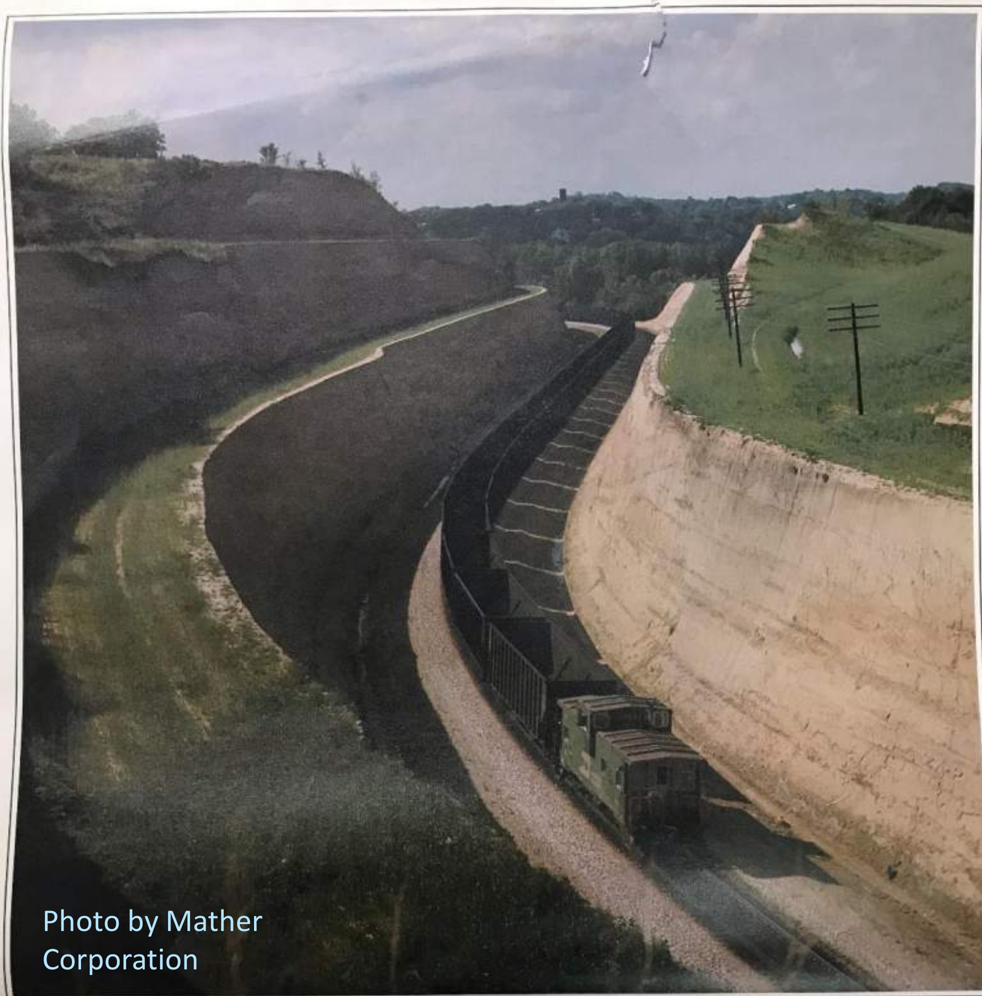


Photo by Mather Corporation

A Burlington Northern unit coal train of approximately 100 cars passes through a cut near Plattsmouth, Nebraska on its return to a western low-sulfur coal mine from a power generating plant. Photo by Mather Corporation.

BURLINGTON NORTHERN

**DECEMBER 1978**

BURLINGTON NORTHERN

# THE CUT A FEW YEARS AFTER CONSTRUCTION

From “Plattsmouth, Nebraska: A Forty Year Coal Line Project” by Gary Seymour, The BN Expediter, July 2021.
Photo by David P. Oroszi

Note the sloughing and accumulation along the lower outside slope

# THE CAUSE

Sloughing was worst in the lower part of the south slope.

Sampling and testing showed that the soil in the lower part was saturated because infiltrating water became perched on the glacial till.

In winter, freezing penetrated about 2 feet into the face and created thin ice lenses parallel to the slope.

In spring, the ice thawed, and the soil loosened by freezing fell down the slope.

The condition worsened each year.

The upper parts were not saturated, and freezing did not create ice lenses.

The north slope was exposed to the sun, and the surface soil was dry.

# THE MISTAKE

A practice that worked well in western Nebraska did not work well in eastern Nebraska .

In western Nebraska, the annual rainfall is low, and the loess is commonly underlain by sand, so a water table did not form within the depth of the canal excavation.

In eastern Nebraska, the annual rainfall is greater, and the loess is commonly underlain by relatively impermeable glacial till.  Infiltrating water perched on the till and saturated loess was exposed to freezing.

Saturated loess is susceptible to damaging frost action.

# Some Lessons Learned Through 54 Years of Mistakes

## Deterioration of a Deep Cut In Loess

From "Plattsmouth, Nebraska: A Forty Year Coal Line Project" by Gary Seymour, The BN Expediter, July 2021.  Photo by David P. Oroszi

QUESTIONS?
COMMENTS?

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# Some Lessons Learned Through 54 Years of Mistakes:

# THE CASE OF THE LEAKING DAM

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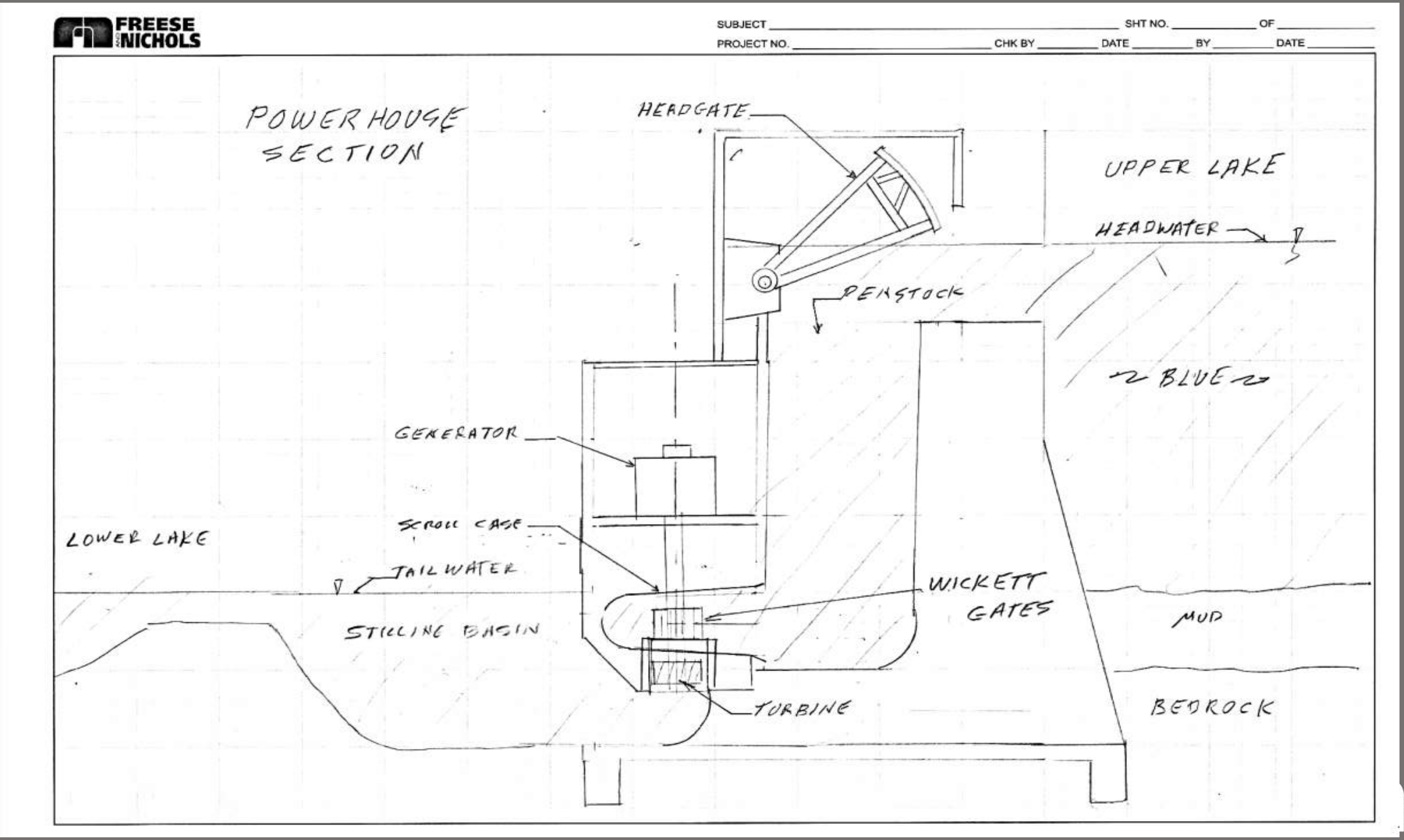



FREESE NICHOLS

# HYDROPOWER PLANT TERMS

- HEADWATER
- HEADRACE
- INTAKE
- HEADGATE
- PENSTOCK
- SCROLLCASE
- WICKETT GATES
- DRAFT TUBE
- TURBINE
- GENERATOR
- TAILRACE
- STILLING BASIN
- TAILWATER

# HYDROPOWER PLANT TERMS

- HEADWATER – THE WATER APPROACHING THE POWER PLANT-0R-THE SURFACE ELEVATION OF THAT WATER-
- HEADRACE – A CHANNEL, OFTEN FUNNEL-SHAPED, THAT DIRECTS THE WATER INTO THE INTAKE
- INTAKE – A STRUCTURE OR ARRANGEMENT THAT REGULATES THE WATER INTO THE PENSTOCK. Often includes a trash rack
- HEADGATE- SOME TYPE OF VALVE USED TO SHUT OFF THE WATER ENTERINGTHE PENSTOCK
- PENSTOCK- A PIPE OR OTHER CONVEYANCE THAT LEADS THE WATER TO THE TURBINE, GAINING HEAD IN THE PROCESS

# HEADRACE, INTAKE, PENSTOCK, POWERHOUSE, AND TAILRACE

# HEADRACE AND INTAKE STRUCTURE

# HYDROPOWER PLANT TERMS

- SCROLLCASE – TRANSTION FROM PENSTOCK TO DRAFT TUBE TO MAKE THE WATER ENTER THE TURBINE UNIFORMLY
- WICKETT GATES – A CYLINDRICAL ARRANGEMENT OF MANY VANES THAT CONTROLS THE AMOUNT OF WATER ENTERING THE TURBINE IN RESPONSE TO THE POWER DEMAND
- DRAFT TUBE – CONVEYS THE WATER INTO AND OUT OF THE TURBINE
- TURBINE- THE ROTOR TO BE TURNED BY THE MOVING WATER AND ITS CASE
- GENERATOR – TURNED BY THE ROTOR, THE GENERATOR CREATES ELECTRIC POWER FOR USE

# SCROLLCASE AND WICKETT GATE

# WICKETT GATE

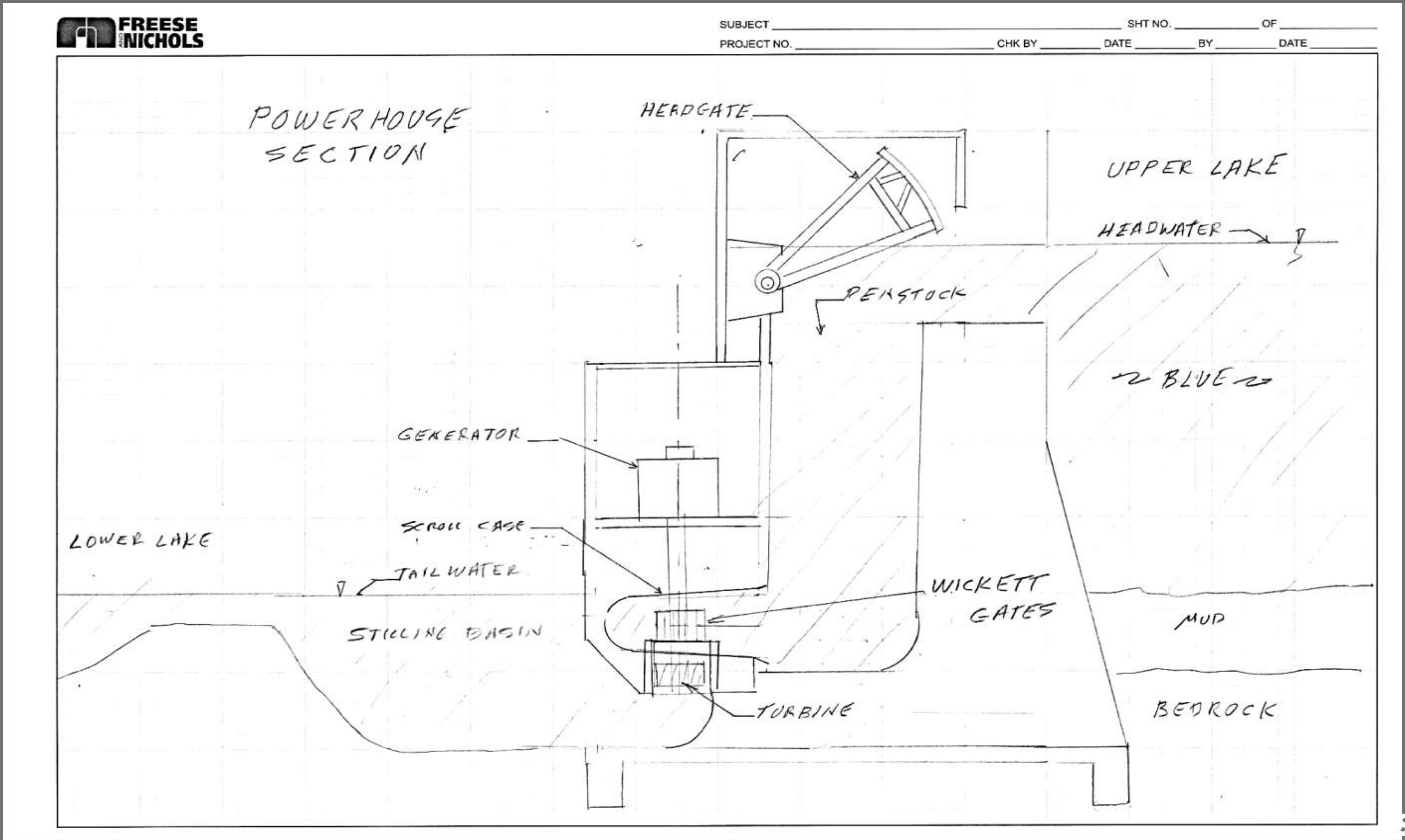
# TURBINE

# GENERATORS

# HYDROPOWER PLANT TERMS

- TAILRACE – WHERE THE WATER FLOWS OUT OF THE TURBINE AND BACK INTO THE RIVER, LOWER LAKE, OR OCEAN
- TAILWATER– THE ELEVATION OF THE WATER IN THE TAILRACE

# THE CASE OF THE LEAKING DAM



# THE CASE OF THE LEAKING DAM

THE LESSON

CHECK YOUR ASSUMPTIONS

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QUESTIONS?

COMMENTS?