ENGINEERING EVALUATION TOOLS
to determine
"WHAT CAUSED THE CRACKS"

By: Kurt Heinrichs, PE

NOVA
ENGINEERING AND ENVIRONMENTAL

Facilities and Forensics

Prepared by: Kurt Heinrichs, PE
Business Unit Leader

Forensics

- Review of Available Drawings
- Condition Surveys & Documentation of Distress
- Nondestructive Testing
- Materials Sampling
- In Situ Physical Testing
- Selective Openings
- Laboratory Testing
- Structural Analysis and Finite Element Modeling

Nondestructive Testing

- Ground Penetrating Radar (GPR)
- Ultrasonic Testing (UPV)
- Impact Echo (IE)
- Electronic Leak Detection
- Water Infiltration Testing
- Infrared and Nuclear Surveys
- Wind Uplift
- Relative Humidity (RH)
- Moisture Content

SUMMARY OF GROUND PENETRATING RADAR METHOD

Method

The ground penetrating radar (GPR) method uses **electromagnetic pulses**, emitted at regular intervals by an antenna to map subsurface features and discrete objects. The electromagnetic pulses are reflected where **changes in electrical properties (dielectric constant)** occur. In the case of collecting GPR data on concrete structures, this may occur due to the presence of rebar, cracking, voids, or the far side of the structure in question. The reflected electromagnetic energy is received by an antenna, converted into an electrical signal, and recorded by the GPR unit. The data is processed, viewed, and printed in real time. The result is a cross-section of the subsurface directly beneath the path of the antenna.

The **depth of penetration** of the GPR signal varies **according to antenna frequency** and the conductivity of the subsurface material. As the frequency of the GPR antenna increases, the resolution increases but the depth of penetration decreases. As the **conductivity of subsurface material increases** the **depth of penetration decreases** due to increased attenuation of the GPR signal.

Ground Penetrating Radar

Ground Penetrating Radar


06/26/2013

Ground Penetrating Radar


NOVA
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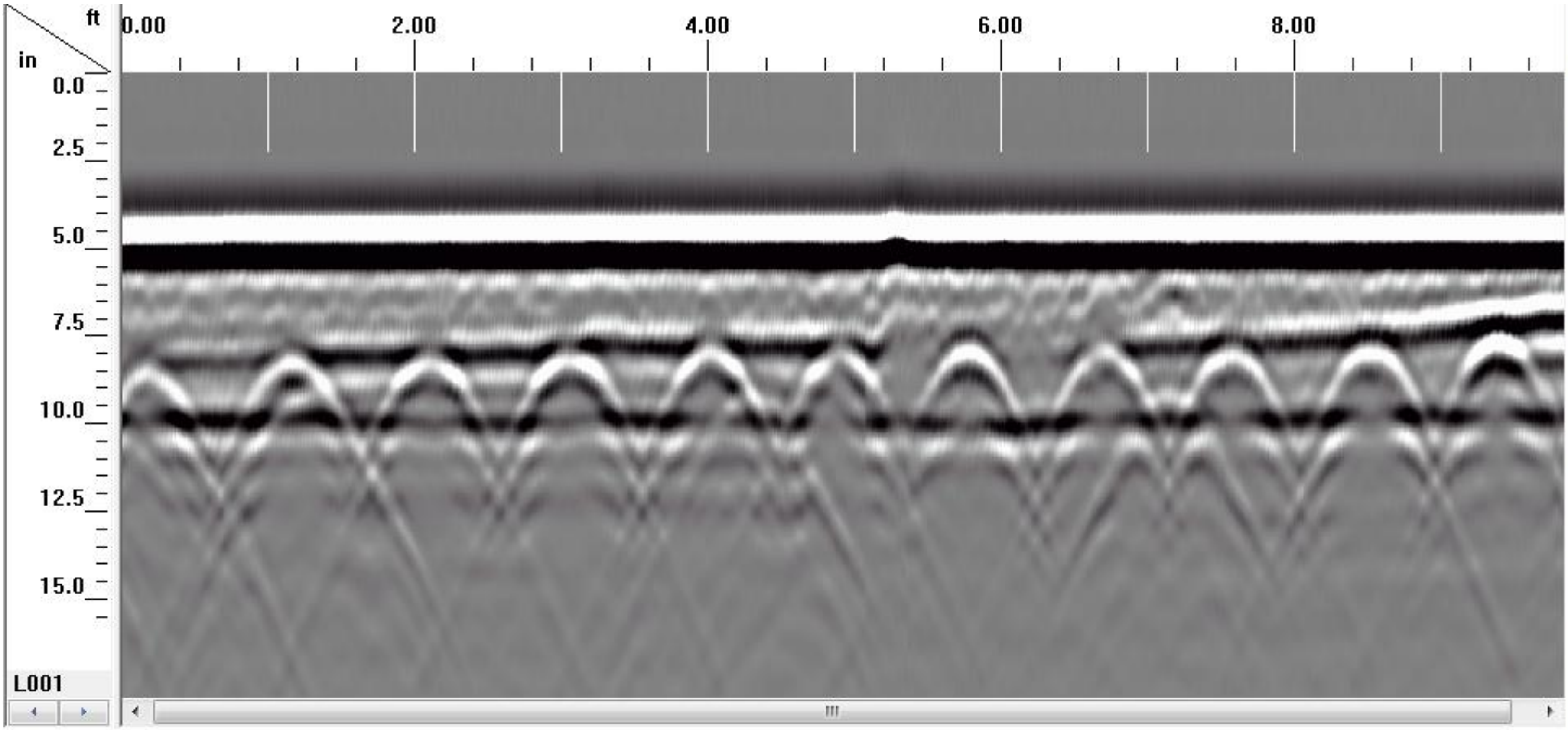
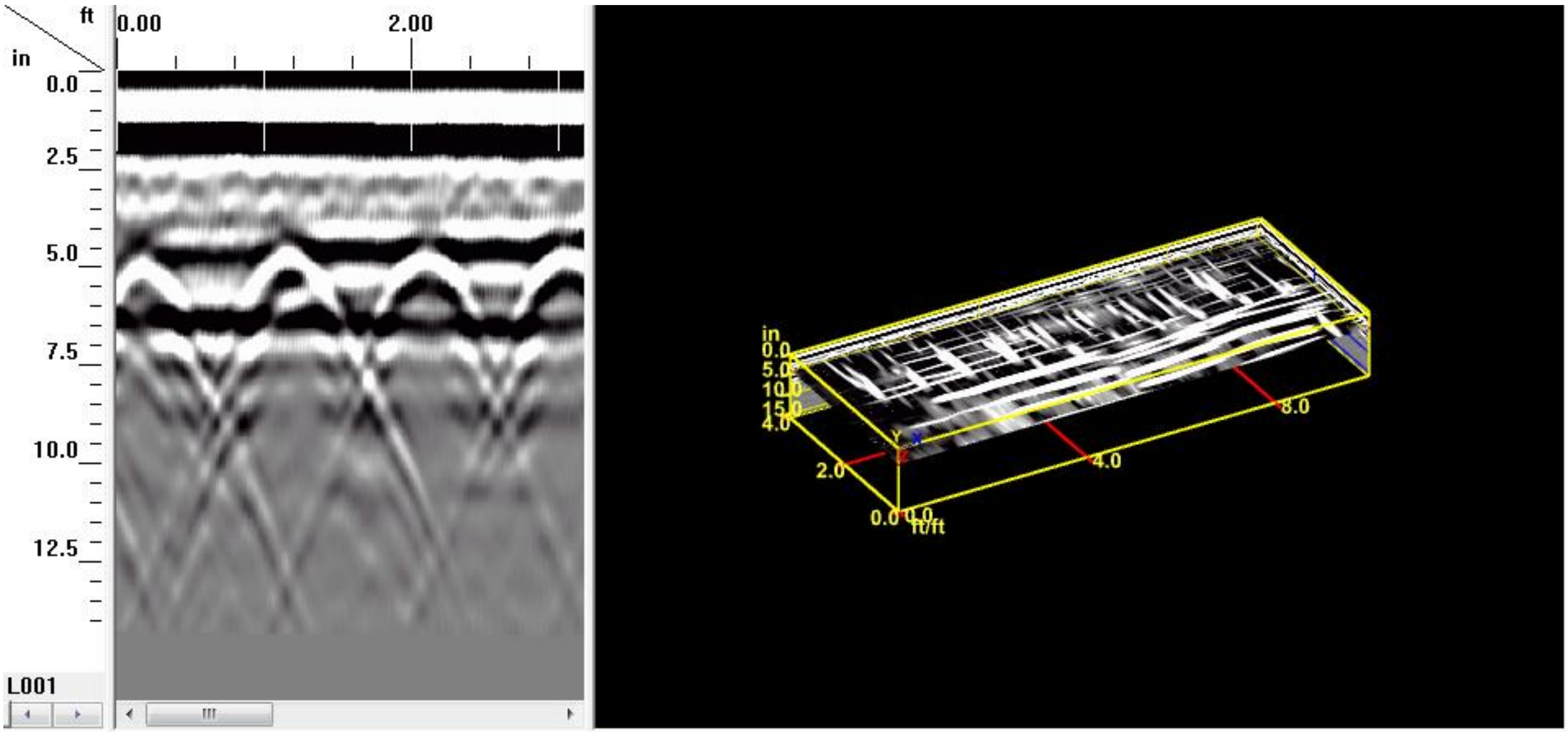
GSSI
1600
02/26/2014


01/27/2014



ft
in
0.00
2.00
4.00
6.00
8.00
0.0
2.5
5.0
7.5
10.0
12.5
15.0
L001


ft
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0.00
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L001
in
0.0
5.0
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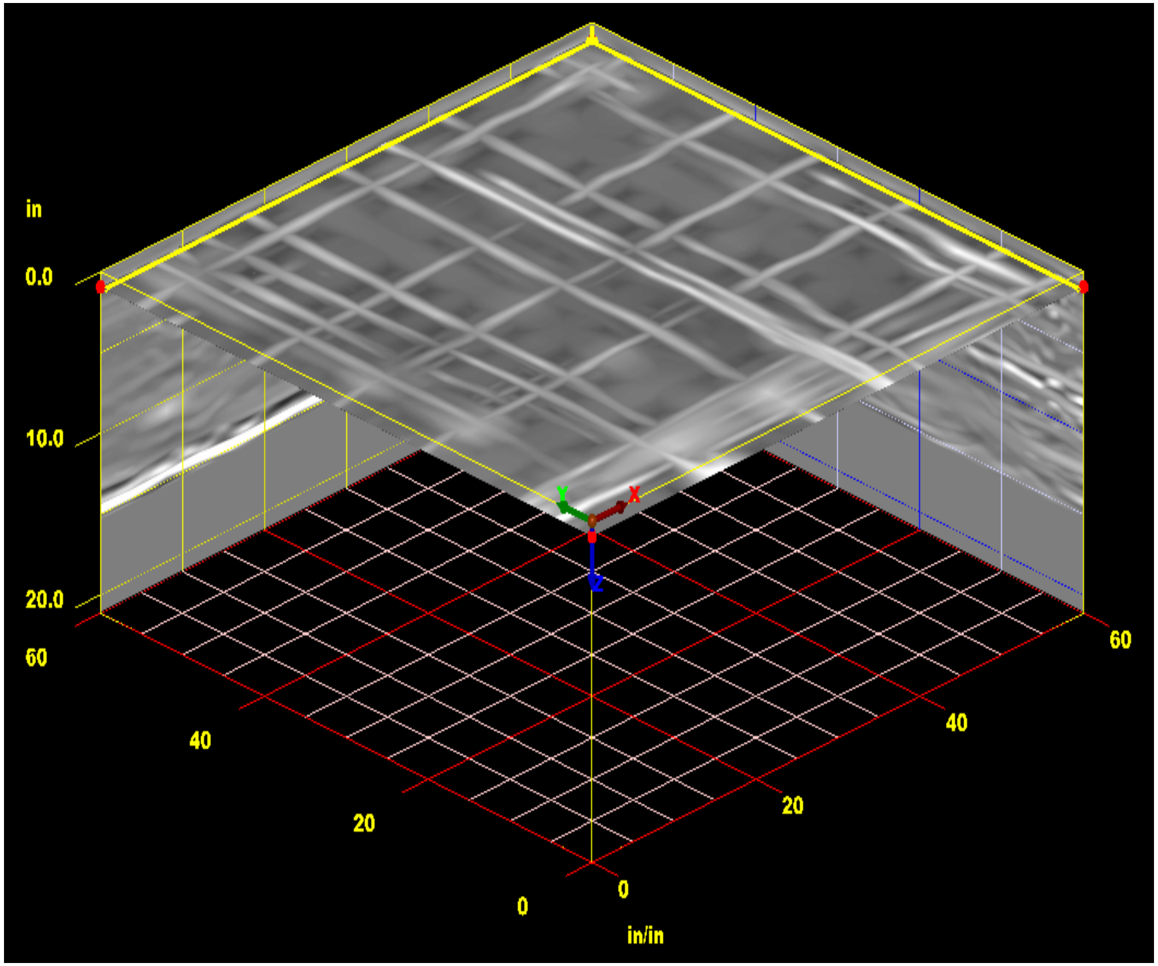
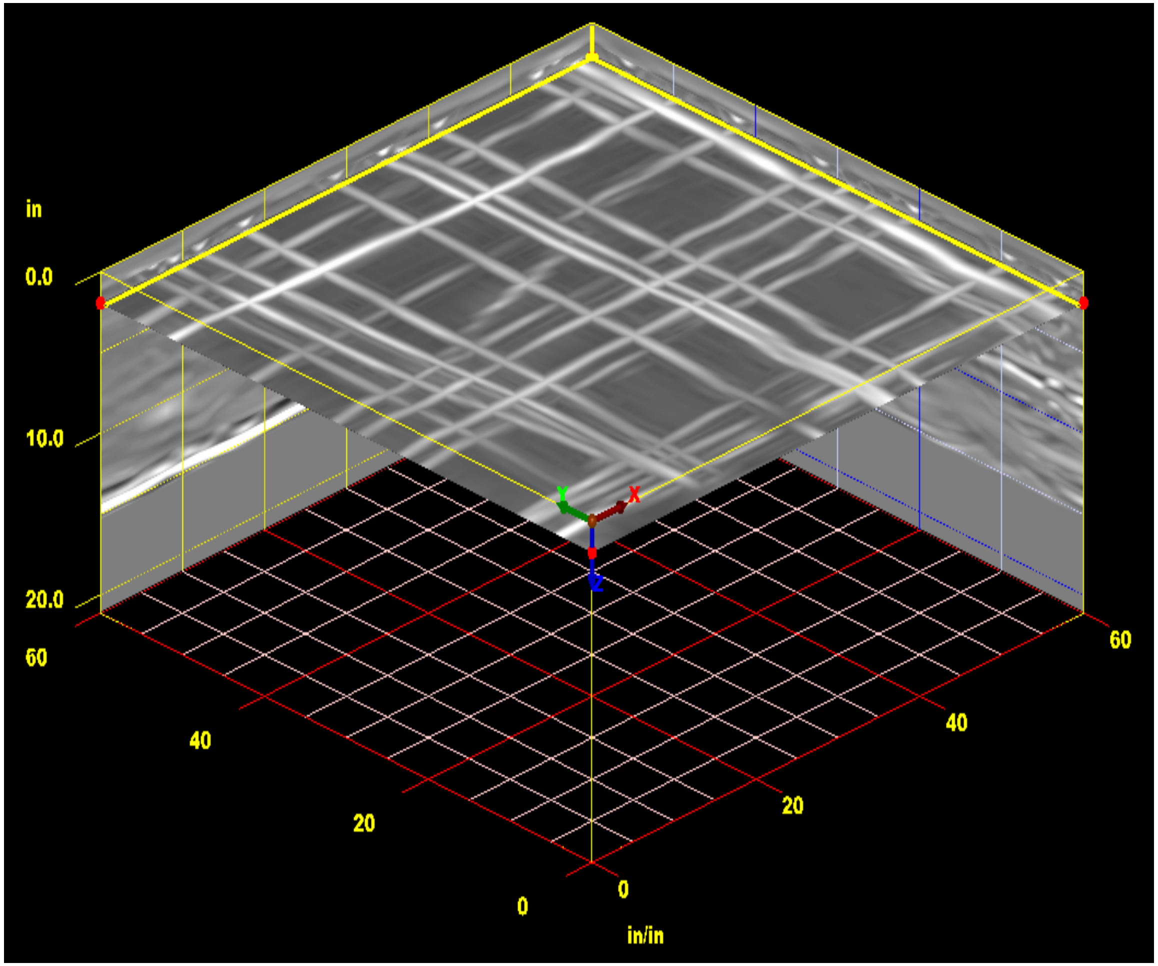
2.0
4.0
8.0
0.0 0.0
ft/ft

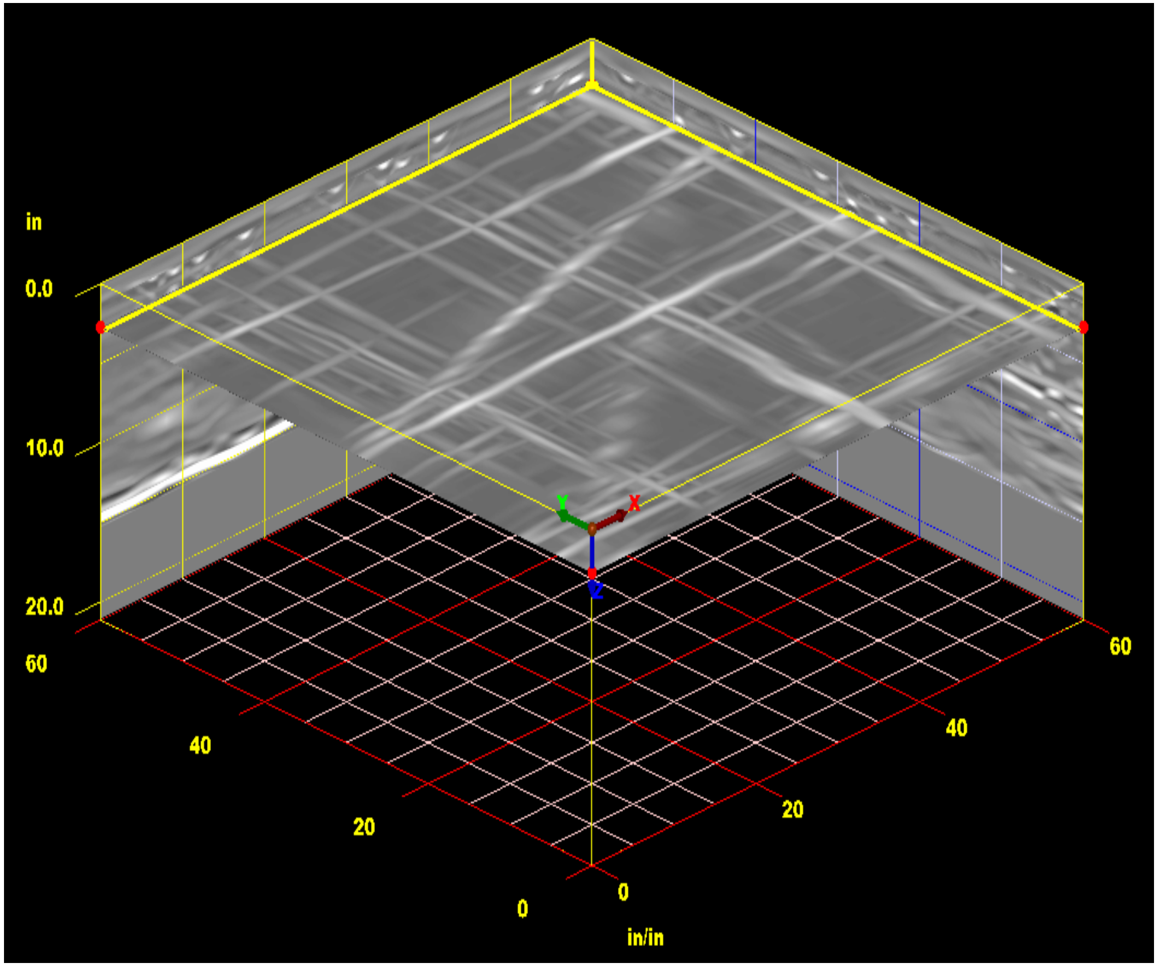
3D scan transferred to slab and chipped out excavations to measure bar size



1 inch Depth

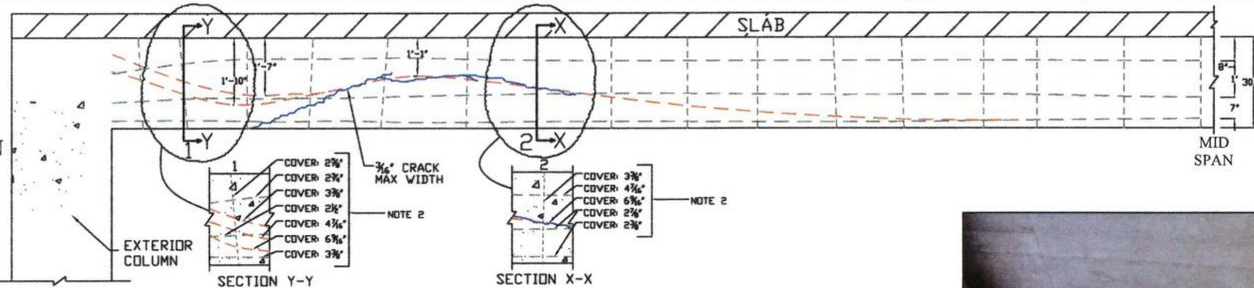


2 inch Depth

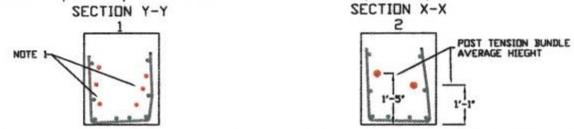


2.75 inch
Depth

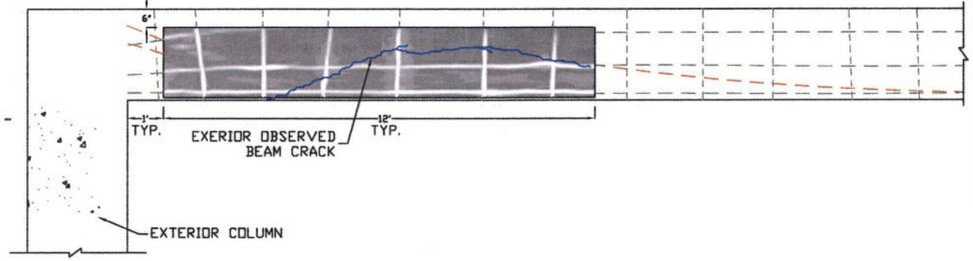
OVERALL GPR DATA EAST ELEVATION



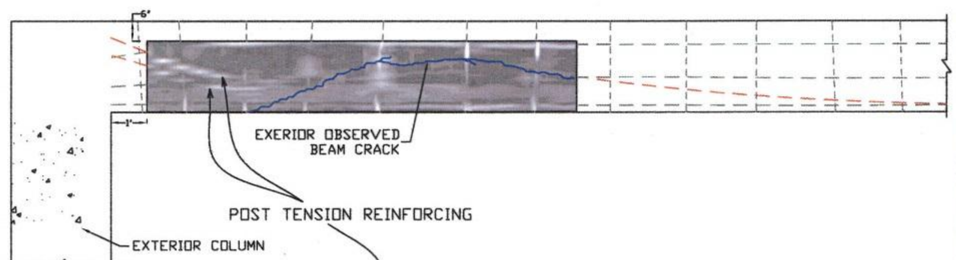
NOTE:
1. LOCATION OF STRAND COULD NOT BE CONFIDENTLY CONFIRMED DUE TO CONCRETE COVER AND CONGESTION OF REINFORCING STEEL
2. ALL COVER MEASUREMENTS WERE ADJUSTED BASED ONE CORRELATION TO CHIPPED AREA



3-D GPR DATA - DEPTH = 3"



3-D GPR DATA - DEPTH = 5"



3-D GPR DATA - DEPTH = 6¼"

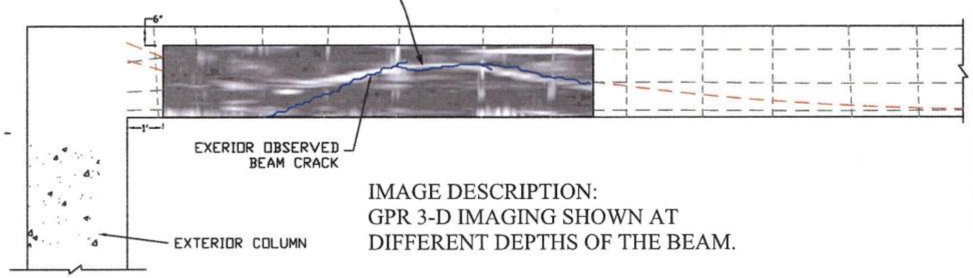


IMAGE DESCRIPTION:
GPR 3-D IMAGING SHOWN AT DIFFERENT DEPTHS OF THE BEAM.

PHOTO ABOVE ILLUSTRATES FIELD WORK AND EXISTING CRACK. SEE PHOTO BOTTOM RIGHT.

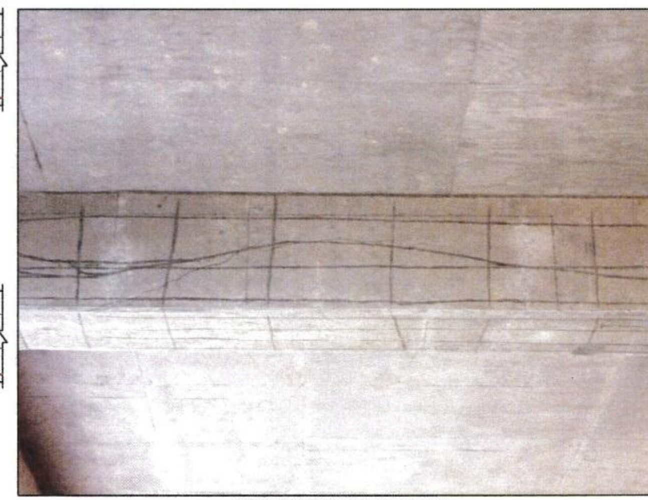


PHOTO ABOVE SHOWS CRACK PATTERN AND IN-FIELD GPR WORK.

ULTRASONIC PULSE VELOCITY TECHNIQUE
ASTM C-597

The nondestructive ultrasonic pulse velocity technique measures the **velocity of stress waves traveling through concrete**. Ultrasonic stress waves are initiated at one face of a concrete member when a transducer containing piezoelectric crystals is excited by high voltage pulses. The piezoelectric crystals convert the electrical pulse to a stress wave pulse. The configuration of the piezoelectric crystal result in a wave frequency of approximately 54 kilohertz. This ultrasonic stress wave pulse travels through the concrete and is received at the opposite face of the concrete member by a similar transducer. Time measurement circuitry in the V-meter determines the elapsed time for the stress wave pulse to travel through the concrete. The **pulse velocity** of the concrete being tested is determined **dividing the measured path length by the elapsed time** measured by the V-meter.

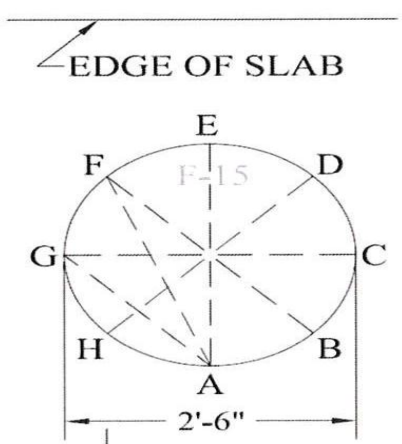
For an investigation, the velocities of stress waves pulses propagating in the compressional mode are measured. The compression wave **velocity** through the concrete is **related** to the **elastic modulus and the mass density of the concrete** as well as other factors. The calculated pulse velocity is dependent on the actual wave pulse path length traveled through the concrete. If the **path length is interrupted by a crack, zone of honeycombing or some other discontinuity**, the wave energy will attempt to circumvent the discontinuity**. The resulting time delay will indicate lower velocities.**


5160
SAFETY
FIRST

Table 1. Ultrasonic Impulse Velocity data at Column F-15

Level	Grid Designation	Signal Path Length, (in)	Delay Time ($1x10^{-6}$ s)	Pulse Velocity (ft/s)	Deviation from average	Comments
4"	A-E	30	154	16230	8%	Measurement offset 3" due to H/C at A side.
	B-F	30	368	6790	55%	Measurement offset 3" due to H/C at B side.
	C-G	30	157	15920	6%	
	D-H	30	156	16030	7%	Measurement taken at 8" due to H/C.
	D-H	30	191	13090	13%	Measurement taken at H/C.
	A-G*	21.2	212	8330	45%	H/C observed. Measurement offset 3".
	A-F*	27.7	222	10400	31%	H/C observed
1'	A-E	30	158	15820	5%	
	B-F	30	159	15720	5%	
	C-G	30	158	15820	5%	
	D-H	30	158	15820	5%	Low severity H/C observed.
	A-G*	21.2	132	13380	11%	
	A-F*	27.7	147	15700	4%	
2'	A-E	30	159	15720	5%	
	B-F	30	158	15820	5%	
	C-G	30	159	15720	5%	
	D-H	30	159	15720	5%	
	A-G*	21.2	116	15230	1%	
	A-F*	27.7	148	15600	4%	
3'	A-E	30	160	15630	4%	
	B-F	30	159	15720	5%	
	C-G	30	158	15820	5%	
	D-H	30	158	15820	5%	
4'	A-E	30	157	15920	6%	
	B-F	30	158	15820	5%	
	C-G	30	157	15920	6%	
	D-H	30	157	15920	6%	
5'	A-E	30	157	15920	6%	
	B-F	30	158	15820	5%	
	C-G	30	160	15630	4%	
	D-H	30	158	15820	5%	
6'	A-E	30	157	15920	6%	
	B-F	30	158	15820	5%	
	C-G	30	159	15720	5%	
	D-H	30	158	15820	5%	
			Min	6790		
			Max	16230		
			Average	15030		

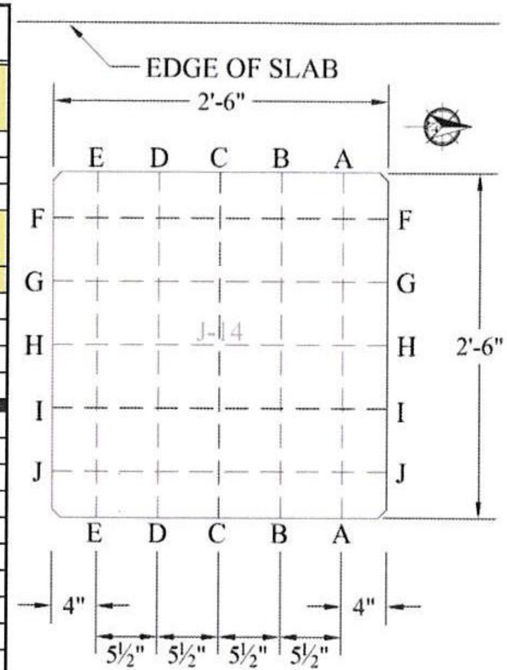
Note: Nova Engineering's Report of Compressive Strength Tests indicate concrete used at this column was made on 10/19/10. Cylinders were observed to have a 28 day compressive strength of 8960 psi. Highlighted rows have velocities less than 11,000 ft/sec and indicate areas of significant discontinuities.
*Diagonal (Chord) Test




E

Table 5. Ultrasonic Impulse Velocity data at Column J-14

Level	Grid Designation	Signal Path Length, (in)	Delay Time ($1x10^{-6}$ s)	Pulse Velocity (ft/s)	Deviation from average	Comments
4"	A-A	30	270	9260	43%	erratic readings; rock pocket found with mason's hammer
	B-B	30	600	4170	74%	erratic readings
	C-C	30	153	16340	1%	
	D-D	30	175	14290	12%	
	E-E	30	600	4170	74%	erratic readings; rock pocket found with mason's hammer
	F-F	30	229	10920	33%	erratic readings
	G-G	30	151	16560	2%	
	H-H	30	160	15630	3%	
	I-I	30	151	16560	2%	
	J-J	30				in accessible
1'	A-A	30	150	16670	3%	
	B-B	30	153	16340	1%	
	C-C	30	153	16340	1%	
	D-D	30	153	16340	1%	
	E-E	30	155	16130	0%	
	F-F	30	154	16230	0%	
	G-G	30	155	16130	0%	
	H-H	30	155	16130	0%	
	I-I	30	152	16450	2%	
	J-J	30				in accessible
2'	A-A	30	153	16340	1%	
	B-B	30	154	16230	0%	
	C-C	30	155	16130	0%	
	D-D	30	154	16230	0%	
	E-E	30	151	16560	2%	
	F-F	30	155	16130	0%	
	G-G	30	155	16130	0%	
	H-H	30	157	15920	2%	
	I-I	30	153	16340	1%	
	J-J	30	154	16230	0%	




F13.5
E1


2440
03/03/2013

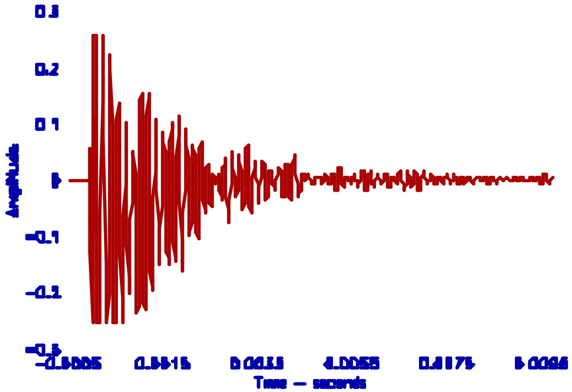

202-C
03/26/2013

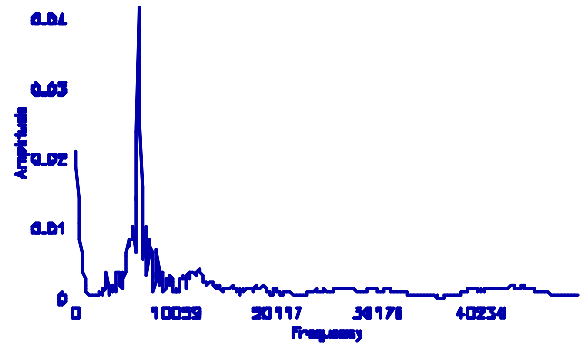

09/27/2013

IMPACT-ECHO TEST METHOD

- Impact-echo testing is a special form of nondestructive stress wave testing of concrete. The test method is described in **ASTM C-1383** "Standard Test Method for Measuring the P-Wave Speed and the Thickness of Concrete Plates using the Impact Echo Method". The test procedure **utilizes stress waves which propagate through the concrete** with the initiation and sensing of the stress wave being on the **same surface of the concrete**. The method can be used to **determine the thickness of a concrete section, or if there are internal defects or cracks** in the concrete. The uniformity of the concrete quality can also be evaluated by this procedure.

- A transient stress wave is initiated by an impact to the concrete surface. The impact must be of short duration in order for the pulsed wave to contain high frequencies components for the analysis. The impact imparts a stress wave containing a broad band of wave frequencies. As these waves travel through the concrete sections, they are reflected by the opposite surface or defects within the concrete. Waves of **certain frequencies are reinforced or resonate** as they are reflected within the concrete. The resonant frequency is dependent on the geometry of the section or distance to the internal defect. An accelerometer or displacement transducer is used to sense the transient waves which propagate in the concrete. The sensing transducer must be coupled to the concrete surface and be able to pickup the stress waves in the range of frequencies of concern. The **selection of the impactor and the type of sensing transducer** are critical to the test procedure.





The concrete surface displacement is sensed by the transducer and recorded with the testing device. The CTG-ITF impact echo test device manufactured by Olson Instruments was used for this testing. The recorded wave is transformed from the time domain to the frequency domain using a Fast Fourier Transform technique. The frequencies (f_p) of peaks in the amplitude spectrum of the frequency domain represent the dominant periodicities or resonance of the waveform. Knowing the stress wave velocity (C_p) of the concrete, the depth (T) to the reflecting interface is calculated by the formula: $T = C_p / (2 \bullet f_p)$


DANGER
TEST FOR LETHAL GASSES
BEFORE ENTERING THIS AREA
07/11/2013

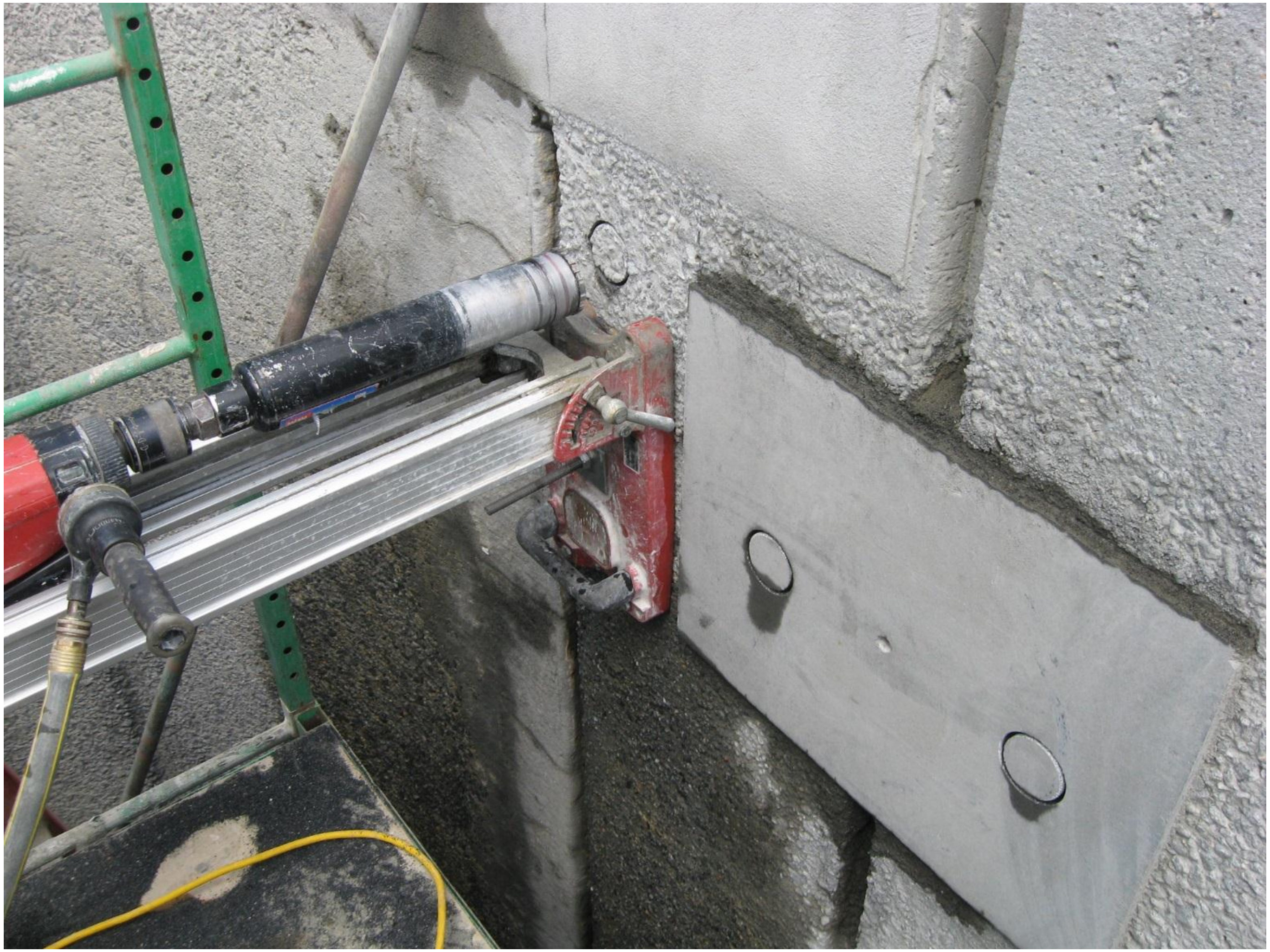
DANGER
TEST FOR LETHAL GASSES
BEFORE ENTERING THIS AREA
07/11/2013


5160
SAFETY
FIRST
entals


PUSH ON
PUSH OFF
ENGLISH
METRIC
BACK
LIGHT
ASPHALT/CONCRETE THICKNESS GAUGE
LOW BATTERY
ENT

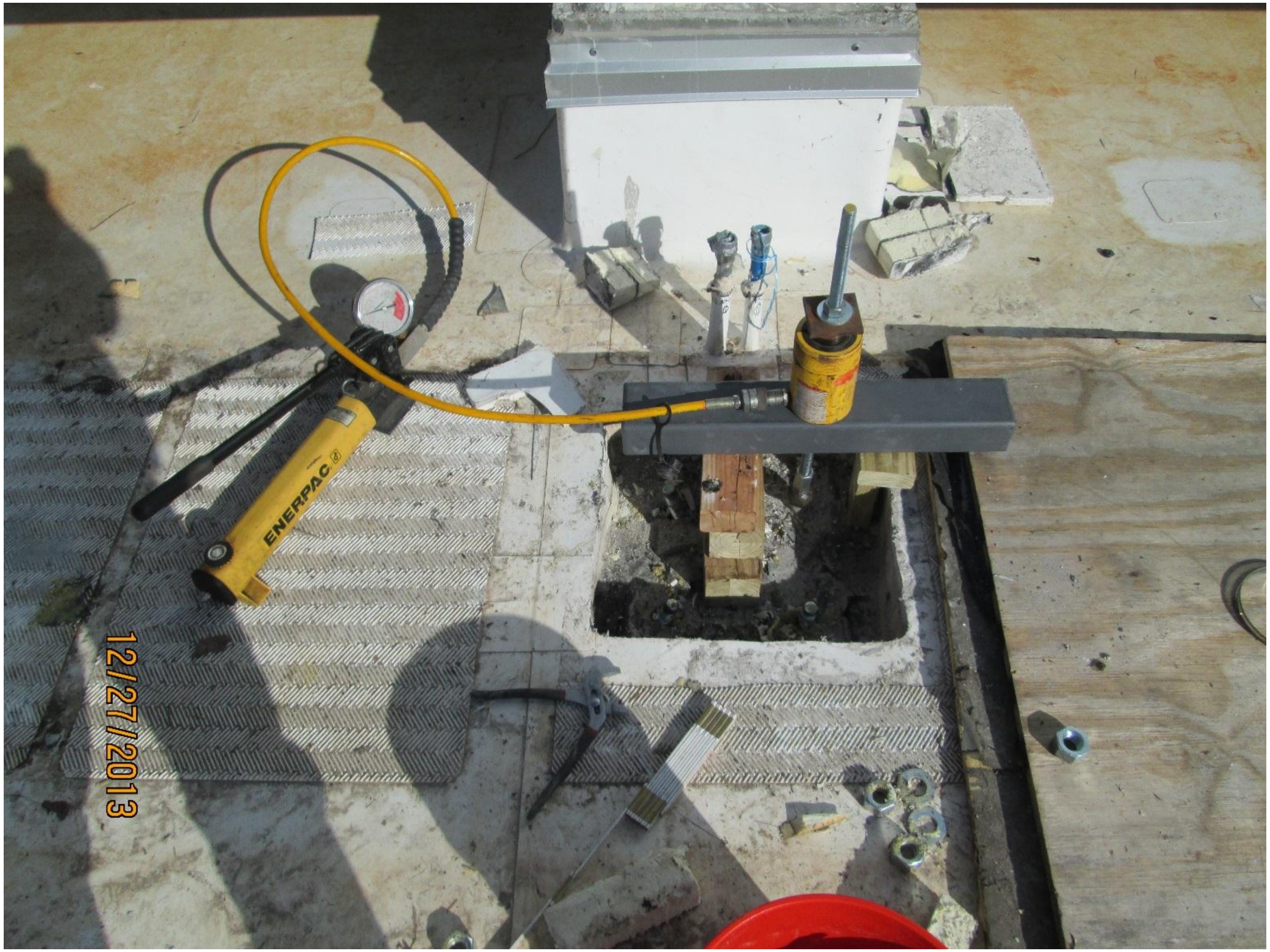
Core No.	Location		Slab Thickness Measurements					
			Core Hole Measurement	Impact Echo		Surveyor		
			(in.)	(in.)	Difference (in.)	(ft.)	(in.)	Difference (in.)
1	Zone 3	1083	4.90	4.9	0.0	0.395	4.7	−0.2
2		1077	4.63	4.7	0.1	0.380	4.6	−0.1
3		1076*	4.84	4.8	0.0	0.385	4.6	−0.2
4		1078	4.41	4.6	0.2	0.370	4.4	0.0
5		1117*	4.78	4.9	0.1	0.385	4.6	−0.2
6	Zone 4	5032	4.64	4.7	0.1	0.360	4.3	−0.3
7		5015	4.47	4.5	0.0	0.320	3.8	−0.6
8		5019	4.61	4.6	0.0	0.335	4.0	−0.6
9		5060	5.77	6.0	0.2	0.355	4.3	−1.5
10		5043*	4.29	4.4	0.1	0.340	4.1	−0.2

*Slab Thickness was measured by measuring length of core.



Bond Testing


3
2



Adhesive Anchor and Safety Tie Back Testing

Proof Load Anchor Bolt Testing

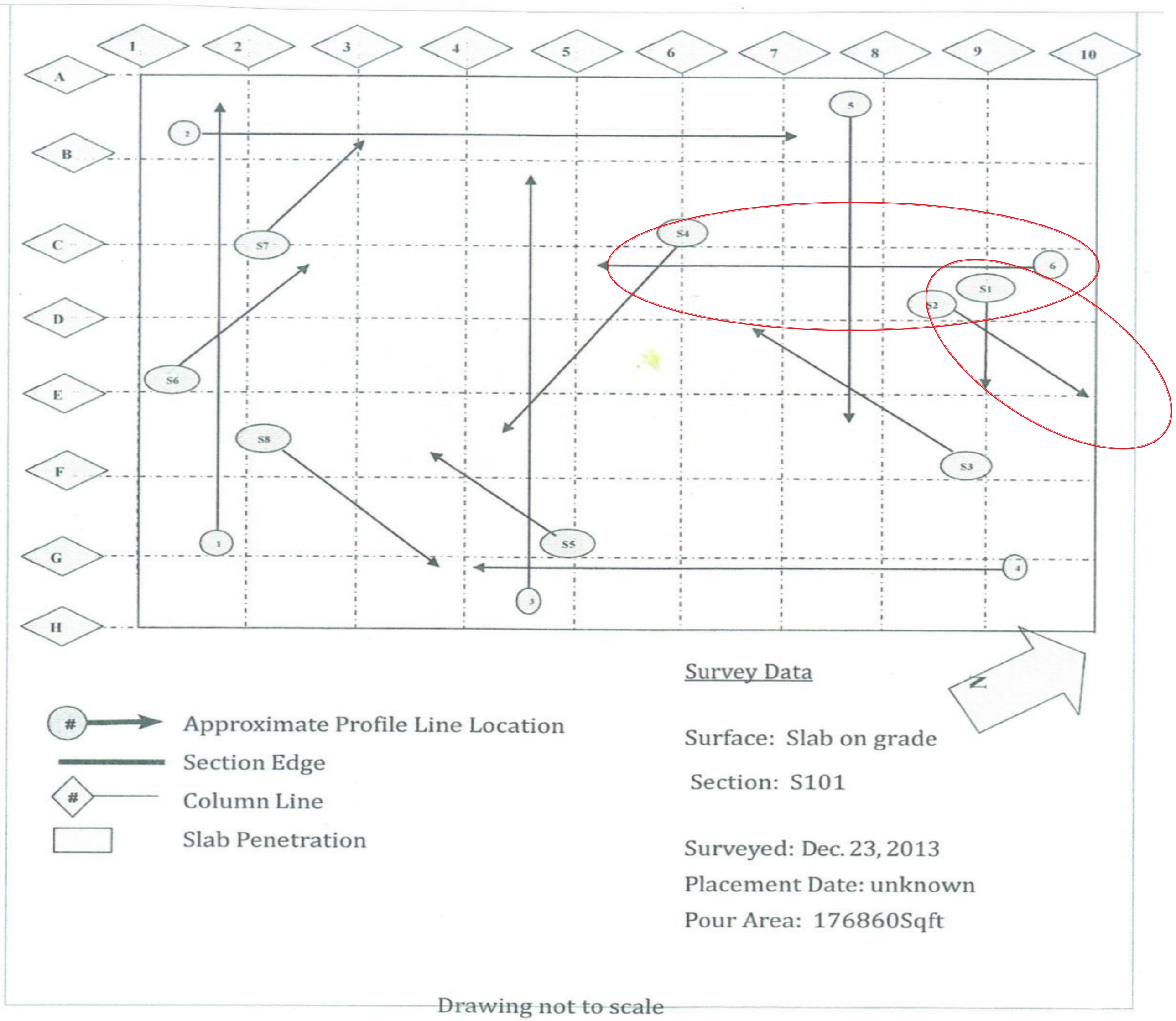
Distressed Warehouse Floor Slab

Distressed Warehouse Floor Slab

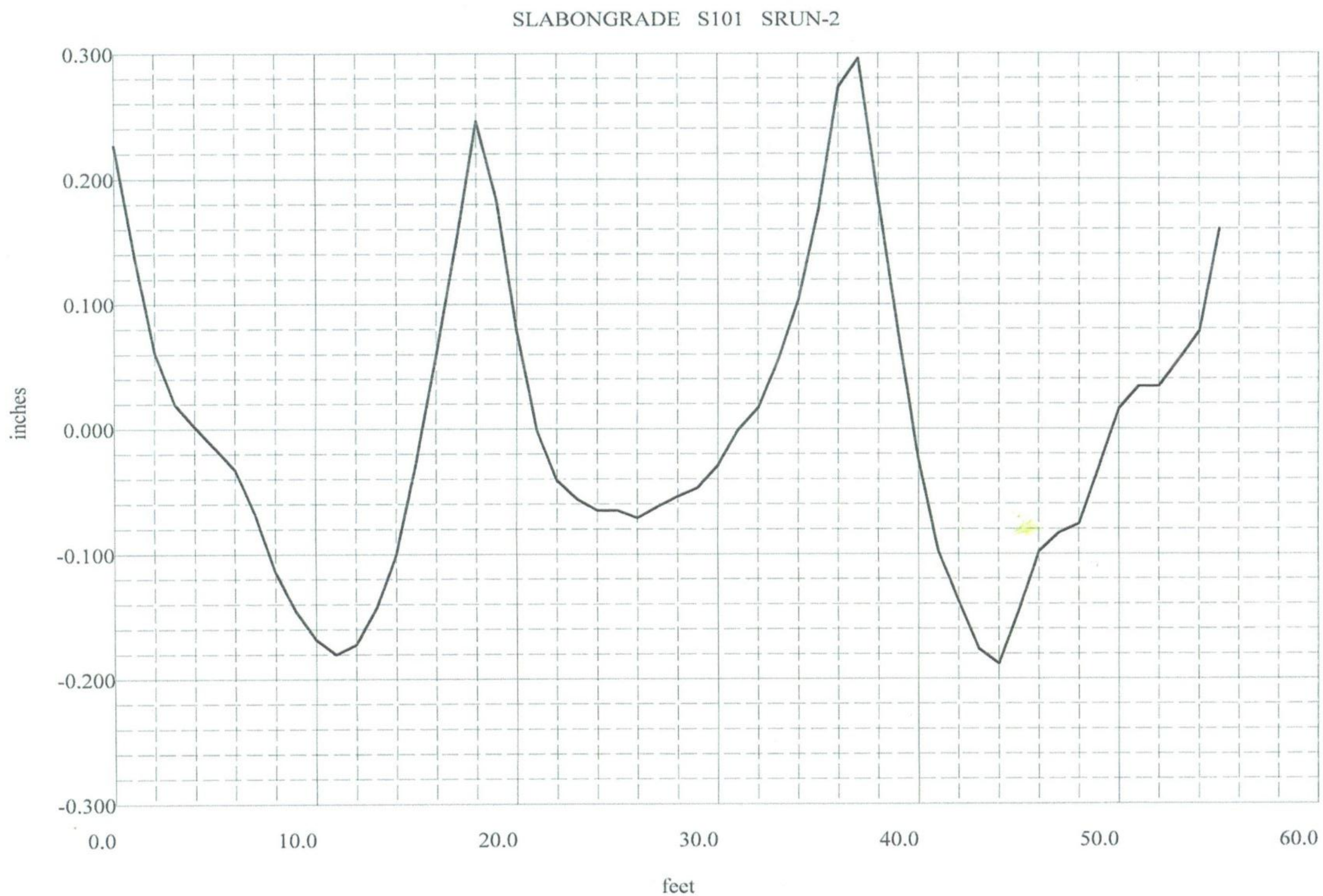
Curling Noted Across Joints

FF and FL Dipstick Testing Device

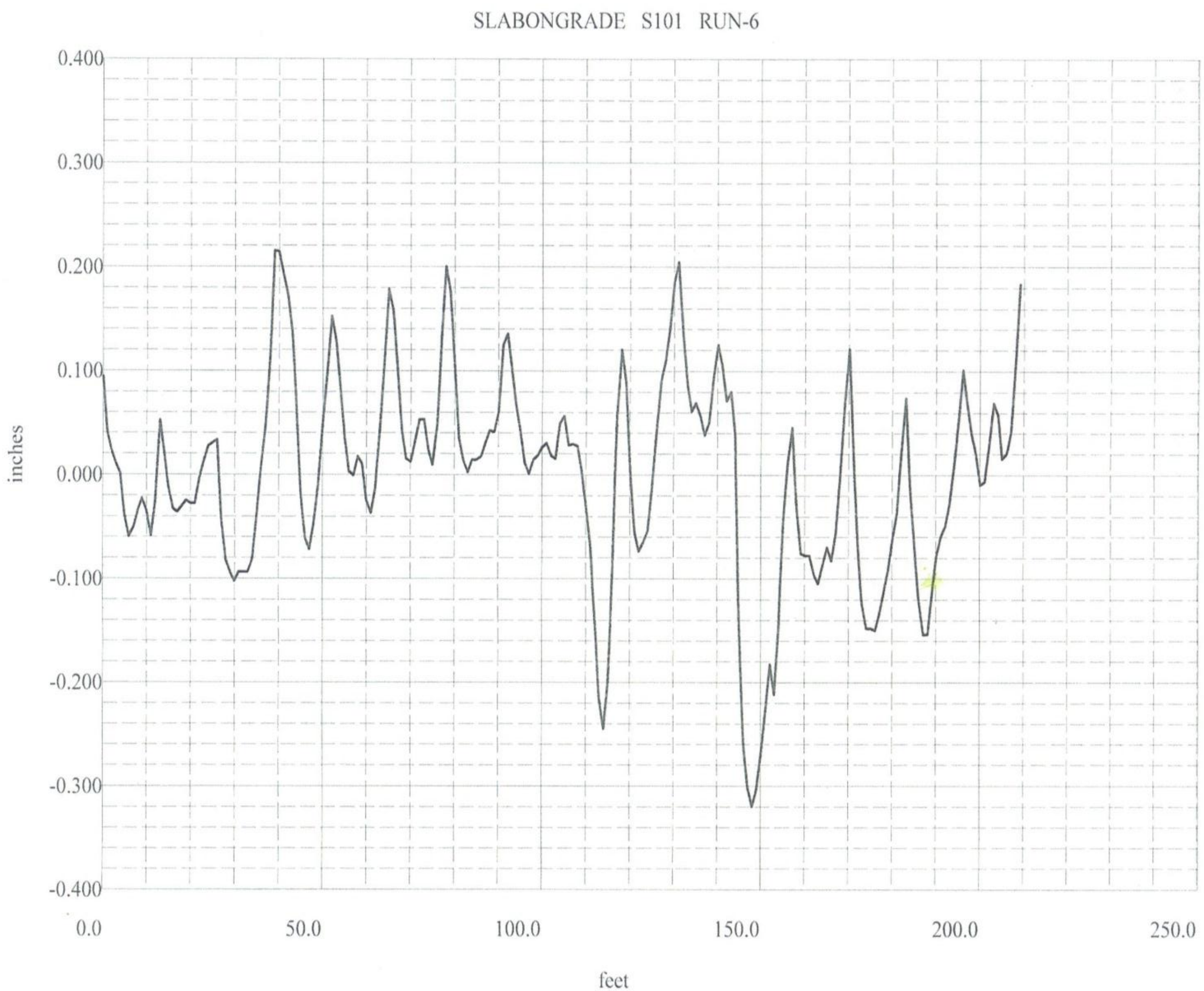
Curling Noted Across Joints



Dipstick Test Runs



FF = 39.5 <32.8 - 46.1> FL = 18.4 <15.0 - 21.9>



FF = 39.2 <36.1 - 42.3> FL = 30.6 <28.1 - 33.1>

RED END
LUFKIN
1
2
3
4
5
INCHES
12/23/2013

Core Sampling

Laboratory Testing

- Strength Testing
- Petrographic Evaluation
- Depth of Carbonation
- Chloride Content
- Absorption and Specific Gravity
- Alkali-Silica Reaction (ASR)

150 Worth Ave

Worn Top Deck Coating


H


2-2
.75 ∅
1.5
23


2-2
3-2
INCHES 1 2 3 4 5 6


TOP DECK 1
TOP DECK 2
INCHES
1
2
3
4
5
6

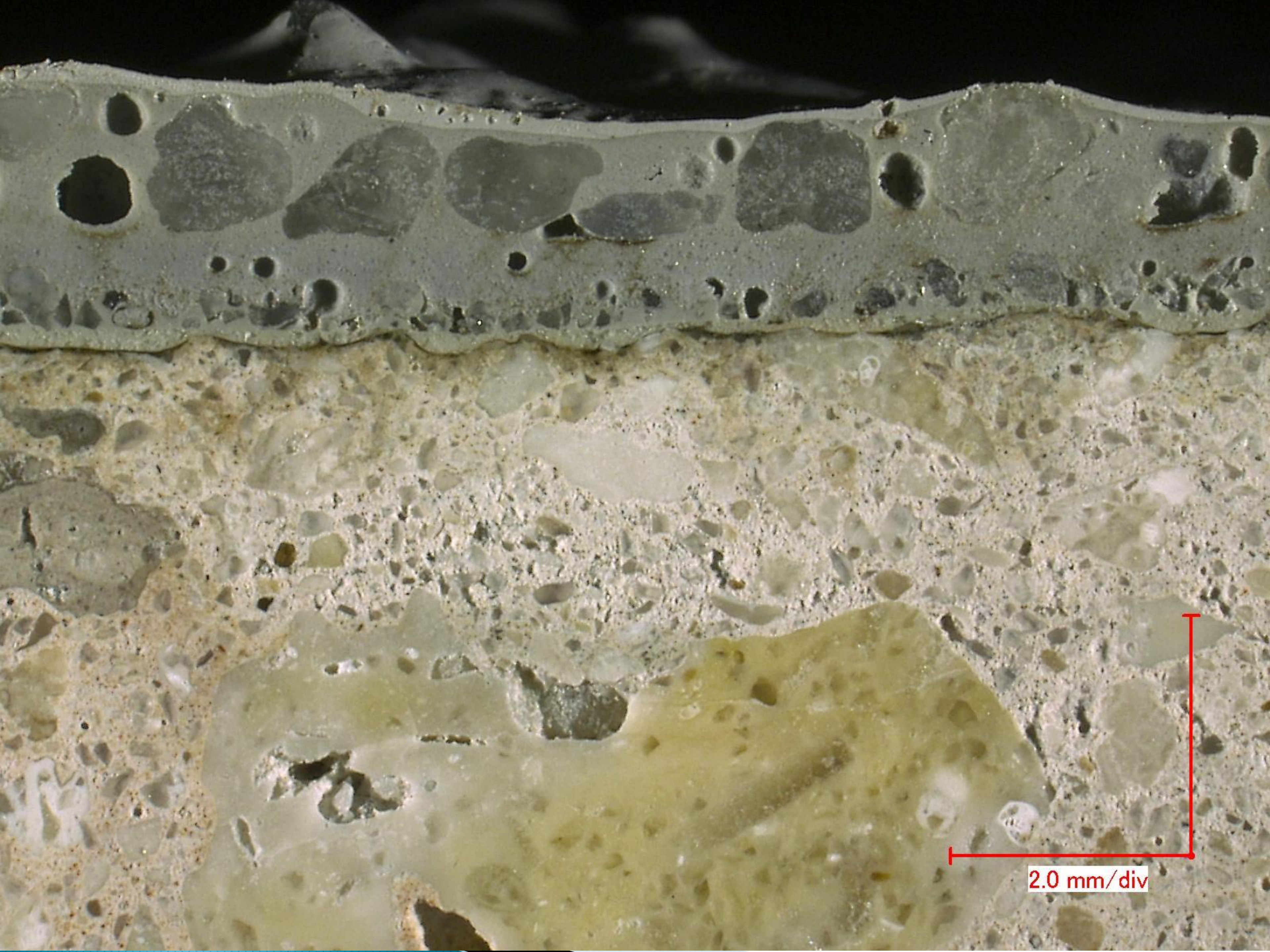
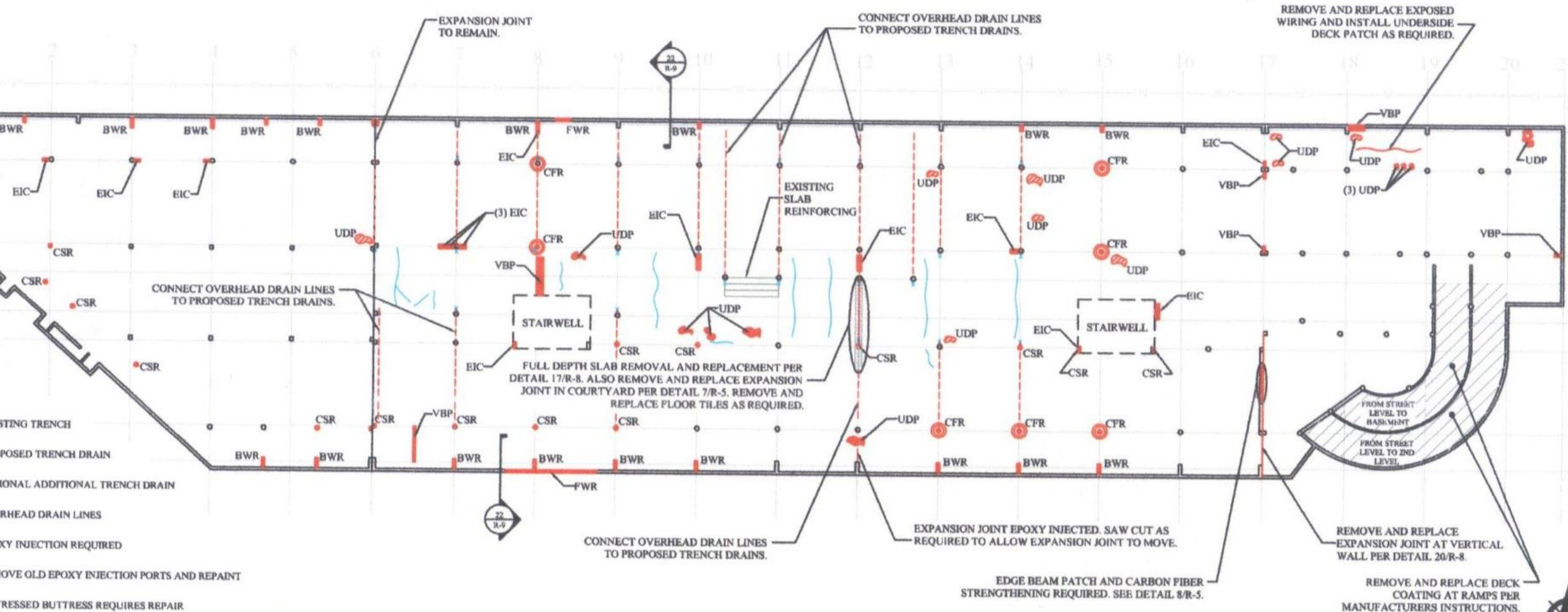

2.0 mm/div

Table 1: Summary of Field Measurements and Laboratory Test Results

Member Type and Condition	Location No.	Core No.	Distressed Area	Concrete Cover Ranges (in.)	Compressive Strength	Saturated Density	Depth of Carbonation	Water Soluble Chlorides (%)		
					(psi)	*(lb/ft^3)*		0 - 1"	1 - 2"	2 - 3"
--	Top Deck	1	NO			137.8				
		2	NO					**0.030**	**0.062**	**0.055**
		3	NO		4190					
Good Buttress	1	1-1	NO	0.1 to 3.0		140.2	1”			
		1-2	NO		5790					
		PS	NO					0.003	0.018	0.010
Poor Buttress	4	4-1	YES	0.15 to 3.5			0”			
		4-2	YES		7020			0.011	0.017	**0.037**
		PS-High	NO					0.004	0.005	0.004
		PS-Low	YES					**0.234**	**0.284**	**0.159**
Poor Buttress	8	None	YES	1.0 to 3.0						

WORTH AVENUE



STING TRENCH
POSED TRENCH DRAIN
IONAL ADDITIONAL TRENCH DRAIN
RHEAD DRAIN LINES
XY INJECTION REQUIRED
OVE OLD EPOXY INJECTION PORTS AND REPAINT
RESSED BUTTRESS REQUIRES REPAIR
RESSED COLUMN REQUIRES REPAIR
UMN/BEAM NEEDS CARBON FIBER WRAP
N SPOUT OR DRAIN
ERSIDE DECK PATCH

DETAIL CODE LEGEND:

BWR	BUTTRESS WALL REPAIR - SEE DETAIL 13/R-7.
CFR	CARBON FIBER REPAIR - SEE DETAIL 6/R-5 OR 19/R-8.
CSR	COLUMN SPALL REPAIR - SEE DETAIL 15/R-7.
EIC	EPOXY INJECT CRACK - SEE DETAIL 12/R-6.
FWR	FOUNDATION WALL REPAIR - SEE DETAIL 11/R-6.
UDP	UNDERSIDE DECK PATCH - SEE DETAIL 5/R-5.
VBP	VERTICAL BEAM PATCH - SEE DETAIL 18/R-8.

2 R-2 FIRST FLOOR FRAMING REPAIR PLAN

SCALE: N.T.S.


06/12/2012


06/20/2012


07/23/2012


07/23/2012


07/03/2012


09/06/2012


07/06/2012
XYPEX


07/31/2012


INGERSOLL-RAND
50KW
07/26/2012


07/26/2012


BRUTE
07/27/2012


08/14/2012


08/14/2012


09/28/2012

Key Project Details

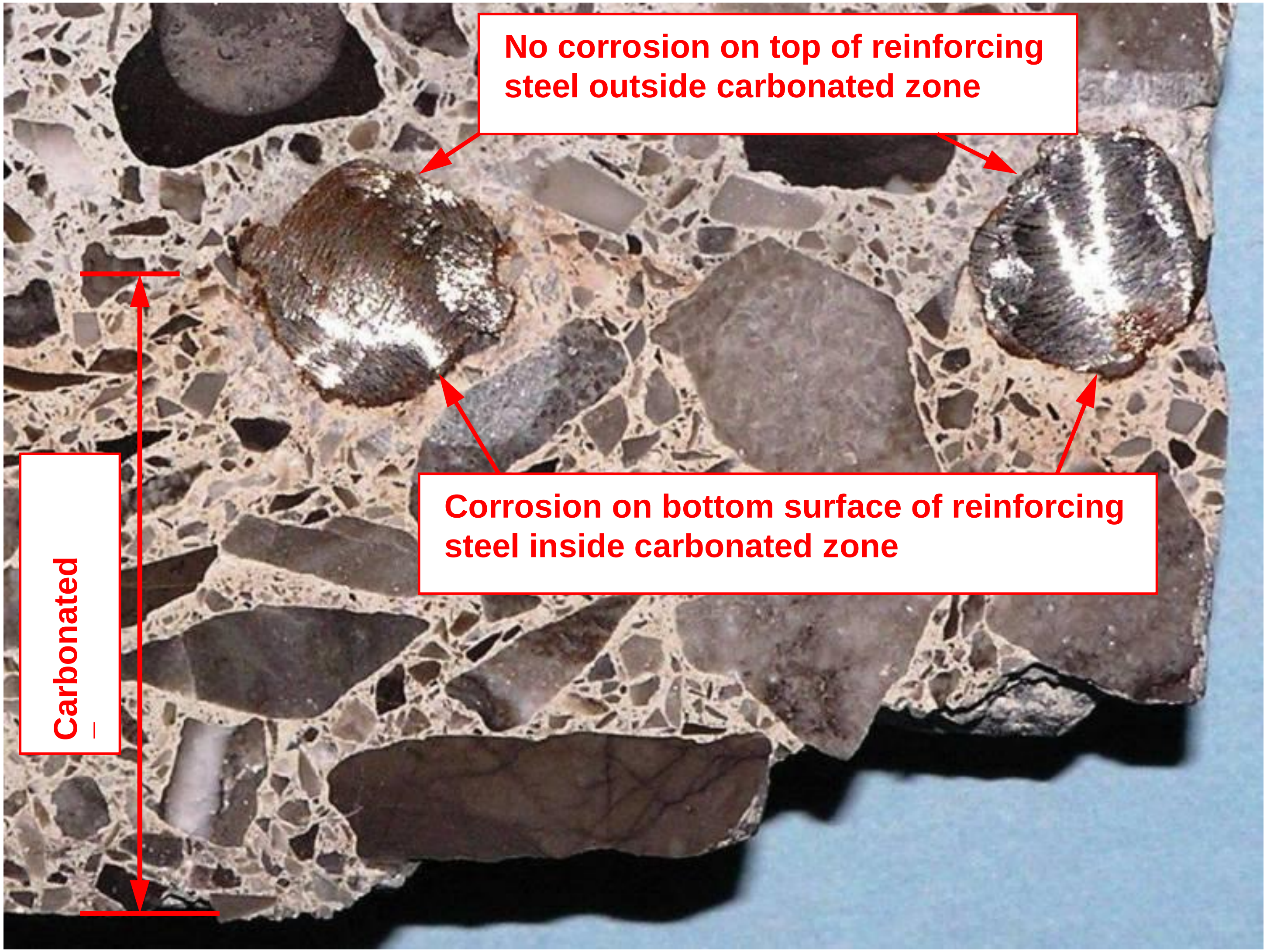
- Engineering and Materials Testing provided cause of distress.
- Repair Details & Materials were selected to provide long term solution.
- Project was completed within 5 month summer schedule
- $1 Million Project was completed within 2% of Owner budget.
- Minimal Change Orders
- Contractor earned $50K bonus.
- Owner achieved a Dry Facility in Time for Winter Season
- Project received a 5 year Warranty

Success is achieved when Owners, Engineers, Contractors & Manufactures work together to develop Cost Effective Repair Solutions

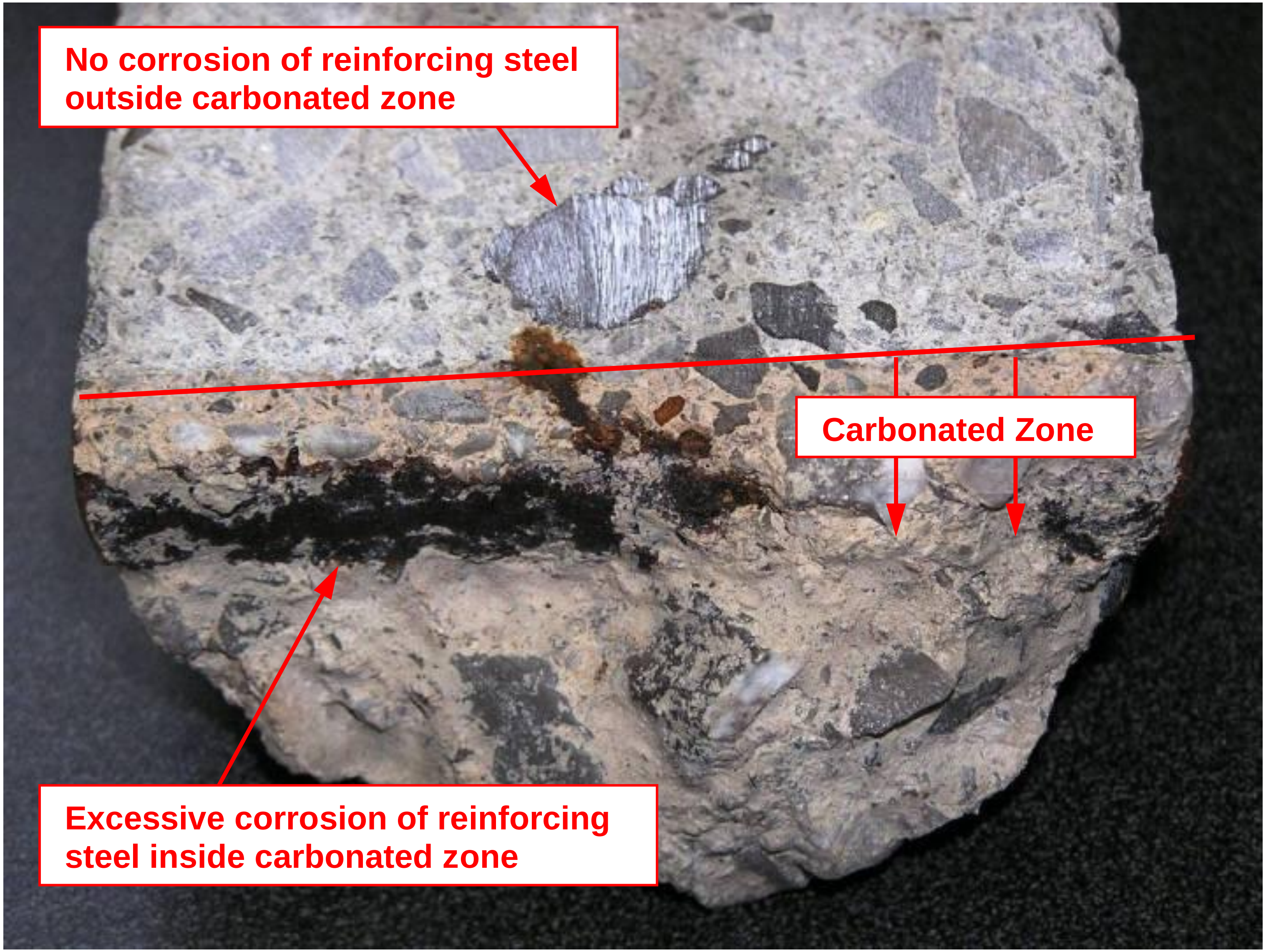
Questions ???

Westview Towers

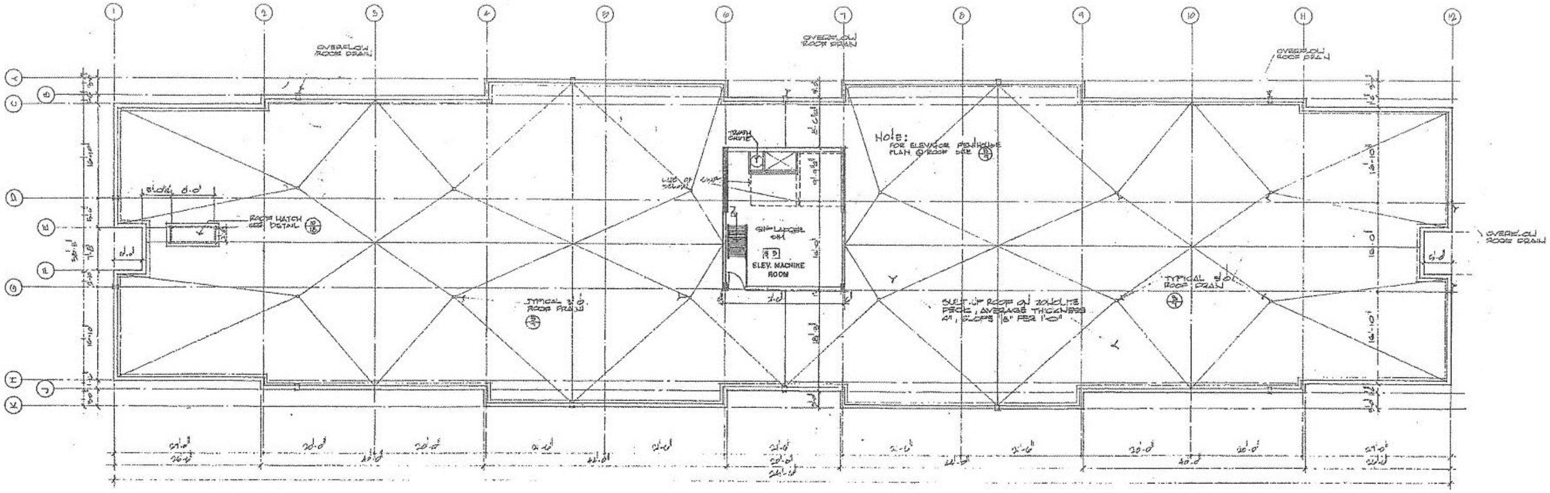
Overall of severe spalling of underside of roof slab *POSTER*.



Polished section of a concrete core illustrating corrosion in carbonated zone



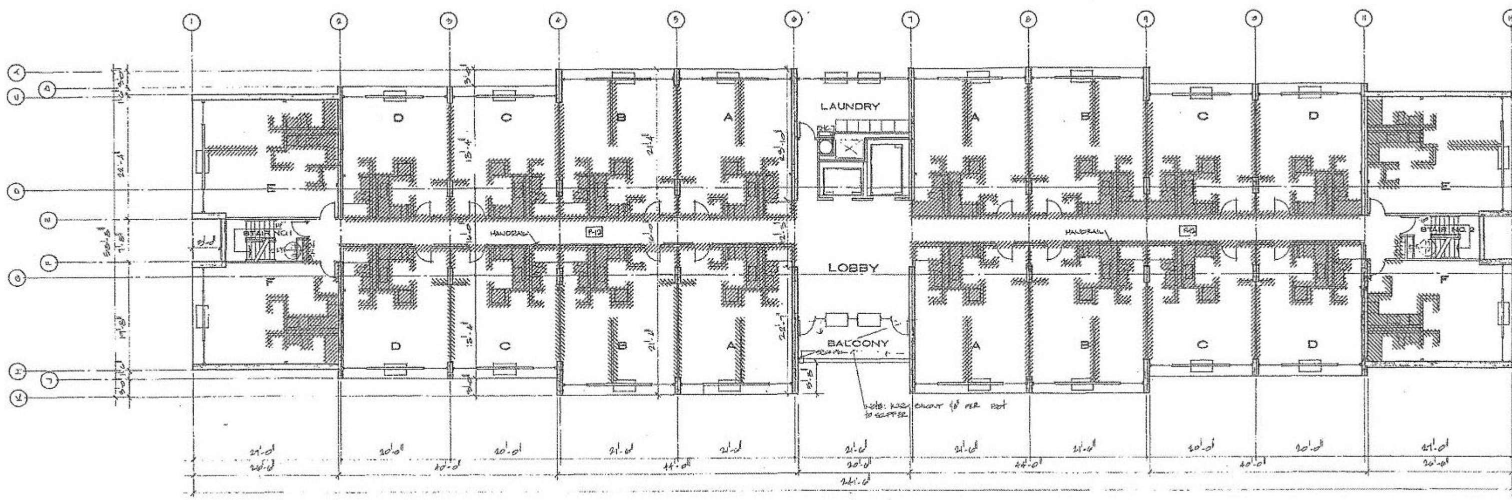
Concrete core illustrating corrosion within carbonated zone.

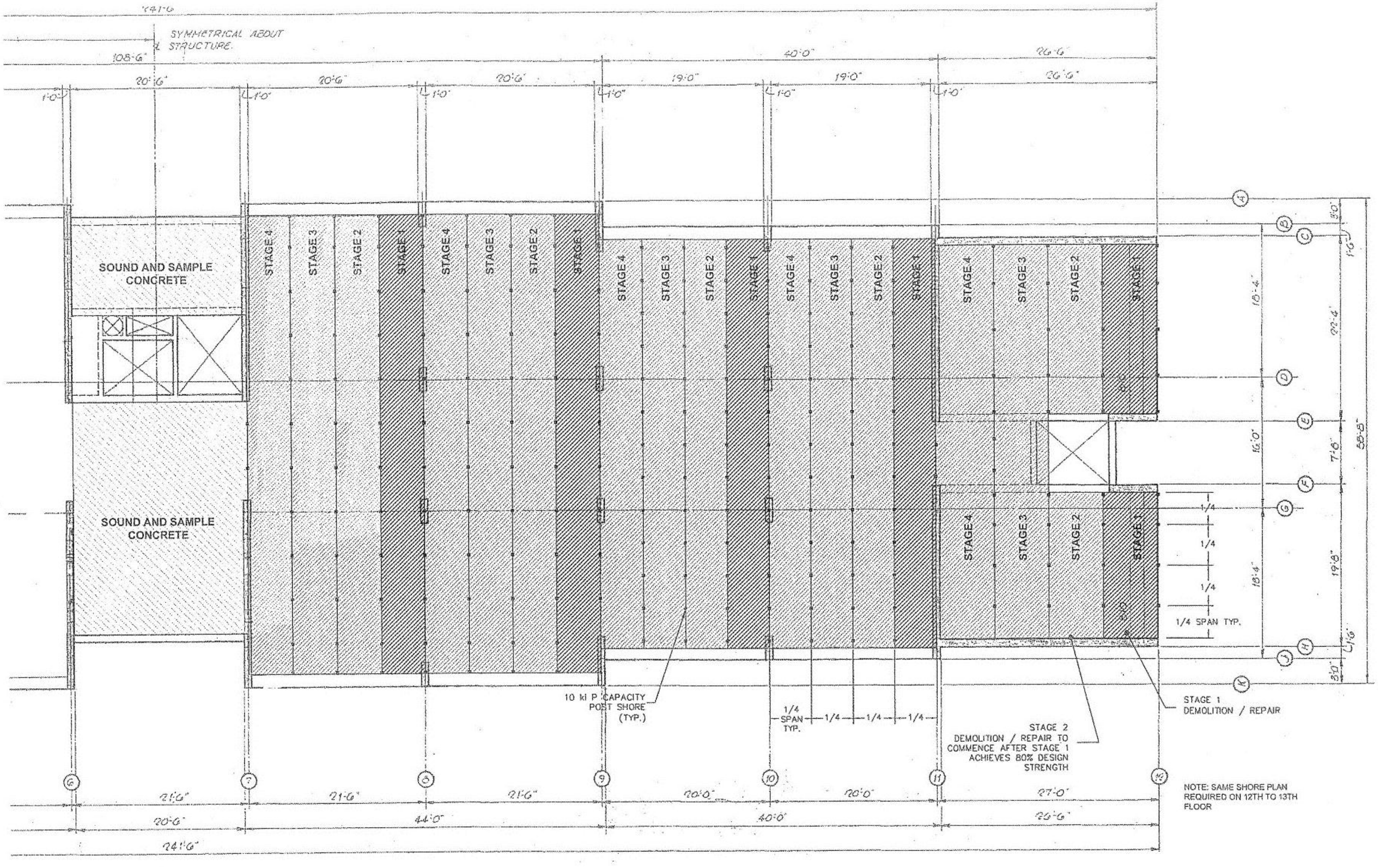


EXISTING ROOF PLAN 1/S2.0
SCALE: N.T.S.

REFERENCE: GREENER & SUMNER: WESTVIEW TOWER
SHEET 7 REV. 1, DATED 22 OCT. 1973

ALL NON-LOAD BEARING PARTITION
WALLS TO BE DEMOLISHED BY OWNER



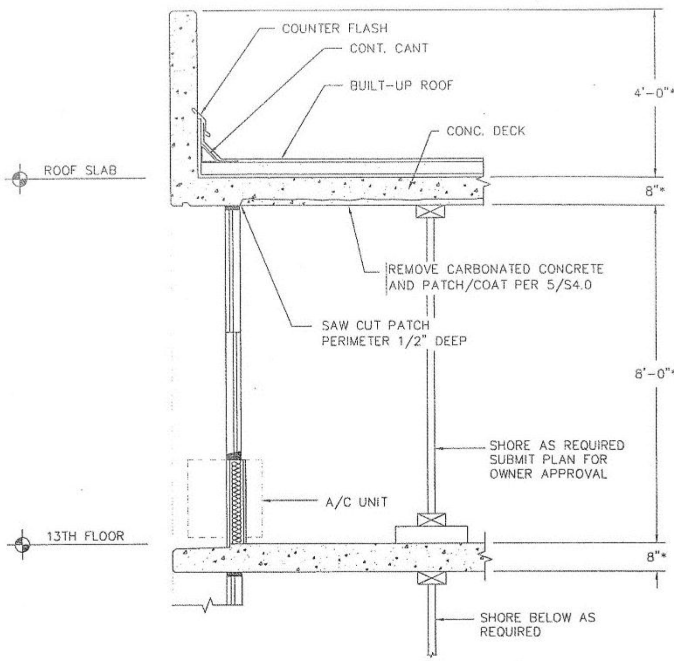


REFERENCE: GREENER & SUMNER: WESTVIEW TOWER SHEET 27 REV 1 DATED 22 OCT. 1973

EAST SIDE 13TH FLOOR TO ROOF SLAB SHORING PLAN

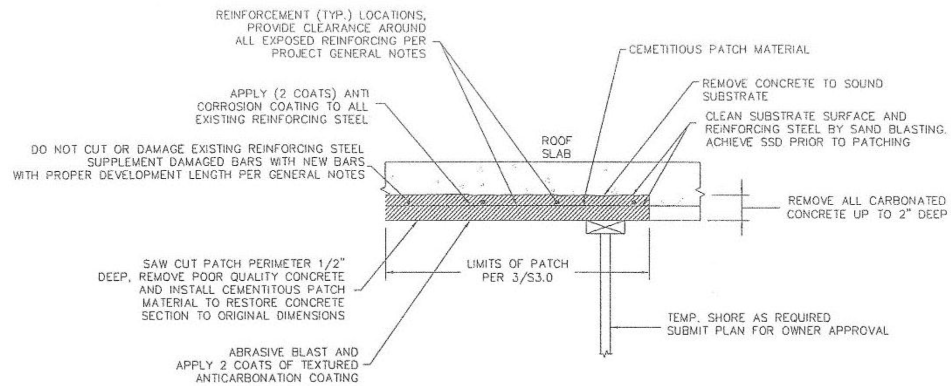
SCALE: N.T.S.

1 SP1.0

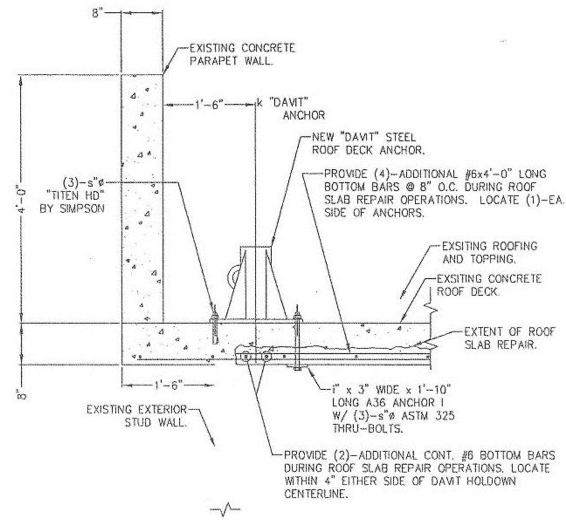


WALL SECTION (4/S4.0)
SCALE: N.T.S.

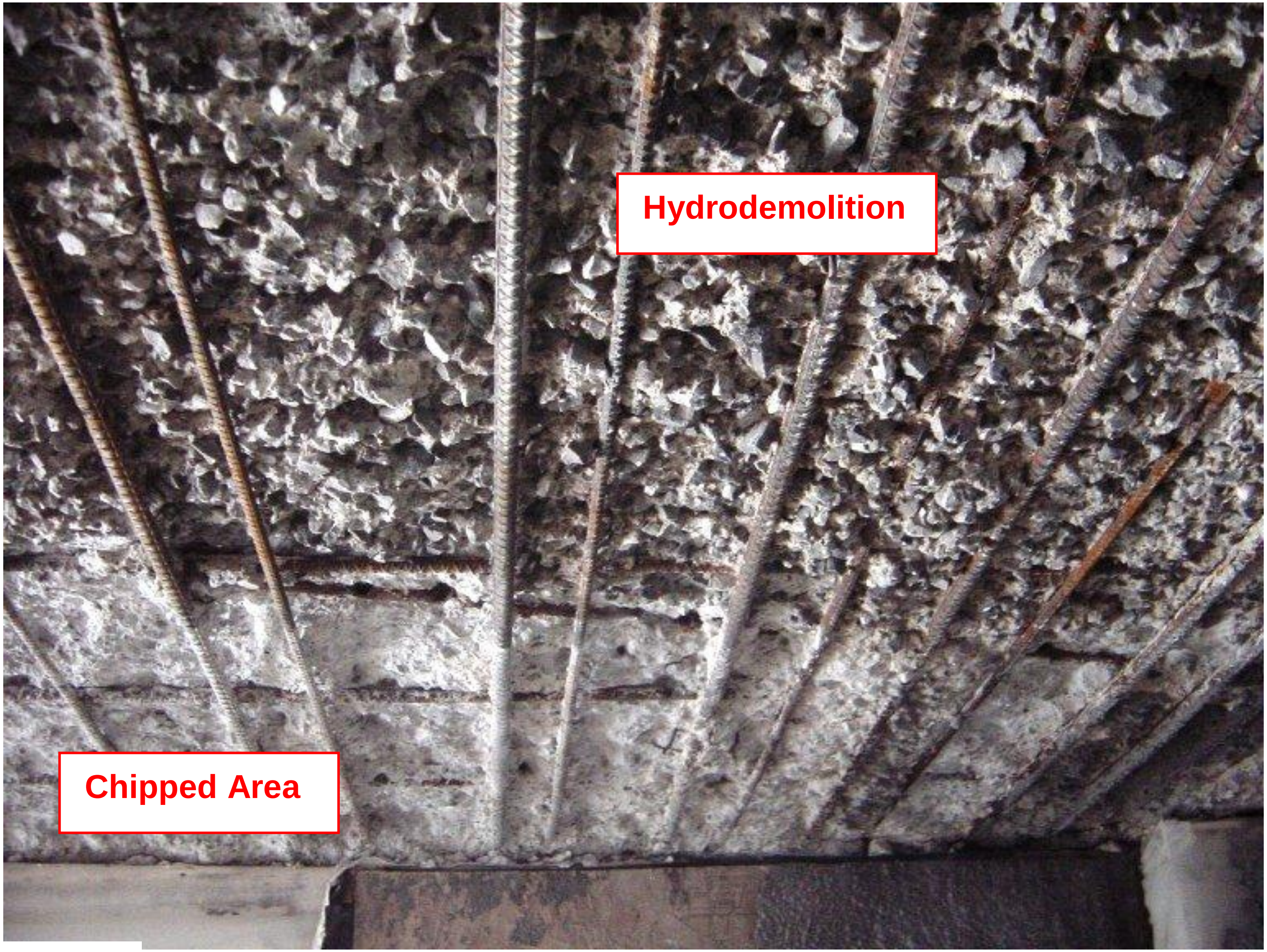
* DIMENSIONS PER ORIGINAL PROJECT DRAWINGS



OVERHEAD PARTIAL DEPTH SLAB PATCH (5/S4.0)
SCALE: N.T.S.



ADDITIONAL REINFORCEMENT MUST BE PROVIDED DURING SLAB REHABILITATION, REGARDLESS IF CARBONATED CONCRETE EXISTS IN THESE AREAS.



Overall illustrating difference between chipped area and hydrodemolition.

Carbonated concrete removed and carbonation checked with phenolphthalein.

Removal of existing concrete along side completed shotcrete repair *POSTER*.

Mixing station outside facility.

Overall of bond test core with failure within the substrate concrete.

Overall of completed repair.

Questions ???