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NON-DESTRUCTIVE TESTING FOR ASSESSMENT OF CONCRETE STRUCTURES

Alfred Gardiner, PE
Technical Concrete Leader, Principal Engineer

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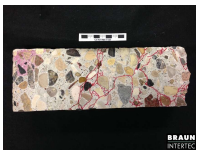
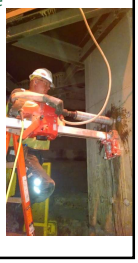
Non-Destructive Testing

- Generally defined as noninvasive method to determine concrete properties.
- Is coring non-destructive?

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NDT METHODS

- Tools of the Trade

Visual Inspection	Backscatter Radiometry	Penetration Resistance
Ultrasonic Pulse Velocity	Gamma-Gamma Logging	Maturity
Ultrasonic Echo	Half-Cell Potential	Resonant Frequency
Polarization	Ultrasonic Inspection	Wave Propagation
Sonic Echo	Fluid Penetrability	Acoustic Emission
Impulse Response	Liquid Penetrant	Modulus of Elasticity
Impedance Logging	Magnetic Particle	Load Testing
Cross-hole Sonic Logging	Positive Material Identification	Vibration Monitoring
Infrared Thermography	Static Testing	Covermeter
Ground Penetrating Radar	Dynamic Testing	Surface Hardness
Parallel Seismic Testing	Microscopic Evaluation	Radiography
Anchor Testing	Coring / Sampling	Instrumentation
F-Number / Floor Flatness	Strain Gauges	FEM Modeling

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SO…… I HAVE THIS PROBLEM?

CASE STUDIES AND EQUIPMENT

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Planning an NDT Investigation

- Plan with the end it mind
  - What are the goals?
  - Are there secondary goals?
  - What is the cost relative to the issue or possible repairs?
  - What is the timeline for the project?
  - How reliable will the NDT be?

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Planning for the Evaluation

- Logistics
  - How will get access the structure?
  - What part of the structures do we have access to?
  - Do we need specialized training?

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Safety

- Do we need site specific training?
- How do we reach the affected area?
- Can we get the equipment there?
- Should we alert authorities first?

If Osha was here we would be in jail lmfap

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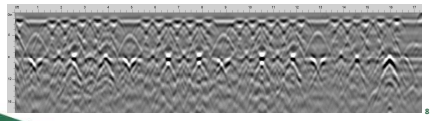
Reporting

- Data, Data, Data, Data, Data
- How do we report the data?
  - Sometimes presenting the data in a meaningful method is required for a client or other engineer.
  - This data needs to be used to develop solutions.



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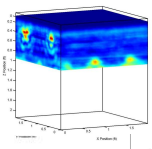
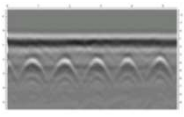
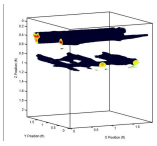
GROUND PENETRATING RADAR (GPR)







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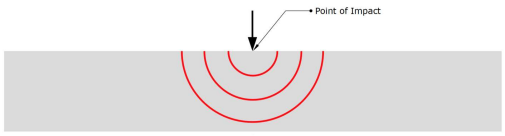
Wave Propagation



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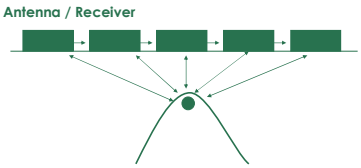
How it works



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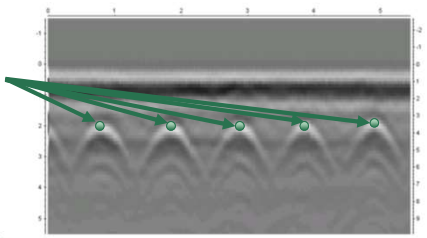
Simple Example

Reinforcing Locations



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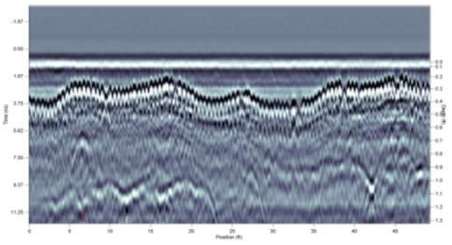
Typical Slab on Grade



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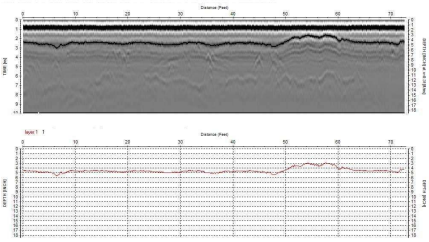
GPR – CONCRETE THICKNESS



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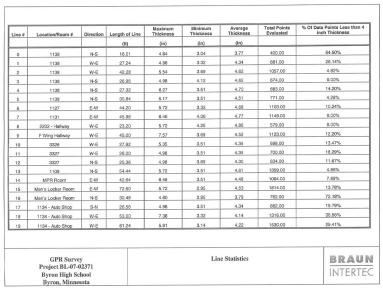
CASE STUDY – CONCRETE THICKNESS



Line #	Location/Room #	Direction	Length of Line (ft)	Maximum Thickness (in)	Minimum Thickness (in)	Average Thickness (in)	Total Points Evaluated	% Of Data Points Less than 4 Inch Thickness
0	1130	N-S	16.01	4.84	3.54	3.77	400.00	84.00%
1	1130	W-E	47.24	4.96	3.50	4.24	681.00	26.14%
2	1130	W-E	42.20	5.54	3.99	4.62	1057.00	4.92%
3	1130	N-S	20.90	4.98	4.13	4.45	574.00	8.02%
4	1130	N-S	27.30	8.27	3.51	4.72	685.00	14.89%
5	1130	N-S	30.84	8.17	3.51	4.51	771.00	4.28%
6	1127	E-W	44.20	8.72	3.30	4.08	1105.00	13.94%
7	1131	E-W	46.90	8.48	4.06	4.77	1149.00	8.00%
8	2002 - Hallway	W-E	23.20	5.72	4.35	4.80	579.00	8.00%
9	F Wing Hallway	W-E	45.00	7.57	3.99	4.58	1130.00	12.20%
10	2004	W-E	27.80	5.35	3.51	4.39	696.00	13.47%
11	2007	W-E	28.00	4.98	3.51	4.35	700.00	15.29%
12	2007	N-S	25.30	4.98	3.99	4.31	634.00	11.67%
13	1109	N-S	24.44	5.72	3.51	4.61	1069.00	4.86%
14	MPR Room	E-W	42.64	8.48	3.51	4.45	1064.00	7.88%
15	Men's Locker Room	E-W	72.80	8.72	3.80	4.53	1814.00	15.78%
16	Men's Locker Room	N-S	30.49	4.80	3.80	3.72	760.00	72.18%
17	1134 - Auto Shop	S-N	26.50	4.98	3.51	4.34	662.00	19.79%
18	1134 - Auto Shop	W-E	53.20	7.06	3.30	4.14	1316.00	36.80%
19	1134 - Auto Shop	W-E	61.24	8.91	3.14	4.22	1530.00	29.41%

GPR Survey
Project BL-07-01371
Byron High School
Byron, Minnesota

Line Statistics

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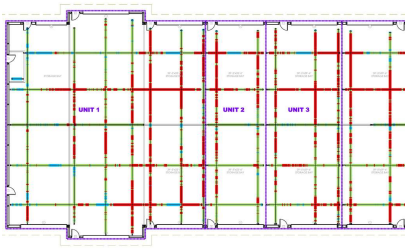
Visual Presentation



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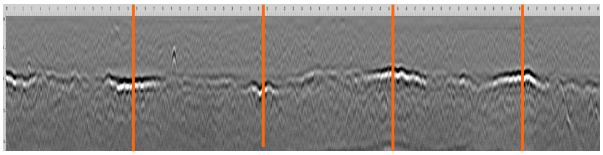
Slab Curling



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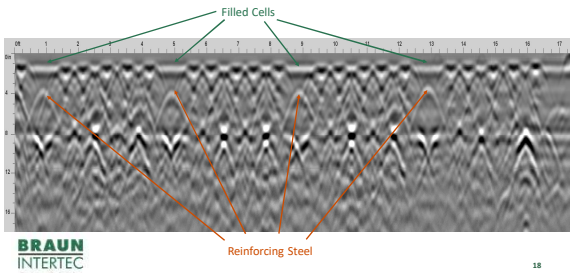
MISSED SPECIAL INSPECTION - MASONRY



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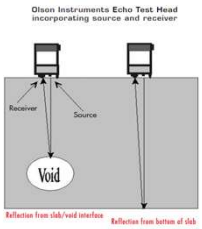
Impact Echo

- ASTM C1383 "Standard Test Method for Measuring Plates Using The Impact-Echo Method"
- Impactor, Transducers
- Baseline
  - Initial Arrival
  - Wave form
  - Frequency Spectrum (FFT)
- Collection Patterns



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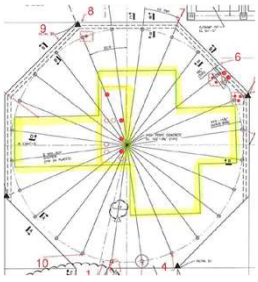
Only Access to One Side

- 4-foot-thick footing
- Yes, there are voids
- How much?



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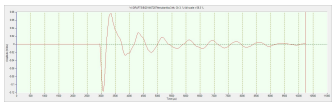
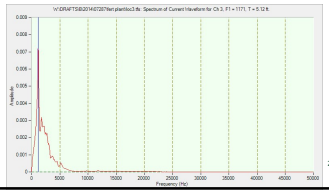
Wave analysis

- Wave



- Spectrum



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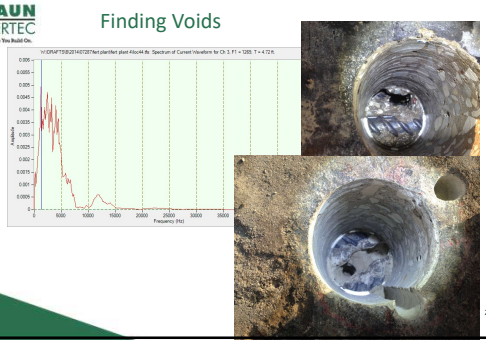
Finding Voids



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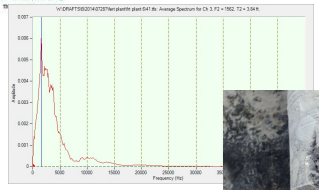
A little Different



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Summary

- Found additional void and consolidation issues.
- Filled voids with grout (75 gallons).
- Were able to return and retest after repairs were complete.
- Found a few areas with voids which were epoxy injected.
- Tested again and receive clean signals in the foundation.

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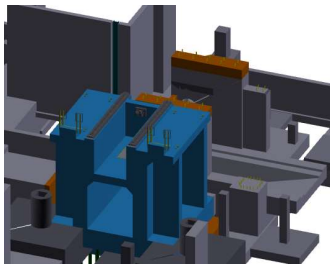
Arc Furnace Supports



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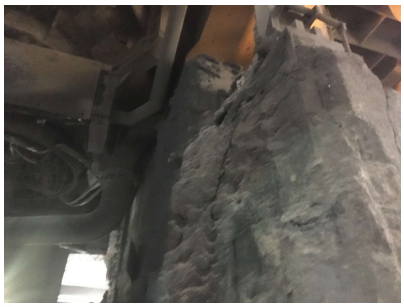

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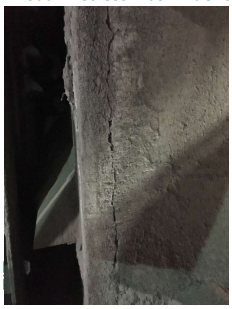
Visual Distress was Evident



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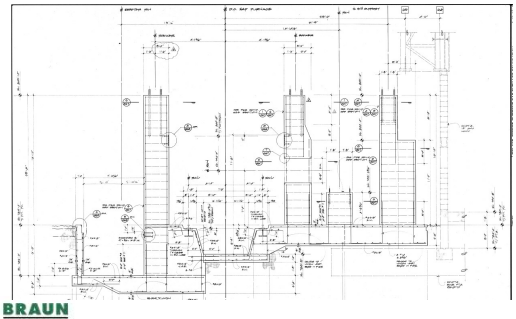

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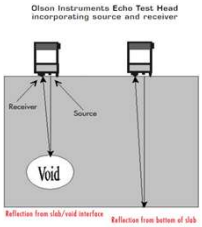
Scope

- Impact Echo
- Cores for Petrographic Analysis
- Visual Observations



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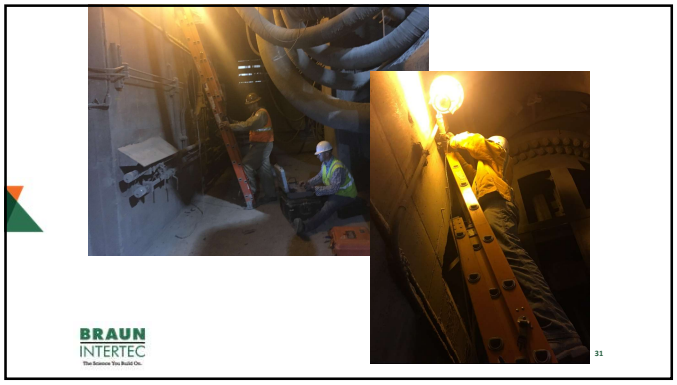

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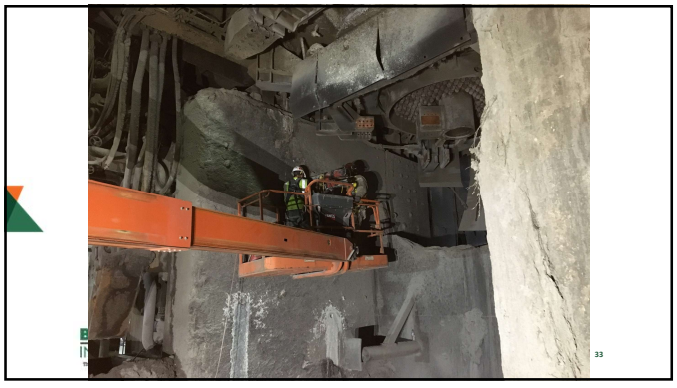

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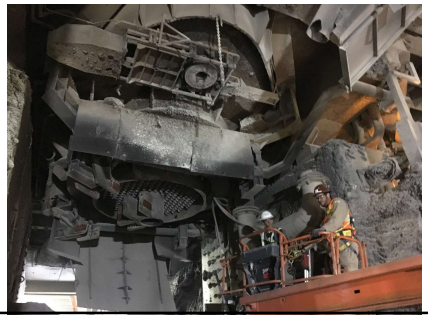
Yes it was hot



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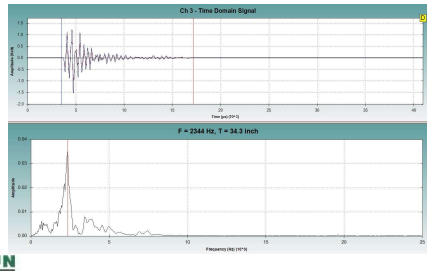
Sound Concrete EI Response



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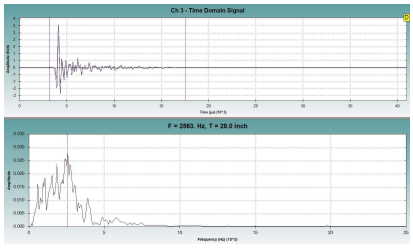
A Few Abnormal Responses from IE



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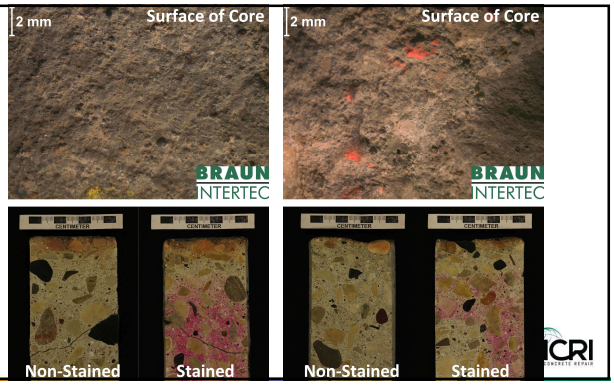

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Our Results

- Compressive Strength of Concrete ~6500 psi
- Most of the remaining concrete was sound
- Damaged Concrete is typically 1 to 1.5 inches from existing surface
- Molten material on surface provided some protection

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Recommendations

- Remove 1 to 1.5 inches of concrete from the interior faces of the columns
- Drill dowel into existing concrete
- Place a new interior grid of reinforcing steel on each pier
- Apply shotcrete to building up the piers

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Outcome

- Damage was less extensive then original thought
- Repair were conducts in several short outages
- Longer outage was used to only to install new equipment
- Less distribution to the plant operations.

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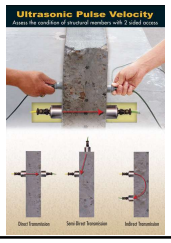
ULTRASONIC PULSE VELOCITY (UPV)

- ASTM C597 “Standard Test Method for Pulse Velocity Through Concrete
- Speaker, microphone
- Baseline
  - Initial Arrival
  - Wave form
  - Frequency Spectrum (FFT)
- Collection Patterns



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ULTRASONIC PULSE VELOCITY (UPV)

- 4 Columns
- 6 feet x 7feet x 36 feet
- 8 feet Max Hydrostatic Head
- Self Consolidating Concrete
- Delayed 22 inch lifts

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ULTRASONIC PULSE VELOCITY (UPV)

- Cold Joints?
- Proper Consolidation?

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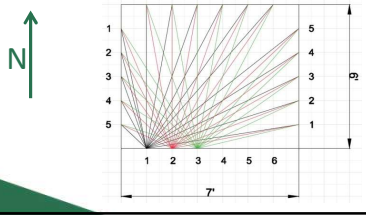
Collection Patterns

- Method 1 (Baseline) – 192 paths through plane



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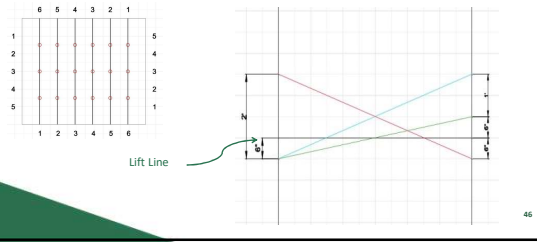
Collection Patterns

- Method 2 – 18 paths through plane



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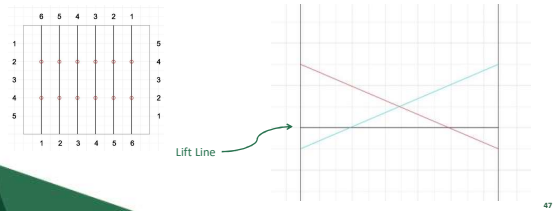
Collection Patterns

- Method 3 – 12 paths through plane



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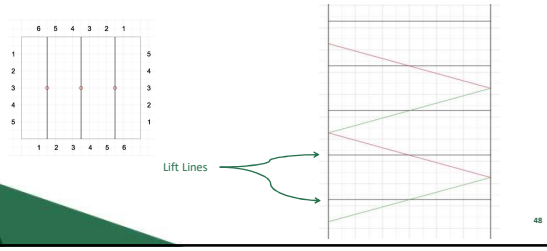
Collection Patterns

- Method 4 – 3 paths through plane



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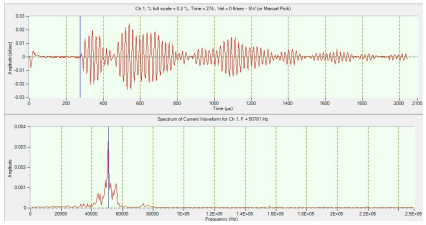
NDT – Data Analysis

- Good UPV Signal



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NDT – Data Analysis

- Bad UPV Signal

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NDT – Data Analysis

Folder	File	y(ft)	x(ft)	Path r(ft)	Amplitude (m/s)	Arrival Time (µs)	Velocity (ft/s)	Velocity (m/s)	Outside Range (3500 M/s - 5500 m/s)	Comment

Path = (x^2+y^2+1)^0.5

Velocity= Path/Arrival Time

PULSE VELOCITY	CONCRETE QUALITY
>4000 m/s	Very good to excellent
3500– 4000 m/s	Good to very good, slight porosity may exist
3000 – 3500 m/s	Satisfactory but loss of integrity is suspected
<3000 m/s	Poor and los of integrity exist.

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NDT – Data Analysis

Folder	File	y(ft)	x(ft)	Path z(ft)	Amplitude (m/s)	Arrival Time (μs)	Velocity (ft/s)	Velocity (m/s)	Outside Range (3500 M/s – 5500 m/s)	Comment
Column 1, Elevation: 5 Feet Above Slab, (Method 1) North and West Face										
1x5	1x51	6	1	6.16	0.005	458	13459	4102		
1x5	2	6	2	6.40	0.009	462	13860	4224		
1x5	3	6	3	6.78	0.004	491	13813	4210		
1x5	4	6	4	7.28	0.005	519	14027	4276		
1x5	5	6	5	7.87	0.013	538	14636	4461		
1x5	6	5	1	5.20	0.009	472	11009	3356	-144	Coupling Issue
1x5	7	5	2	5.48	0.005	451	12145	3702		
1x5	8	5	3	5.92	0.006	407	14536	4431		
1x5	9	5	4	6.48	0.009	435	14898	4541		
1x5	10	5	5	7.14	0.009	496	14398	4389		
1x5	11	4	1	4.24	0.025	298	14237	4340		
1x5	12	4	2	4.58	0.007	325	14100	4298		
1x5	13	4	3	5.10	0.015	315	16187	4934		
1x5	14	4	4	5.74	0.004	399	14397	4388		
1x5	15	4	5	6.48	0.006	451	14370	4380		
1x5	16	3	1	3.32	0.03	236	14053	4284		
1x5	17	3	2	3.74	0.015	264	14173	4320		
1x5	18	3	3	4.36	0.008	303	14386	4385		
1x5	19	3	4	5.10	0.009	356	14323	4366		
1x5	20	3	5	5.92	0.002	406	14572	4441		
1x5	21	2	1	2.45	0.015	174	14078	4291		
1x5	22	2	2	3.00	0.013	220	13636	4156		
1x5	23	2	3	3.74	0.02	261	14336	4370		
1x5	24	2	4	4.58	0.01	325	14100	4298		
1x5	25	2	5	5.48	0.006	402	13625	4153		
1x5	26	1	1	1.73	0.05	125	13856	4223		
1x5	27	1	2	2.45	0.06	122	20078	6120	620	
1x5	28	1	3	3.32	0.03	230	14420	4395		
1x5	29	1	4	4.24	0.013	367	11560	3524		
1x5	30	1	5	5.20	0.008	390	13323	4061		

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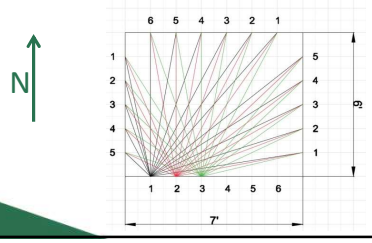
Collection Patterns

- Method 1 (Baseline) – 192 paths through plane



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NDT – Data Analysis

Folder	File	y(ft)	x(ft)	Path z(ft)	Amplitude (m/s)	Arrival Time (μs)	Velocity (ft/s)	Velocity (m/s)	Outside Range (3500 M/s – 5500 m/s)	Comment
Column 1, Elevation: 5 Feet Above Slab, (Method 1) North and West Face										
1x5	1x51	6	1	6.16	0.005	458	13459	4102		
1x5	2	6	2	6.40	0.009	462	13860	4224		
1x5	3	6	3	6.78	0.004	491	13813	4210		
1x5	4	6	4	7.28	0.005	519	14027	4276		
1x5	5	6	5	7.87	0.013	538	14636	4461		
1x5	6	5	1	5.20	0.009	472	11009	3356	-144	Coupling Issue
1x5	7	5	2	5.48	0.005	451	12145	3702		
1x5	8	5	3	5.92	0.006	407	14536	4431		
1x5	9	5	4	6.48	0.009	435	14898	4541		
1x5	10	5	5	7.14	0.009	496	14398	4389		
1x5	11	4	1	4.24	0.025	298	14237	4340		
1x5	12	4	2	4.58	0.007	325	14100	4298		
1x5	13	4	3	5.10	0.015	315	16187	4934		
1x5	14	4	4	5.74	0.004	399	14397	4388		
1x5	15	4	5	6.48	0.006	451	14370	4380		
1x5	16	3	1	3.32	0.03	236	14053	4284		
1x5	17	3	2	3.74	0.015	264	14173	4320		
1x5	18	3	3	4.36	0.008	303	14386	4385		
1x5	19	3	4	5.10	0.009	356	14323	4366		
1x5	20	3	5	5.92	0.002	406	14572	4441		
1x5	21	2	1	2.45	0.015	174	14078	4291		
1x5	22	2	2	3.00	0.013	220	13636	4156		
1x5	23	2	3	3.74	0.02	261	14336	4370		
1x5	24	2	4	4.58	0.01	325	14100	4298		
1x5	25	2	5	5.48	0.006	402	13625	4153		
1x5	26	1	1	1.73	0.05	125	13856	4223		
1x5	27	1	2	2.45	0.06	122	20078	6120	620	Travel Along Steel
1x5	28	1	3	3.32	0.03	230	14420	4395		
1x5	29	1	4	4.24	0.013	367	11560	3524		
1x5	30	1	5	5.20	0.008	390	13323	4061		

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NDT – Data Collection

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NDT – Data Analysis

- 1152 Data points
- Data and cores revealed poor consolidation was limited to cover of rebar cage.
- Outliers excluded; the results indicated well consolidated concrete

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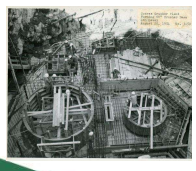
Mining Crusher

- Foundation concrete placed in 1954
- Pellet production began in 1956
- Crusher has been in service for 59 years



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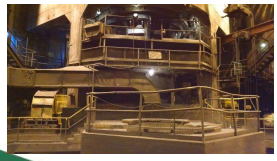
Coarse Crusher Concerns

- Concerns of fatigue damage
- Visual distress on 2 of 4 columns



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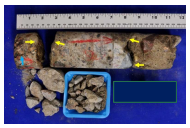
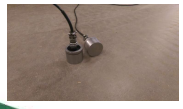
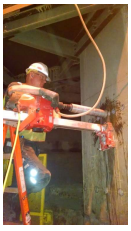
Approach

- Non-Destructive Testing (UPV)
- Core samples
- Petrography







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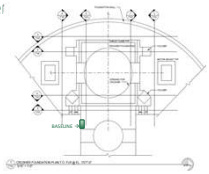
Baseline

- Selected in an area assumed to receive a lower level of vibrations
- Wingwall on level below crusher
- 15 data points collected
- Average = 3786 m/sec



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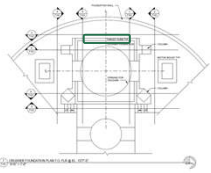
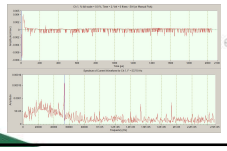
Crusher Pad

	0	2 ft	4 ft	6 ft	8 ft	10 ft	12 ft	14 ft	16 ft	18 ft	20 ft
1 ft		2655	2843	2171	1718	2201	2380	3693	3610	3693	4016
2 ft		3679	1913	3839	2109	3377	2848	3511	3723	2888	3679
3 ft		2805	2805	1933	5444	2958	3539	5444	3036	2135	3580
4 ft		2512	2544	2713	3719	2762	2216	1961	3696	2654	3361

- East Face
  - Limiting Geometry
  - Frequency Domain
- West Face
  - Inconsistent Data





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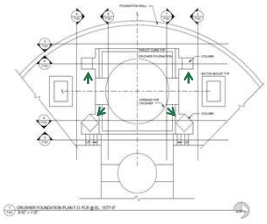
Columns

- West Columns vs. East Columns Visually
- East Columns
  - Pattern observed near rebar cage
- West Columns
  - No Signal
  - Inconsistent Signal



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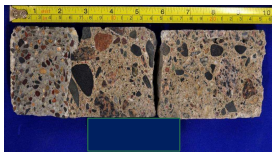
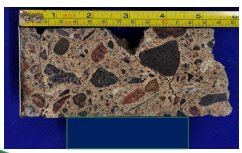
Crusher Pad Core Samples

- Large-scale cracking
- Limited microcracking
- Repair material





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Southwest Column Core Sample

- Surface-parallel cracking

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Conclusions

- Cracking occurring near rebar cage
- No significant microcracking
- Damage on the west columns extends beyond the surface

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Summary

- Keep the end in mind
- What is the goal of the evaluation
- What tools are best suited to get the answers you need
- Sometimes NDT is not the correct method.

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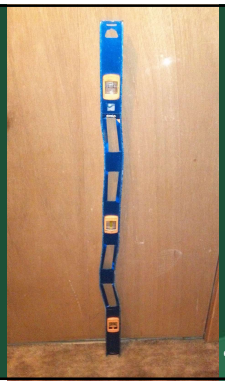
RIGHT TOOL FOR THE RIGHT JOB

Questions?



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