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LOWER LOCKS PARKING GARAGE NONDESTRUCTIVE TESTING AND CONCRETE ANALYSIS REPORT

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ABSTRACT:

The deteriorating condition of the concrete in the Lower Locks parking garage was assessed through Ultrasonic Testing, a Non-Destructive Testing method. This report focuses on the results from Team 2's final inspection. Cast-In-Place concrete slabs, prestressed concrete beams and columns were tested at sites where there were no visible defects found and also where defects could clearly be seen as identified in the visual inspection. The results of the tests helped provide a comparison of "good concrete" and "bad concrete" using shear wave velocities. Results varied due to the different conditions of the concrete and ability to properly test it. In general, variances in results could be seen in the defective concrete and concrete with no visible defect.

BACKGROUND:

As part of UMass Lowell's Service-Learning Program, students have been asked by the City of Lowell to assess the condition of the Lower Locks parking garage, located at 90 Warren Street in Lowell, MA.

The Lower Locks parking garage is a five level concrete structure comprised of both cast-in-place and prestressed concrete. The garage was constructed nearly three decades ago. There are three stairwells located in the parking garage, two along its south side and one along the north side. An elevator is located near the UML student entrance.

The first level is reserved for UMass Lowell student parking only, while the other levels are open to the public. Students have access to the parking garage by going the lower entrance located across from the University's Inn & Conference Center. The public gains access to the parking garage through the entrance off of Warren Street.

The first portion of the service learning project consisted of identifying defects in the concrete elements of the parking garage and ranking them in order of importance to the overall structural health of the garage. This report is the second portion of the project. In this portion of the project, nondestructive testing was to be used to determine a comparison of "good concrete" and "bad concrete" based on testing those elements previously determined to have a defect.

AVAILABLE INFORMATION:

During the visual inspection, our team used plans of the Lower Locks parking garage, provided by the city of Lowell. Plans were created by Engineers Design Group, Inc. City of Lowell Parking Director, James Troup, was our main contact during the initial and subsequent inspection.

INTRODUCTION:

There has been a great effort since the 1940's to produce rapid, nondestructive test that would provide a reproducible measure of the quality of concrete in a structure without damaging the concrete or the performance of a structure. A nondestructive test that is widely used in the world is ultrasonic pulse velocity. In order to use the ultrasonic testing it is important to understand the physics involved.

A mechanical wave is a wave that propagates as an oscillation of matter, and therefore transfers energy through a medium. Ultrasound is an oscillating sound pressure with a frequency of 20 kHz and above. Thus, ultrasound is just a sound wave in which the human anatomy cannot interpret the number of cycles of medium compressions/rarefactions per second. For waves the higher the frequency, the less depth penetration, however the resolution is improved.

In solids, sounds waves can propagate in four principle modes that are based on the way the particles oscillate. Longitudinal and shear waves are the two modes of propagation most widely used in ultrasonic testing. Using an ultrasonic device we can determine time that it takes for the mechanical waves to propagate from the transducers to receivers. Knowing the time and distance the device can determine the velocity of the wave.

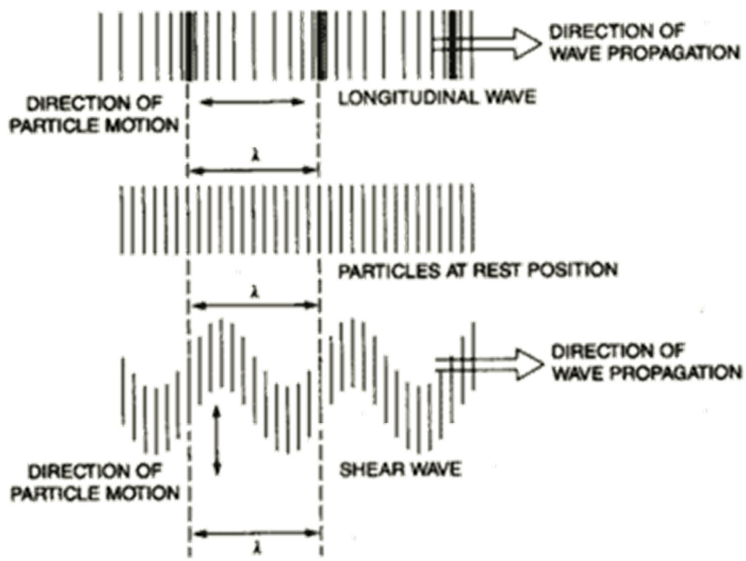

Figure 1: Longitudinal and shear waves

EQUIPMENT:

All nondestructive testing was performed using the proceq Pundit Lab Plus Ultrasonic Instrument. The ultra sonic velocity equipment includes a transducer, a receiver and an indicator for showing the time travel from the transducer to the receiver (pundit manual 2011). To produce the oscillations needed the ultrasonic pulse uses rapid potential difference to create vibrations. To vibrate the concrete the transducer is securely attached to the concrete surface. The receiver will get the pulses that are going through the concrete.

The velocity of the pulse can be found by using the following equation:

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Where v = pulse velocity (ft/s), d=path length (ft), t= transit time (µs)

The velocity of sound in a concrete is also related to the concrete modulus of elasticity and density:

Where, E = modulus of elasticity, = density of the concrete

The transducer detects the pulses, which gets to it first. The mode that reaches the transducers first is longitudinal vibration. The positions of pulse velocity measurements that Team 2 used were direct transmission and indirect or surface transmission. For our testing we used the direct method for columns and beams. The indirect method was used for slabs. Ultrasonic Tests can be performed by placing the transducers in a range of positions, which include direct, semi-direct, and indirect, as seen in the figure below. It is important that the proper placement of the transducers is used in order to obtain accurate results. When the direct method is used, there is minimal transmission of energy across a concrete-air boundary. This will cause the pulse to diffract around the defect, increasing the time it takes to travel to the receiver. The indirect method is used when contact of two surfaces is not possible. Waves travel through the test specimen and are sensed by the receiver.

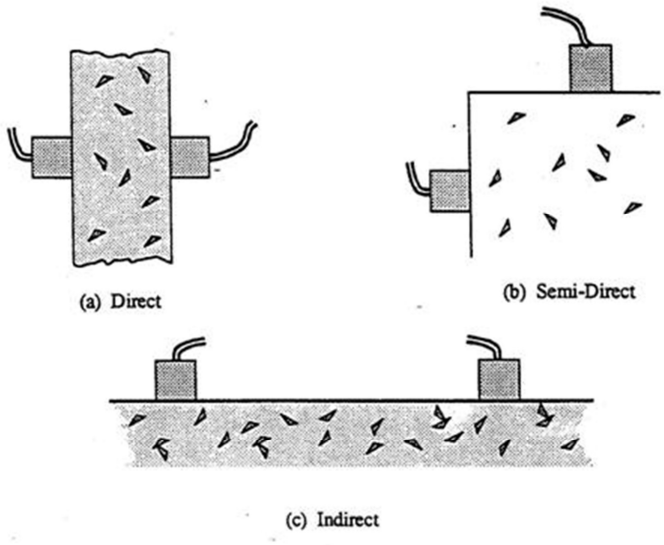


Figure 2: Schematic of direct, semi-direct

RESULTS OF NON-DESTRUCTIVE TESTING:

During the visual inspection, many components of the garage were identified as having a visual defect. Many defects were observed in multiple locations and therefore due to time constraints, ultrasonic testing was only conducted on the defects that Team 2 deemed to be most critical to the overall structural health of the structure. Some defects such as ponding water or deteriorated expansion or contraction joints were not investigated in this report because ultrasonic testing would yield no usable data.

Research into ultra-sonic testing of concrete has produced many empirical equations and methods to determine the mechanical properties of concrete, such as compressive stress and elastic modulus. Many of these methods have a low level of accuracy based on large amounts of experimental error associated with concrete as an engineering material. As a basis for establishing reasonable results, Team 2 elected to compare the shear wave velocity provided by the Ultrasonic tester to the specimen with a known defect and to the control specimen as a basis for the strength of the concrete. This methodology is based on research by Muhure et al., 2011. The equation used below is a direct correlation between pulse velocity and compressive strength.

$$CV = 4.104PV + 19.23$$

Where CV is compressive strength in MPa and PV is the pulse wave velocity in km/s.

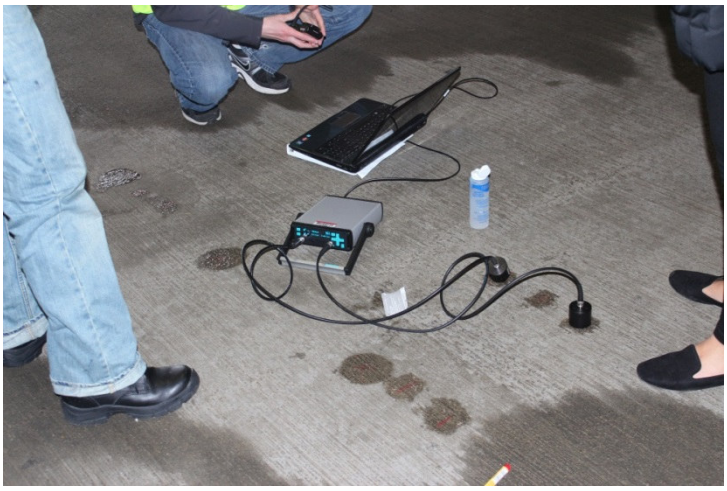
In order to determine the characteristics of "bad concrete" tests were conducted on elements that were identified in the visual inspection which had known defects such as cracking, spalling, corrosion, etc. Duplicate tests were conducted on the other elements that were free of visual defects and assumed to not contain any subsurface defects. The results are as follows.

A. CAST-IN-PLACE CONCRTE SLAB

During the visual inspection, the observed defect on the cast-in-place concrete slab deemed to be most critical was the spalled concrete on the ceiling located at north part of level 1. It is about one meter in length and half meter in width. Due to the location of the defect, a surface test on the top of the slab was conducted from level 2. Surface testing was the chosen method of testing because the leads from the transducer to the receiver are of insufficient length for direct testing. Since this defect was observed on portions or concrete that was cast-in-place, the baseline tests were performed on concrete free of visible defects as close as possible to the observed defect in order to limit the possibility of experimental error due to differences in cast-in-place concrete batches.

Photograph 1 – Corroded Reinforcing and Spalled Concrete – Bottom View

In an attempt to limit error from the presence of rebar, and to obtain average readings, several readings were conducted in a uniform pattern. This pattern consisted of a cross shape with a minimum of three readings taken in each direction. The t_1 measurements were taken at a transducer to receiver length of 5" and the t_2 measurements were taken at a transducer to receiver length of 10".



Photograph 2 - Cast-In-Place Slab Testing (Surface Testing)

A summary of the surface testing data for the cast-in-place slab with the visual defect and the control specimen can be seen below in Table 1. As is evident with the data, the slab with known defects has a slower average wave velocity and the lower compressive strength than the portion of the slab that was free from visual defects.

Table 1. Cast-In-Place Slab Test Results

Specimen With Visual Defect

Test No.	t_1	t_2	velocity (meter/sec)	Average Velocity (m/sec)	Compressive Strength (Mpa)
678	57.4	109	2463		
679	80.2	139.6	2140		
509	87.1	146.6	2173		
510	62.3	124.9	2030		
511	48.8	107.3	2136	2188.4	28.21

Control Specimen

Test No.	t_1	t_2	velocity (meter/sec)	Average Velocity (m/sec)	Compressive Strength (Mpa)
673	462.3	963.4	254		
674	368.8	949.3	219		
675	98	954.2	148		
676	82.7	163.9	1565		
677	60.4	140.9	1579	753	22.32

B. COLUMNS

As detailed in the visual inspection, many columns are in bad condition. The column deemed by Team 2 to be in the most critical condition was B-16. The column observed to be in good condition and used for the control specimen was B-15 which is the next column. Because these columns had a known width and length dimension, direct testing could be conducted on each axis. As stated in the proceq Pundit Lab Operating Instruction, the direct method ensures the maximum signal transmission between the transducer and receiver.

Based on the observed level of cracking and deterioration in the test column multiple measurements at several heights were taken on both the wide and narrow faces of the columns in an effort to intersect the multiple cracks. Similar to the cast-in-place slab, the shear wave velocity was used to estimate the compressive strength of the columns and to compare “good concrete” with “bad concrete”. The test results are provided below in Table 2.

Photograph 3 – Defect Column

Photograph 4 – Control Column

Table 2. Column Test Results.

Specimen With Visual Defect

Test No.	t_1	t_2	velocity (meter/sec)	Average Velocity (m/sec)	Compressive Strength (Mpa)
522	347.5	N/A	1810		
523	348.5	N/A	1804		
524	157.5	N/A	3992		
525	250.3	N/A	2512	2530	29.61
Control Specimen					
Test No.	t_1	t_2	velocity (meter/sec)	Average Velocity (m/sec)	Compressive Strength (Mpa)
518	150.4	N/A	4181		
519	151.1	N/A	4161		
520	147.5	N/A	4263		
521	149.9	N/A	4195	4200	36.47

C. PRESTRESSED CONCRETE DOUBLE TEE BEAMS.

During the visual inspection of the parking garage, several prestressed beams were observed to have longitudinal cracks along the base of the web. Since contact of both sides of a beam could be reached, the direct method was applied when testing the prestressed beams on the first floor of the Lower Locks garage. The defective beam chosen by Team 2 as the most critical was the beam near column C3-8 located on the first floor.

Three tests were done on the control prestressed beam as well as the defective beam. The results can be seen in Table 3. Again, consistent with previous results, the beams with defects show a lower velocity and a lower compressive strength.

Photograph 5 – Defective Prestressed Beam With Test Locations – Bottom View

Table 3. First Floor Prestressed Beam Test Results.

Specimen With Visual Defect					
Test No.	t_1	t_2	velocity (meter/sec)	Average Velocity (m/sec)	Compressive Strength (Mpa)
526	30.3	N/A	4406		
527	31.5	N/A	4238		
528	30.6	N/A	4363	4336	37.02
Specimen With Visual Defect					
Test No.	t_1	t_2	velocity (meter/sec)	Average Velocity (m/sec)	Compressive Strength (Mpa)
530	30.3	N/A	4406		
531	32.3	N/A	4103		
532	45.4	N/A	2941	3816	34.89

D. PRESTRESSED BEAM TOP FLANGE ON FIFTH FLOOR

During the visual inspection, deterioration around the existing drain had caused the end of the prestressed beam to completely disintegrate. The moisture has also caused cracking in the top flange as seen from and below.

Photograph 6 – Defective5th Floor Prestressed Beam– Bottom View

In order to test the concrete slab on the fifth floor, the indirect method was utilized. The transducers were placed on the top of the prestressed concrete beam flange at five-inch increments for four tests at each site. Once these results were obtained, four more tests were done at a distance of 12 inches below the original testing locations. Extra sets of tests were done on the defective side of the concrete slab since deterioration and cracking was so severe.

Photograph 7 Control 5th Floor Prestressed– Bottom View

Control Specimen

Test No.	t_1	t_2	velocity (meter/sec)	Average Velocity (m/sec)	Compressive Strength (Mpa)
544	78.2	147.9	1823.62		
545	93.7	186.9	1363.68		
546	84.8	143.3	2172.61		
547	51	170.1	1067.10		
548	415.8	979.9	45.11		
549	86.6	151.7	1952.55		
601	63.6	139.5	1674.88		
660	46.2	122	1676.70	1676	26.11

Specimen With Visual Defect

Test No.	t_1	t_2	velocity (meter/sec)	Average Velocity (m/sec)	Compressive Strength (Mpa)
661	57.4	112.4	2310.99		
662	44.3	126.4	1548.08		
663	65.8	190.6	1018.34		
664	96.5	1029.2	136.25		
665	59.4	139.9	1578.86		
666	61.9	142.7	1573.07		
667	77.9	138.2	2107.69		
668	87.3	156.4	1839.47		
669	127.2	403.3	460.25		
670	78	148.8	1795.27		
671	66.5	184	1081.74		
672	69.6	140.7	1787.65	1436	25.13

Table 4. 5th Floor Prestressed Beam Test Results.

A clear difference could be observed when the transducers were placed directly on a crack. For instance, the velocity found from one crack was 1082 m/s while the velocity where the transducer wasn't placed on a crack was 1795 m/s. The average velocity for the control concrete was approximately 1676 m/s and 1436 m/s for the defective concrete.

SUPPLEMENTAL INSPECTION

During the visual inspection, Team 2 identified that a drain on the fifth floor was not located at the low point for drainage, and that this had resulted is deterioration in both the cast-in-place closure pour and in the prestressed beam flange. The deterioration in the corner of the prestressed flange was so severe that a hole was developing. This prestressed beam is the same beam tested in section D of this report. On

March 18, 2013 Jim Troup, the Parking Director for the City of Lowell, sent an email to Team 2 indicating that this hole had increased in size. Below are pictures of the location in question from the visual inspection (February 2013) and the nondestructive testing (May 2013).

Photograph 8 - 5th Floor Prestressed Beam Flange (February 2013)

Photograph 8 - 5th Floor Prestressed Beam Flange (May 2013)