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Evaluation of the Use of Lithium Compounds in Controlling Alkali-Silica Reactivity in Concrete Pavement

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Nebraska Department of Roads
Project Number RDT-QX5(1)

US Army Corps of Engineers
Omaha District

University of Nebraska Lincoln

NDOR
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16. Abstract

Presented herein are findings from a three-year field trial in which lithium nitrate was applied on an existing concrete pavement in Norfolk, Nebraska, in the attempt to arrest on-going alkali-silica reaction (ASR) distress. Various destructive and non-destructive means were utilized to measure the effectiveness of the lithium treatments. Concrete cylinders were cored for petrographic examination and split-tension testing. Powder samples were taken to determine lithium content. Nondestructive evaluations included using crack mapping, a Schmidt hammer, a velocity ("V") meter, and an impact echo apparatus. The results to date have not shown definitive benefits of the lithium material in arresting the ASR process; however, the observed lithium penetration by gravity soaking has been very limited. Presumably the pavement has not reached the deterioration state for optimal permeability for penetration of the lithium material.

Other application techniques on hardened concrete such as surface pressurization and vacuum impregnation have been investigated to a limited extent as an alternate method to gravity soaking. The surface pressurization technique has shown promising results in so far as achieving higher lithium contents. Effort is now needed in achieving higher lithium contents on a larger scale so that a more realistic evaluation of the effects of the lithium can be preformed.

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List of Acronyms

ASR: Alkali-Silica Reaction

EDX: Energy Dispersive X-Ray Fluorescence Spectronmetry

FHWA: Federal Highway Administration

K2O: Potassium Oxide

lbs: pounds

LiOH: Lithium Oxide

LiNO3: Lithium Nitrate

NDT: Non-Destructive Evaluation Techniques

Na2O: Sodium Oxide

SEM: Scanning Electron Microscopy

SHRP: Strategic Highway Research Program

SSD: Saturated Surface Dry

TOC: table of contents

USACE: United States Army Corps of Engineers

V-Meter: Velocity Meter

List of References

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2 – Johnston, D.P., R. Surdahl and D.B. Stokes, “A Case Study of a Lithium-Based Treatment of an ASR affected Pavement,” Proceedings from the 11th International Conference on Alkali Aggregate Reactions, CRIB< Quebec City, Canada, pp.1140-1158, 2000.

3 – Johnston, D.P., Mitigation of Potential Alkali-Silica Reactivity Using Lithium”, SHRP Concrete and Structures ASR Showcase Test and Evaluation Project 34, 2001.

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Chapter 1 Introduction

1.1 General

In FY 2000, the Federal Highway Administration (FHWA) was directed by Congress to fund a program of research and implementation of lithium-based technologies for the mitigation of alkali-silica reactivity (ASR) in Portland cement concrete. Two types of field trials were considered: (1) New construction or reconstruction projects using lithium-based technologies to prevent ASR, and (2) Application of lithium-based technologies on existing hardened concrete to mitigate ASR. The objective of these field trial studies was to demonstrate the use of lithium-based technologies to state transportation agencies and to document field performance of these technologies.

Studies have shown that adding lithium compounds to concrete in the plastic state to be effective in the control of ASR. Lithium-based technology; however, has not been widely applied to existing and aged concrete bridge decks and pavements. The goals and objectives of this current project were to evaluate the ability of lithium nitrate to arrest the ASR attack in hardened concrete and to develop materials and specifications for field implementation.

1.2 Background

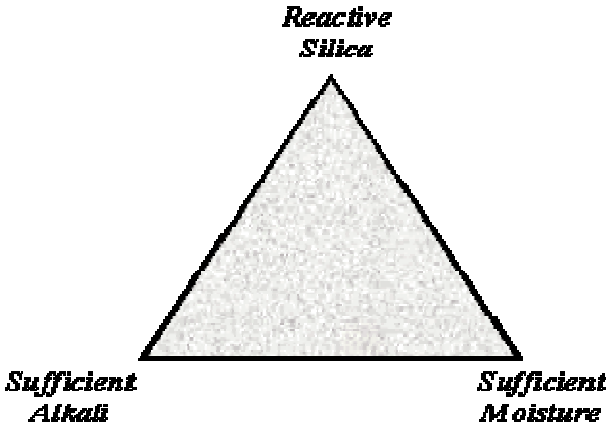
Alkali-Silica Reaction (ASR), which was first documented by Stanton[1] in 1940, is the most recognized cause of the deterioration of highway concrete structures and pavements in the United States. ASR takes place between certain reactive siliceous aggregates (e.g., opal, chalcedony and volcanic glass) and the alkali (Na_2O and K_2O)

from Portland cement paste and external sources. A reaction product gel forms that, in the presence of water, expands and may result in cracking of mortar and concrete. These surface cracks are aggravated by winter deicing salts and freeze-thaw action, leading to shallow delaminations, rebar corrosion, potholes, and other serious problems including structural failure. Three conditions are required for the reaction to take place: high alkali content (sodium and potassium) primarily from the cement, reactive silica or silicate in the aggregate and sufficient moisture in the concrete. The mechanism governing ASR and its expansion is rather complex. Several schools of thought about this phenomenon have been presented over the years. In its simplest form, ASR can be visualized as a two-step process [2]:

Step 1: Silica + Alkali + Moisture → silicate gel (ASR gel)

Step 2: ASR gel + Additional moisture → Expansion

For ASR to occur, three essential components must be present as shown in the following diagram: (1) reactive forms of silica in the aggregate, (2) sufficient alkalis primarily from the cement, and (3) sufficient moisture.



ASR Triangle

Previous studies conducted under the SHRP program [3] have shown that the addition of certain lithium-based admixtures such as lithium hydroxide (LiOH) or lithium nitrate ($LiNO_3$), to fresh concrete will significantly reduce the ASR gel expansion. Research has also been conducted using lithium to treat hardened concrete; however, minimal documentation of "measurement" of the effects of lithium is available.

1.3 Project Location and Description

The structure selected for this study is a nine (9) inch thick concrete pavement located at the intersection of a 4-lane road in the North-South directions (First Street) and a two-lane road in the East-West directions (Bluff Avenue) in Norfolk, Nebraska. The pavement was constructed in two phases, Phase I and Phase II. Phase I of the pavement was constructed in 1994, while the Phase II was constructed in 1997. The mix design identifying the components of the concrete mix is presented in Table No. 1 (Appendix II) for information.

Eighteen (18) 9 feet × 9 feet panels were selected for instrumentation and evaluation as shown in Figure Nos. 1 and 1a, Appendix I. Of the eighteen (18) panels, twelve (12) panels were designated as “test panels” and six (6) panels as “control panels.” Control sections were established for base-line references to document and differentiate from the ASR-induced expansion of lithium treated and untreated portions of the pavement.

The test site was surveyed prior to the initiation of the actual instrumentation and lithium application to confirm the presence of ASR. Visible longitudinal cracks subdivided in a polygonal pattern along with a gel material were observed indicating ASR expansion-related distress as shown in Photo Nos. 1 & 2.

1.4 Petrographic ASR Confirmation

A detailed petrographic examination was performed on concrete cores obtained from the site to ascertain the presence of ASR gel product. A petrographic analysis was performed on 4-inch diameter core samples to determine the concrete condition, quality, and cause for surface cracking. The coring locations are indicated in Figure 1, Appendix I. The cored concrete samples were composed of 1-inch crushed limestone, angular to round siliceous sand, and hydrated Portland cement paste matrix. The concrete contained both entrapped and entrained air voids that appeared to be of normal distribution. The presence of entrapped air voids in the paste matrix was due to incomplete consolidation, but did not appear to be

excessive. The core surfaces were flat and relatively smooth, with several irregular shaped fractures transecting the surface. The fractures were filled with soft, carbonated alkali-silica gel precipitate. The mechanism that caused distress in the pavement appeared to be due to deleterious expansion associated with ASR attack on reactive fine aggregate particles. Numerous fine aggregate particles were surrounded by micro-cracked, darkened, reaction-rims due to gel saturation. Scanning Electron Microscopy (SEM) with Energy Dispersive X-ray Fluorescence Spectrometry (EDX) characterization of the ASR gel indicated the presence of elemental sodium and potassium, typical of an expansive ASR gel. These conditions are characteristic of concrete distress associated with ASR expansion. Other forms of concrete deterioration such as freeze-thaw, alkali-carbonate, sulfate attack, chloride attack, or excessive surface pop-out formation were not evident during the examination.

Specimens of Phase II concrete were cored from Panels No. 1 and 2, while specimens of Phase I concrete were cored from Panels No. 17 and 18. These cored cylinders were subjected to the splitting-tension tests in accordance with the ASTM C 496. Panel No. 17 was in such poor condition that the specimen broke during coring. The splitting-tensile strengths of these specimens are presented in Table No. 2 of Appendix II. As can be observed, the tensile strength of the cores taken from the treated panels was somewhat higher than taken from the untreated panels.

1.5 Control and Test Panel Layout

In the effort to allow the test panels to “react” or not “react” to the ASR mechanism, each test panel was outlined with a full depth (9”) saw cut to free it from the surrounding concrete slab, as shown in Photo Nos. 3 & 4. The saw cut was then filled with compressible filler and sealed to prevent the entry of water and debris as shown in Figure No. 2, Appendix I.

In-situ non-destructive testing was conducted on the lithium-treated and untreated pavement panels. Non-destructive evaluation (NDE) techniques were used to characterize the pavement condition prior to and following lithium treatments. Those techniques included crack mapping, photographic survey, impact echo test, Velocity (V) meter test, Schmidt Hammer test, and expansion/contraction measurements.

1.6 Lithium Application Procedures

Initially a liquid solution containing 30 percent lithium nitrate and a surfactant was applied to the pavement surface at the rate of 0.012 gallons per square foot (12.35 gallons per 1000 square feet). Prior to application, the concrete pavement surface was saturated with water and then allowed to drain and dry to a saturated surface dry (SSD) condition. The lithium material was measured out in a container of known volume, poured onto the test panels and distributed with the use of a broom as shown in Photo Nos. 5 & 6. It was extremely difficult to physically contain the material within the area to be treated and avoid runoff. This made it difficult to maintain the desired lithium dosage. Following evaporation of the lithium material a

gray in color, dense “lithium salt” residue appeared on the pavement surface as shown in Photo Nos. 7 & 8. The addition of water, as the evaporation process progressed, only aggravated the runoff problem. In an effort to minimize the runoff problem, the dosage was cut in half to 0.006 gallons per square feet. The pavement surface was again treated with water to achieve an SSD condition, and the lithium material applied and distributed with the use of a broom/paint roller. A similar runoff problem was encountered but to a lesser degree. The deposition of a lithium salt was again encountered upon evaporation following this procedure. In the third trial, the lithium was placed on a “dry” pavement at the rate of 0.006 gallons per square foot. The material was then distributed with the use a 9-inch long nap paint roller. As the material soaked in as well as evaporated; however, minimal “salting” was observed. Small amounts of water were sprayed on the test panels using a garden watering can as shown in Photo Nos. 9, 10 & 11 as salt appeared to promote “soaking in” of the lithium material. The salting did not reappear. In addition, runoff was minimal using this method. The lithium treatment (quantities and dates) was applied as indicated on Figure No. 1 and 1a, Appendix I.

In addition to gravity soaking of the pavement with the lithium solution, limited pressure injection and vacuum impregnation was also investigated.

In the attempt to “force” the lithium into the concrete, pressure cells, approximately 3 feet square, were constructed and anchored to the pavement surface as shown on Photo Nos. 12, 13, 14, 15 & 16. Silicone caulk was used to seal the base of the cell

to prevent loss of the lithium during pressurization. After sealing the pressure cell was filled with the lithium solution and a positive pressure applied.

In the attempt to “draw” the lithium into the concrete, a reservoir using a bead of caulk was constructed as shown in Photo No. 17. A full depth hole was drilled through the concrete pavement within the “reservoir”. A vacuum was then drawn with the use of a shop vac as shown on Photo No. 18.

Chapter 2 Field Instrumentation and Pavement Evaluation Methods

2.1 General

Various non-destructive evaluation (NDE) techniques were utilized to evaluate the pavement condition prior to and following the lithium treatments. These techniques included impact echo testing, Schmidt Hammer, V-meter testing, crack mapping, photographic survey, and expansion and contraction measurements. The locations of all the nondestructive tests conducted on a typical concrete panel are presented in Figure 3, Appendix I.

As discussed in Chapter 1, to relieve the compression built up in the pavement due to the ASR expansion and /or other mechanisms and to allow the treated and control panels to freely “react”, each of the 9-ft by 9-ft panels was saw-cut at the perimeter. The joints were 0.25 in. wide and through the full depth of the 9-inch pavement thickness. The joints were filled with a preformed backer rod and sealed with a flexible joint sealant afterwards.

2.2 Impact Echo

The impact-echo encompasses a complete system consisting of a portable computer, test control and analysis software, a hand-held scanning unit containing six impactors and a sensitive displacement transducer as shown in Photo No. 19. A transient stress pulse is introduced into a plate-like test structure by a mechanical impact on the surface. The stress pulse consists of P and S waves, which propagate into the

structure along spherical wavefronts, and an R wave, which propagates along the surface on a circular wavefront centered at the impact point. The P and S waves are reflected by internal cracks and voids and the boundaries of the structure. The arrival of these reflected waves, which were measured by a receiving transducer, were displaced at the surface where the impact was generated. The theory states that increased displacement would suggest an increase in cracks and other voids.

2.3 Schmidt Hammer

Although the Schmidt hammer does not provide a direct index of ASR distress, this instrument does provide for a relative measurement of concrete quality. A Type M Schmidt hammer as shown in Photo No. 20 was employed for quantifying the relative strength and evaluating the quality of concrete of the pavement panels. In testing, a "rebound number" is registered which is dependent upon the strength of the mortar (i.e., concrete without coarse aggregate) close to the surface. Since the strength of the mortar determines the strength of the concrete as a rule, the rebound number gives an indication of the strength of the concrete. Higher values suggest better quality and higher strength of concrete. The correlation between rebound number and strength of the concrete has been derived from a great number of hammer tests on cubes,

each cube being crushed in the machine immediately after carrying out the

hammer tests. The mean error is approximately ± 20 percent for low quality concrete and ± 15 percent for high-strength concrete. The uncertainty inherent in this

correlation is slight. Three readings were taken at each location. The average of the readings was then used to determine the concrete quality at that particular point.

2.4 Velocity (V) Meter

The V-meter is composed of an ultrasonic, pulse-velocity system widely used for quality control and evaluation of concrete structures. The V-meter can assess the uniformity and relative quality of concrete, to indicate the presence of voids and cracks, to estimate the depth of cracks, and to evaluate the effectiveness of crack repairs. Poisson's ratio and modulus of elasticity of the concrete also can be calculated using S-wave transducers. Since the pulse velocity depends only on the elastic properties of the material and not on the geometry, it is a very convenient technique for evaluating concrete quality. The testing apparatus consists of a pulse generator, a pair of transducers (transmitter and receiver), an amplifier, a time measuring circuit, and a time display unit as shown in Photo No. 21. The transmitter and receiver were placed at distances of 3, 6, and 9 inches apart at each location.

2.5 Crack Mapping and Photographic Documentation

Surface cracks, spalls and other surface defects serve as indicators of concrete deterioration. Crack mapping along with photographic documentation on all the panels was conducted prior to and at various intervals following the lithium treatments. Five (5) one-foot square areas were identified for detailed crack mapping in each of the eighteen (18) panels. A 1-foot by 1-foot wood frame as shown in Photo No. 22 was fabricated for the "picture frame." A clear plastic sheet was then

placed under the frame, and cracks, holes and other apparent surface defects were then traced onto the plastic sheets. Each one of the five (5) areas was tied to specific reference point locations for future repeatability. The locations of cracking mapping locations on the concrete panels are shown in Figure 3, Appendix I.

Photographic documentation of cracks and other defects located inside the “picture frames” was also established to monitor further surface deterioration in both the treated and the untreated slabs with time.

2.6 Demac Points for Strain Measurement

As a means to physically measure expansion and contraction of the concrete pavement, stainless steel knurled pins (or Demac points) having 1-mm diameter pin hole on the top, were inserted and grouted into pre-drilled holes in the pavement, as shown on Figure No. 4, Appendix I and in Photo Nos. 23 & 24. The depth of the drilled holes was such that the top of the pins were located approximately 0.25” below the pavement surface. There were nine (9) Demac points installed in each panel as previously shown in Photo No. 24. A four (4)-ft long, digital caliper with an accuracy of 0.001 inch was used to measure the distances between adjacent Demac points, as shown in Photo No. 25. All distances were read twice (i.e., in both directions) and then averaged to ensure data accuracy. Initial measurements along with ambient temperature readings were recorded before lithium treatment for a baseline reference. Following the initial measurements, the drilled holes were sealed with a flexible sealant that could be removed at a later time for subsequent

measurements. The primary purpose of the sealant was to protect the Demac points and prevent debris from entering the drilled holes.

Chapter 3 Data Evaluation

3.1 Concrete Expansion and Contraction (Demac Points)

Initial distances between Demac points were measured following installation on 9 December 2002. The second set of expansion/contraction measurements was taken on 27 May 2003. Each slab was then saw-cut full depth (9-in.) parallel to the existing joints and/or exterior edges. Expansion/contraction measurements were again taken on 29 May 2003. An analysis of the data revealed that all of the panels experienced a stress relief (expansion/contraction) following the saw cut. The most recent measurements were taken on 15 June 2005. All of the panels experienced a net growth (expansion) except Panel No. 8 from the time of saw cut operation until June 2005. Panel No. 8 experienced 0.01% contraction in the east-west direction and a 0.01% expansion in the north-south directions. Typical expansion/contraction data plots for both treated and control panels are presented on Plate Nos. 1 thru 8 in Exhibit No. 1, Appendix III. A summary of the east-west expansion/contraction data for the Phase II concrete (new) is presented on Plate No. 9, Exhibit No.1, Appendix III. A summary of the north-south expansion/contraction data for the Phase II concrete (new) is presented on Plate No.10, Exhibit No.1, Appendix III. A summary of the east-west expansion/contraction data for the Phase I concrete (old) is presented on Plate No.11, Exhibit No.1, Appendix III. A summary of the north-south expansion/contraction data for the Phase I concrete (old) is presented on Plate No.12, Exhibit No.1, Appendix III. Plate Nos. 13 & 14 in Exhibit No. 4, Appendix III presents the overall east-west/north-south expansion/contraction of all of the panels.

As can be observed, the older panels (Phase I) exhibited a greater degree of expansion than did the newer (Phase II) concrete. The “treated” panels actually exhibited a greater degree of expansion than did the “control” panels. Possibly the panels experienced a pessimism effect.

3.2 Crack Propagation

Crack mapping was used to document progressive deterioration of the concrete slabs. As described previously, five (5) 1-foot square areas were established in each of the 18 panels. Details of crack pattern and other surface defects of all the slabs were initially mapped in October 2002 for baseline references. Panel Nos. 6, 7, 17 and 18 were also mapped in May 2004 and June 2005. This information is presented on Plate Nos. 1 thru 12 in Exhibit No. 2, Appendix III. It is evident that there is significant crack development in the untreated panel (No.17) as compared to the treated panel (No.18). There has been only minor crack growth in the Phase II panels (Panels 6 & 7) with no appreciable difference between the control and the treated panels.

3.3 Concrete Quality Evaluation by Impact Echo

The quality of panel Nos. 6, 7, 17 and 18 were evaluated by using the impact echo apparatus in October 2002, October 2003 and May 2004. Numerical impact echo data obtained in October 2002 and May 2004 is presented in Table Nos. 3a, 3b, 3c & 3d, Appendix II.

A graphical summary of the data is presented in Exhibit No. 3, Appendix III. With the exception of the October 2003 data, the October 2002 data and the May 2004 data are comparable, except for Panel No. 6 which actually exhibited an increase in quality, indicating little difference between the treated and control panels from 2002 to 2004.

3.4 Concrete Quality Evaluation by Schmidt Hammer

The Schmidt hammer is a convenient but less accurate tool for concrete quality evaluations; however, the instrument does provide for a comparison of quality over time. Numerical Schmidt Hammer data obtained in October 2002 and June 2005 is presented in Table Nos. 4a, 4b, 4c & 4d, Appendix II.

The Schmidt Hammer data obtained from the testing (Oct 02, Oct 03, May 04 & Jun 05) is presented graphically in Exhibit No. 4, Appendix III. As can be observed little change in concrete quality was exhibited between October 2002 and June 2005 using the Schmidt Hammer.

3.5 Concrete Quality Evaluation by V-meter

V-Meter data was obtained from specific test panels in Oct 02, Oct 03, May 04 and Jun 05. Numerical V-Meter data obtained in October 2002 and June 2005 is presented in Table Nos. 5a, 5b, 5c & 5d, Appendix II.

V-Meter data obtained from the testing (Oct 02, Oct 03, May 04 & Jun 05) is presented graphically in Exhibit No. 5, Appendix III. Similar to the Schmidt hammer data, little change in the concrete quality was exhibited between October 2002 and May 2004; however a definite trend is apparent following the June 2005 readings. A definite decrease in concrete quality is apparent following the June 2005 reading indicating that all of the concrete, treated and untreated deteriorated at approximately the same rate.

Chapter 4 - Conclusions and Recommendations

4.1 Conclusions

Based on the NDT techniques utilized to evaluate the on-going ASR deterioration in both the treated and control panels, it is evident that the results to date have not shown definitive benefits of the lithium material in arresting the ASR process. The observed lithium penetration by gravity soaking; however, has been very limited. Presumably the pavement has not reached the deterioration state for optimal permeability for penetration of the lithium material.

Powder samples were obtained from the pavement, as shown on Photo Nos. 26, 27 & 28, for laboratory analysis to determine the actual lithium content. Samples were obtained from both the treated panels and the control panels for comparison. Lithium content profiles, obtained both early and late in the research, of both a treated panel (Panel 18) and a control panel (Panel 1) are presented on Plate Nos. 1 & 2, Exhibit No. 6 Appendix III. Plate No. 3, Exhibit No. 6, Appendix III presents a comparison of the average lithium content observed in the upper 4" in both the older concrete (Phase I) and the newer concrete (Phase II) when using a flood coat application method. The maximum lithium content observed in the flood coated panels was 46 PPM in Panel No. 18. Panel No. 18 is in the old Phase I concrete and has deteriorated to the point of excessive cracking and resulting high permeability. The normal "noise" level of lithium that can be expected during the testing is in the range

of 5-10 PPM which is consistent with the lithium contents determined for Panel Nos. 1, 3, & 8. The maximum lithium content in the control panel (Panel 17, Phase I) was approximately 27 PPM as shown on Plate No. 4, Exhibit No. 6, Appendix III.

It is evident that even if the lithium is beneficial in arresting ASR, adequate amounts were not achieved by the gravity flood coating method utilized in the test program to realize this benefit.

In addition to gravity soaking of the pavement with the lithium solution, limited pressure injection and vacuum impregnation was also investigated as discussed in Chapter One.

In the attempt to “force” the lithium into the concrete a pressure cell, approximately 3 feet square, was constructed and anchored to the pavement surface as shown on Photo Nos. 12, 13, 14, 15 & 16. Silicone caulk was used to prevent loss of the lithium during pressurization. The pressure cell was filled with the lithium solution with a positive pressure applied. Plate No. 5, Exhibit No. 6, Appendix III presents a lithium content profile of a treated panel using external positive pressure. Lithium contents as high as 275 PPM (Panel No. 13) were realized using a positive pressure cell.

In the attempt to “draw” the lithium into the concrete, a reservoir using a bead of caulk was constructed as shown in Photo No. 17. A full depth hole was drilled

through the concrete pavement within the “reservoir”. A vacuum was then drawn with the use of a shop vac as shown on Photo No. 18. Lithium contents as high as 102 PPM (Panel No. 15) were realized using a vacuum impregnation method. Plate No. 6, Exhibit No. 6, Appendix III presents a lithium content profile of an area in Panel No. 15 using vacuum impregnation.

Overall summaries of lithium contents using various application methods are presented on Plate Nos. 7 & 8, Exhibit No. 6, Appendix III. As can be observed, greater lithium contents were achieved using the vacuum impregnation method as compared to simply a flood coat application. The pressure injection method achieved even a higher content.

Based on the lack of benefit observed towards controlling the ASR mechanism and the limited lithium contents achieved in the flood coated panels it is concluded that the potential benefit or lack thereof of the lithium is still unknown.

4.2 Recommendations

Based on the lithium contents achieved in the limited testing using pressure injection and vacuum impregnation methods, it is concluded that achieving higher lithium contents in the hardened concrete is possible. It is recommended that cost effective means be investigated to increase the lithium content in the hardened concrete at which time the exact benefit of the lithium or lack thereof can be fully ascertained.

PHOTOGRAPHS

Photo No. 1 - ASR Damage

Photo No. 2 – ASR Damage

Photo No. 3 - Saw Cutting Operation

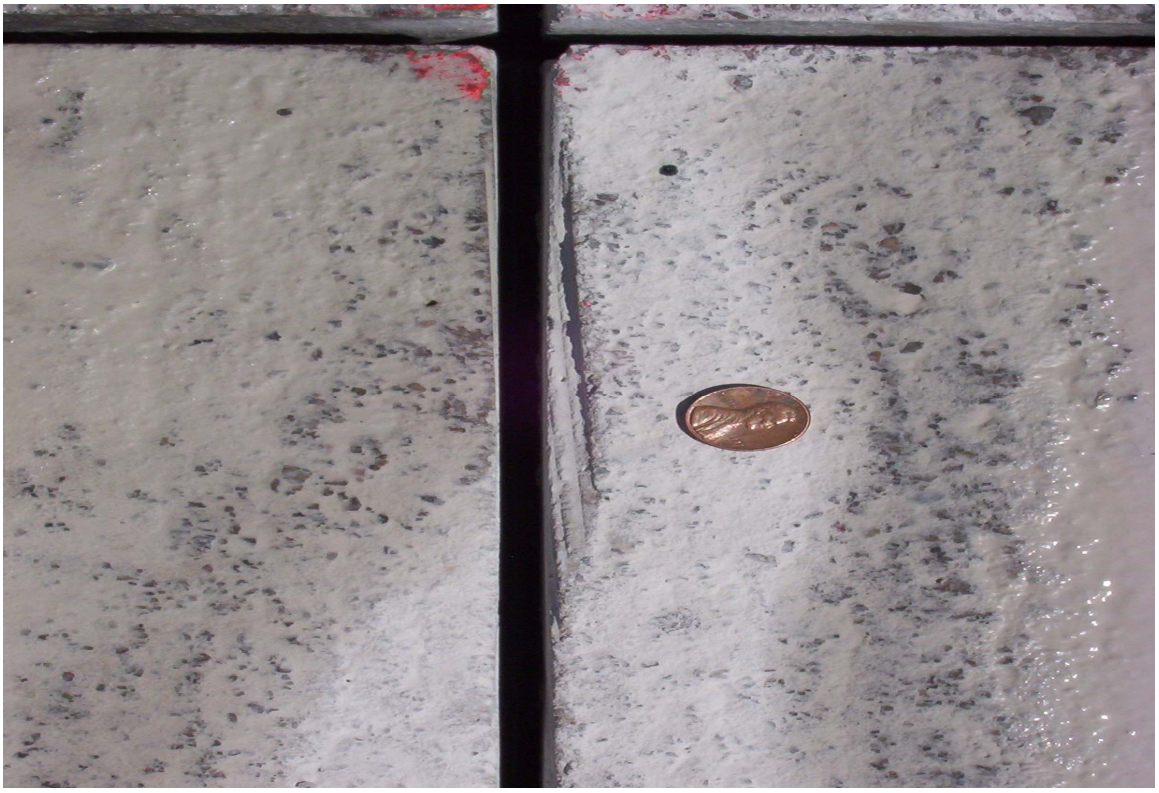


Photo No. 4 - Finished Saw Cut

Photo No 5 - Lithium Application

Photo No. 6 - Lithium Application

Photo No. 7 - Lithium Salt Residue

Photo No. 8 – Lithium Salt Residue

Photo No. 9 – Application of Water

Photo No. 10 – Application of Water.

Photo No. 11 - Lithium Treated Pavement

Photo No. 12 – Pressure Cell

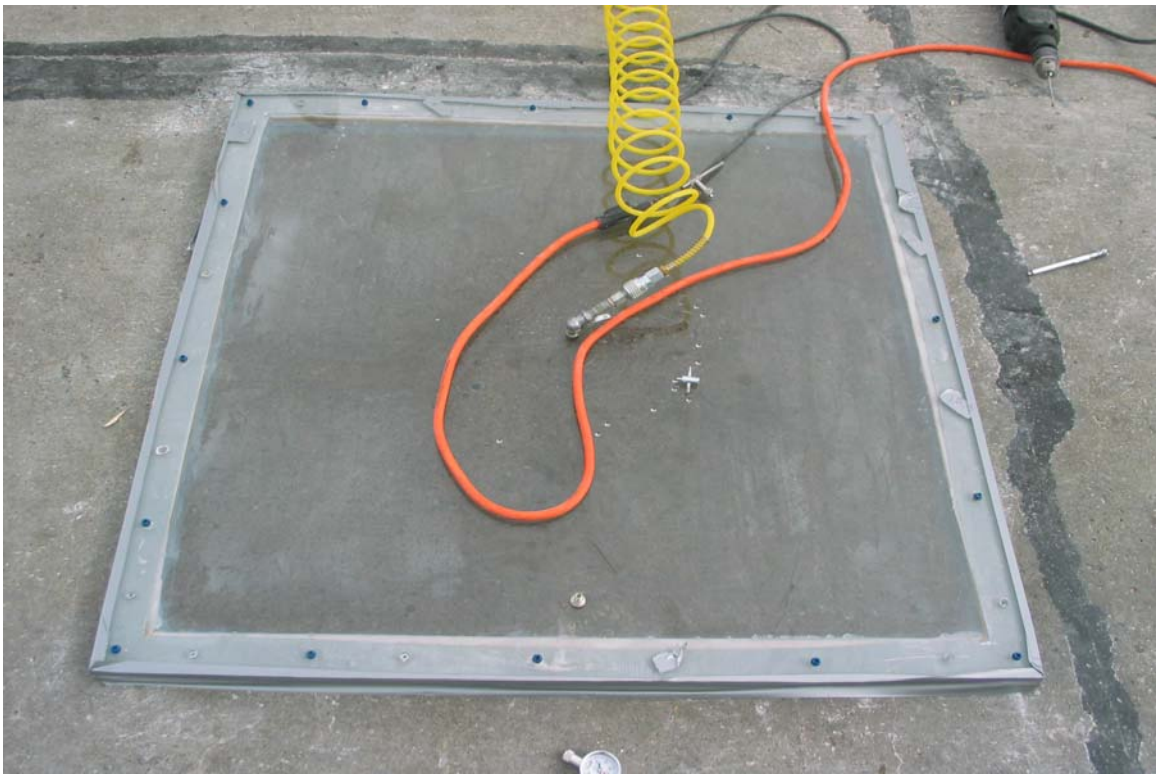


Photo No. 13 - Pressure Cell

Photo No. 14 – Pressure Cell

Photo No. 15 - Pressure Cell

Photo No. 16 – Pressure Cell

Photo No. 17 - Vacuum Impregnation of Lithium Nitrate

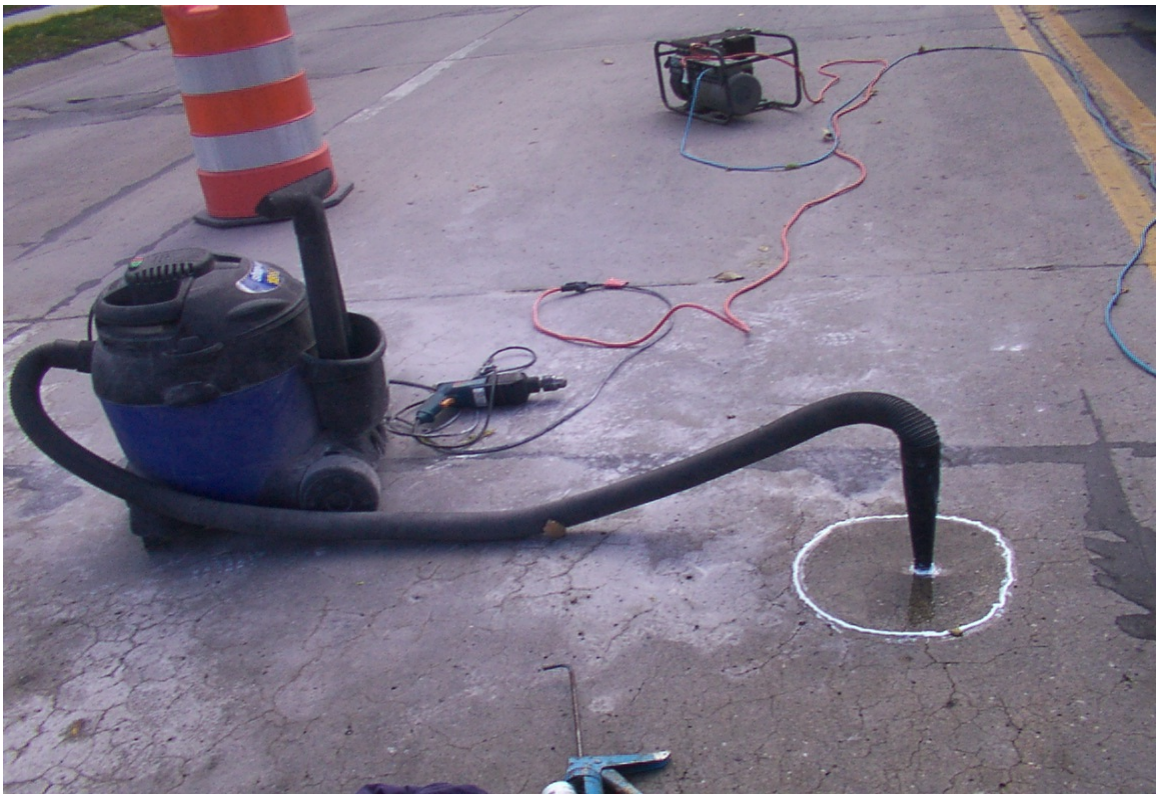


Photo No. 18 - Vacuum Impregnation of Lithium Nitrate

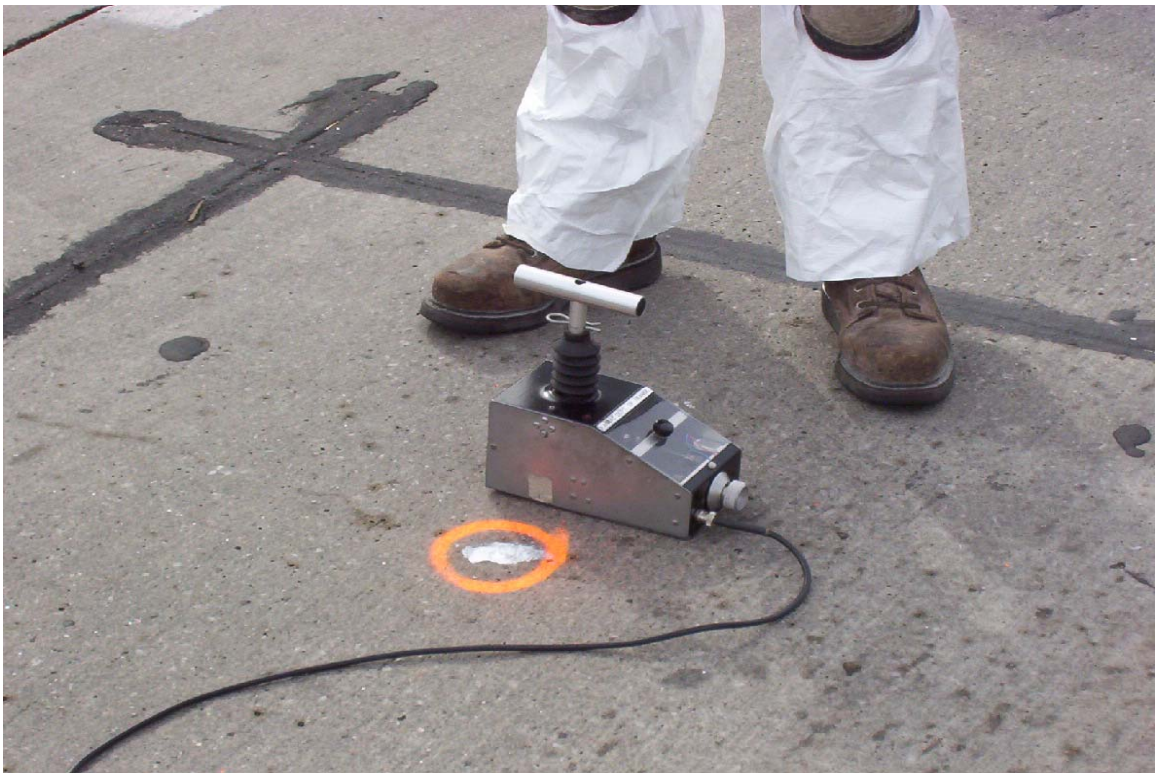


Photo No. 19 - Impact Echo Evaluation

Photo No. 20 – Schmidt Hammer Evaluation

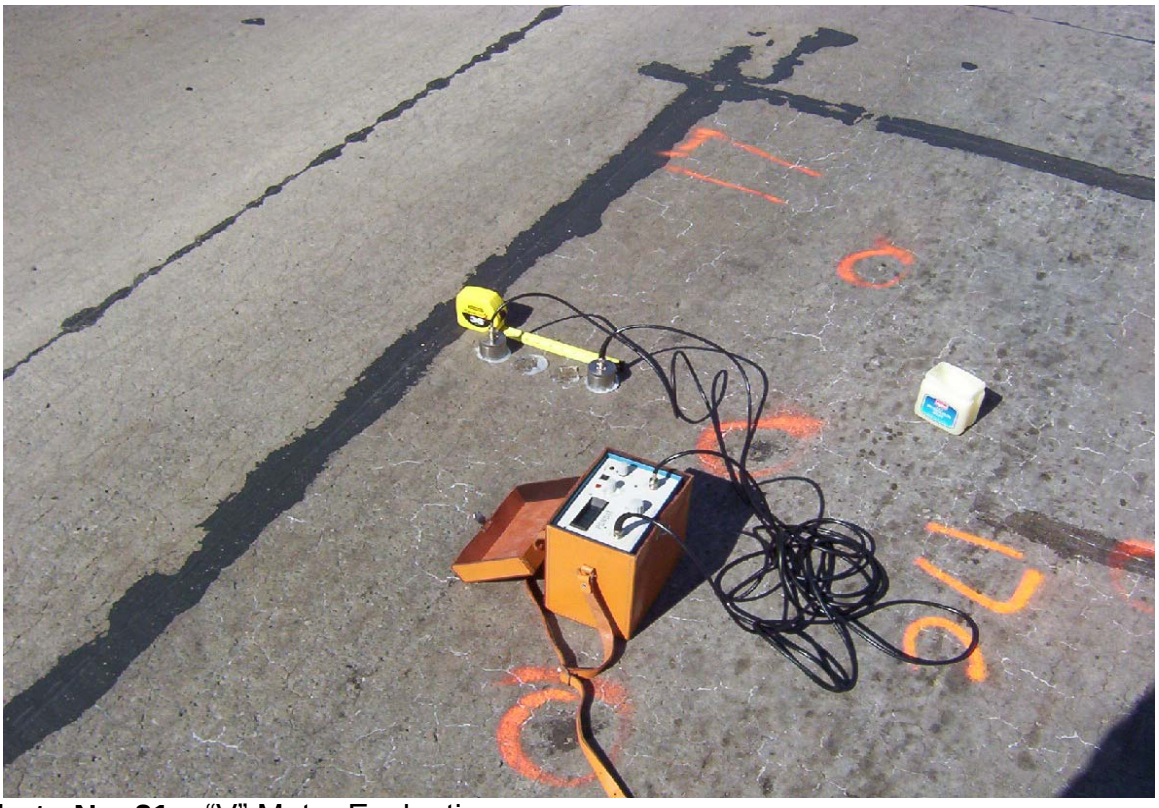


Photo No. 21 – “V” Meter Evaluation

Photo No. 22 – Crack Mapping

Photo No. 23 – Demac Point

Photo No. 25 – Demac Point Locations

Photo No. 25 - Expansion / Contraction Measurements

Photo No. 26 – Powder Samples for Lithium Content

Photo No. 27 - Powder Samples for Lithium Content

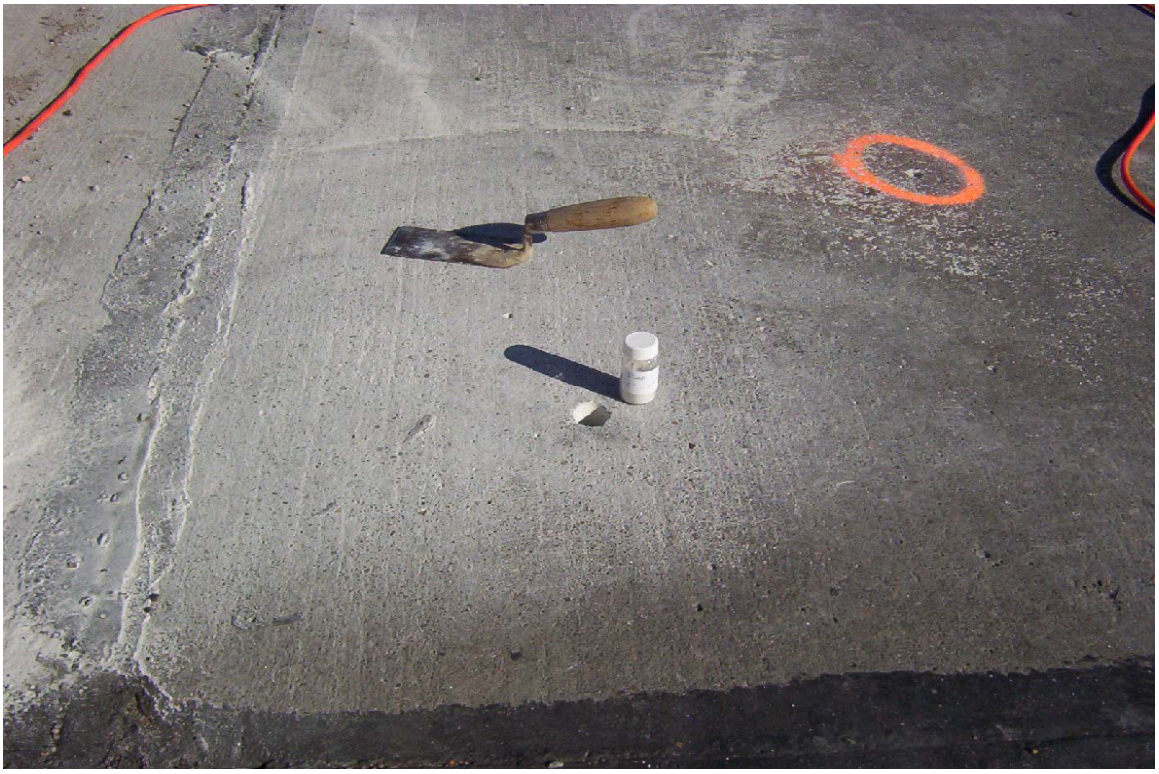


Photo No. 28 – Powder Samples for Lithium Content

APPENDIX I

FIGURES

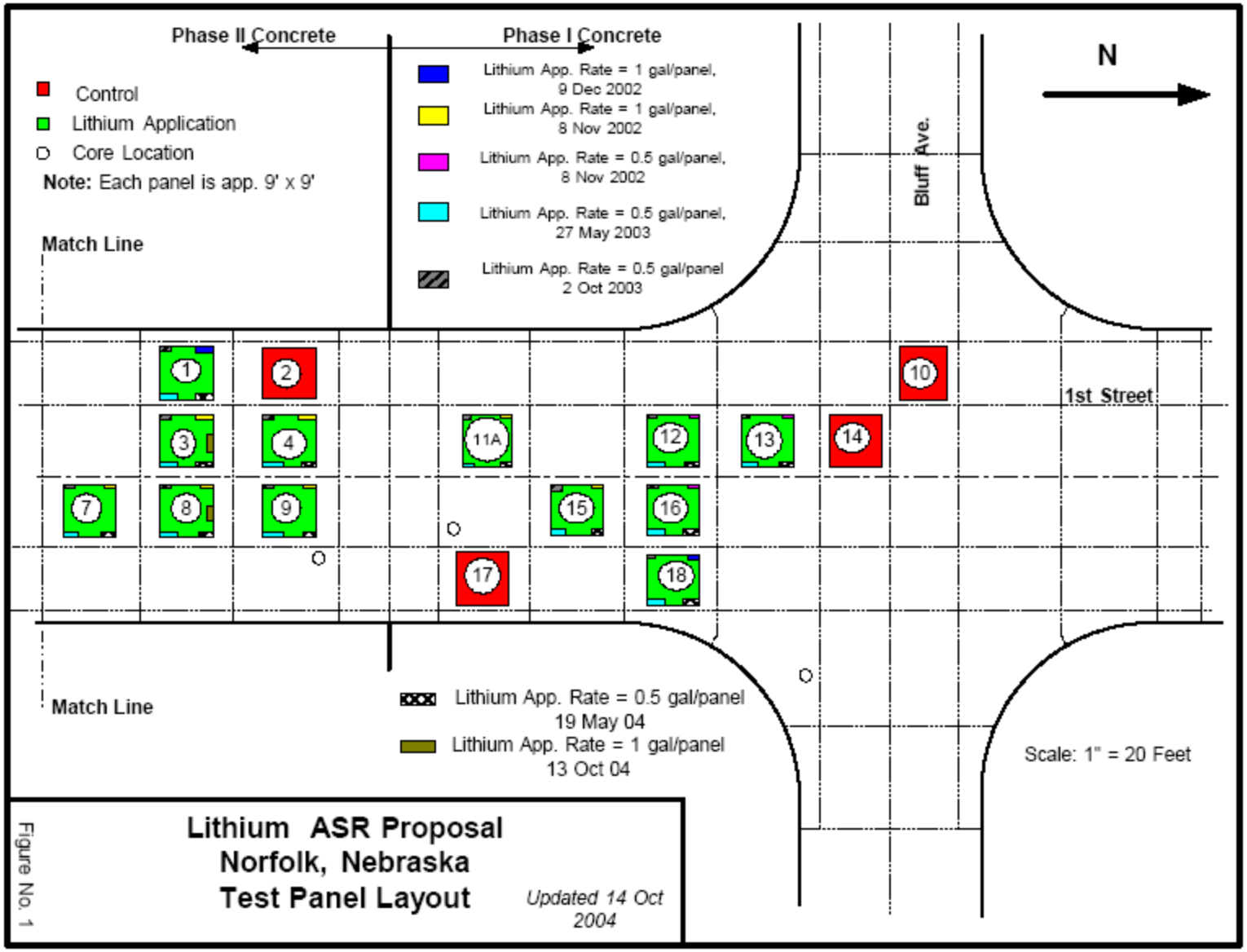
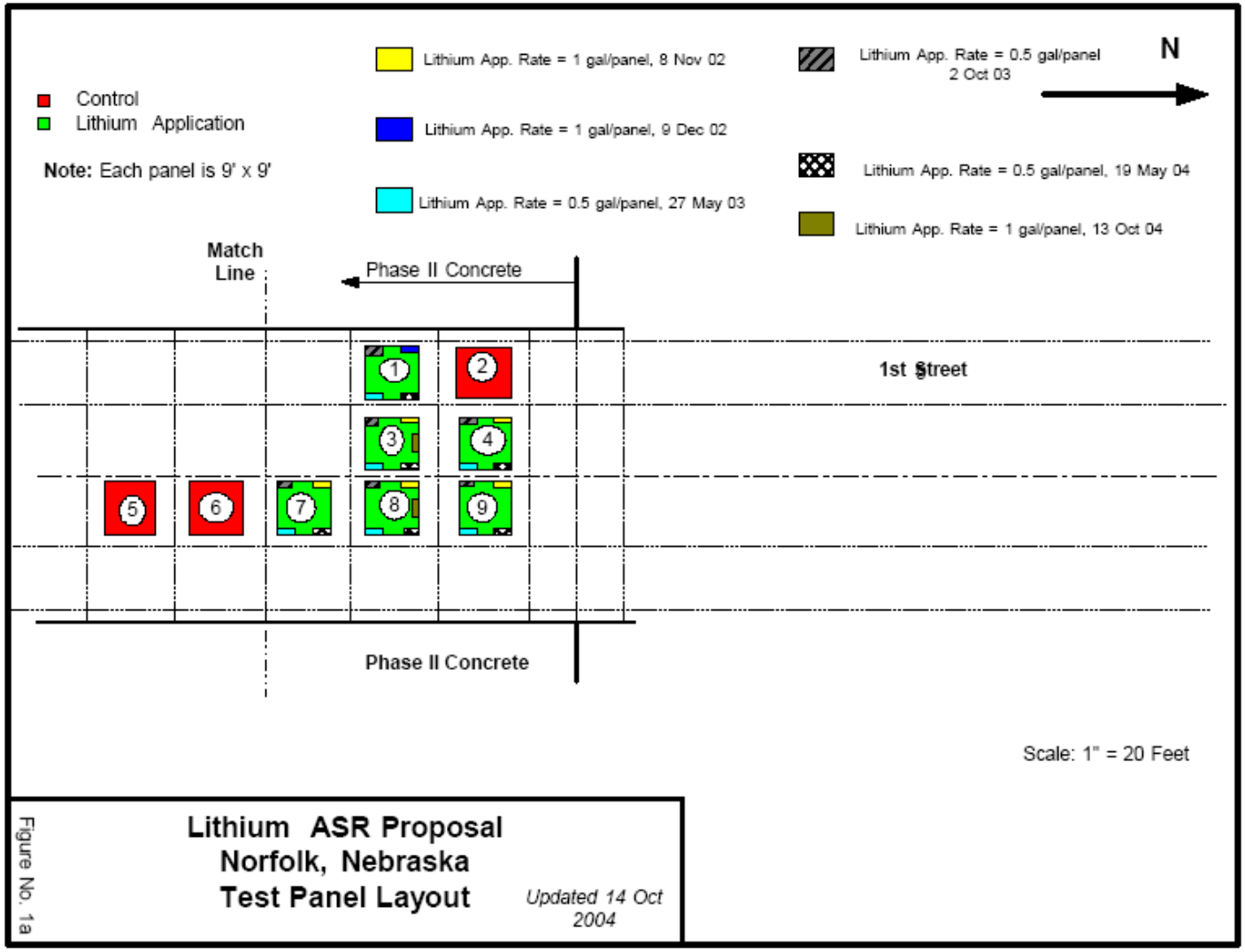
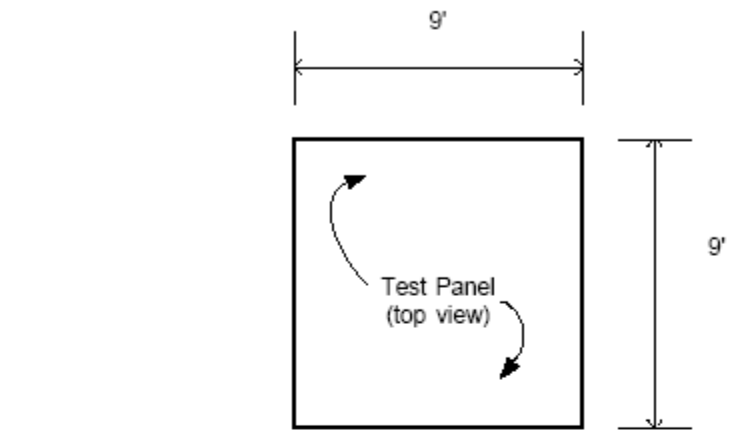


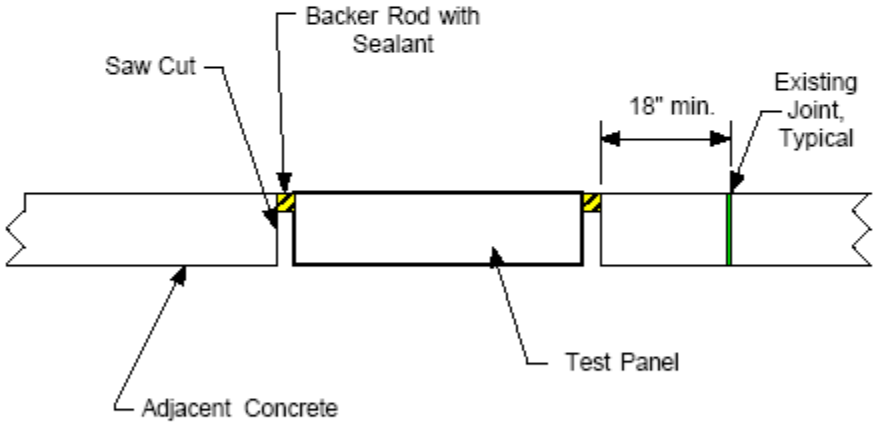
Figure No. 1

Lithium ASR Proposal
Norfolk, Nebraska
Test Panel Layout

Updated 14 Oct 2004

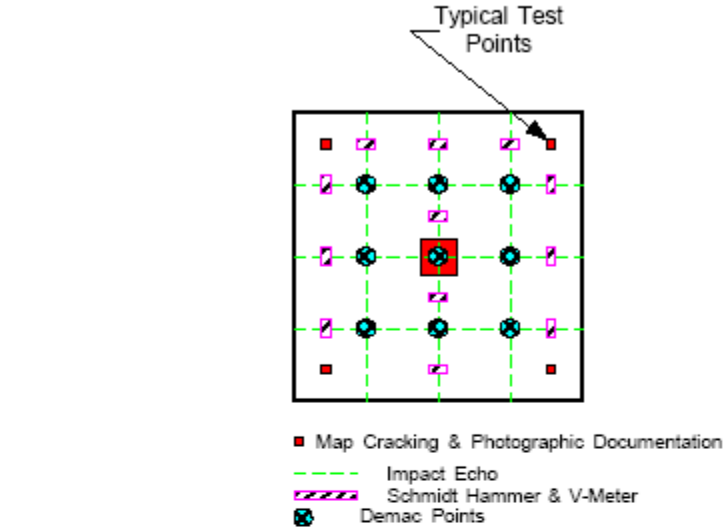

Control
Lithium Application
Note: Each panel is 9' x 9'
Lithium App. Rate = 1 gal/panel, 8 Nov 02
Lithium App. Rate = 1 gal/panel, 9 Dec 02
Lithium App. Rate = 0.5 gal/panel, 27 May 03
Lithium App. Rate = 0.5 gal/panel 2 Oct 03
Lithium App. Rate = 0.5 gal/panel, 19 May 04
Lithium App. Rate = 1 gal/panel, 13 Oct 04
N
Match Line
Phase II Concrete
1st Street
Phase II Concrete
1
2
3
4
5
6
7
8
9
Scale: 1" = 20 Feet
Lithium ASR Proposal
Norfolk, Nebraska
Test Panel Layout
Updated 14 Oct 2004
Figure No. 1a

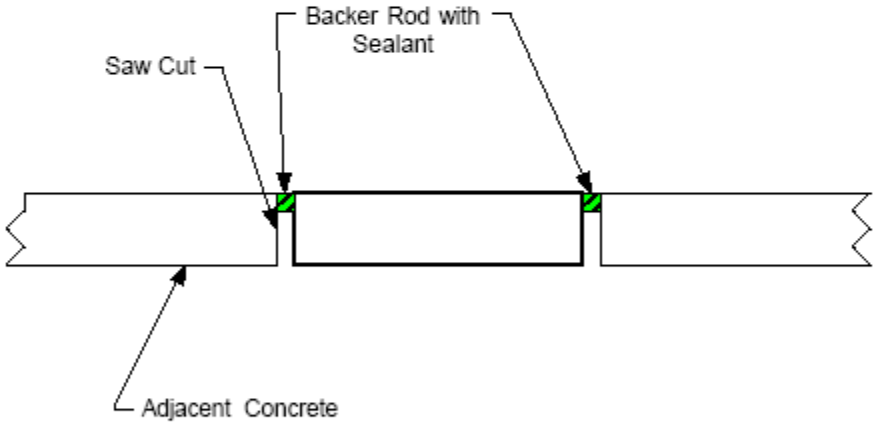




Notes:
1.) All saw cuts were full depth.
2.) Panel size: 9' x 9'.
3.) Test point locations to be determined in the field.
4.) Saw cuts placed 1' from existing joints.

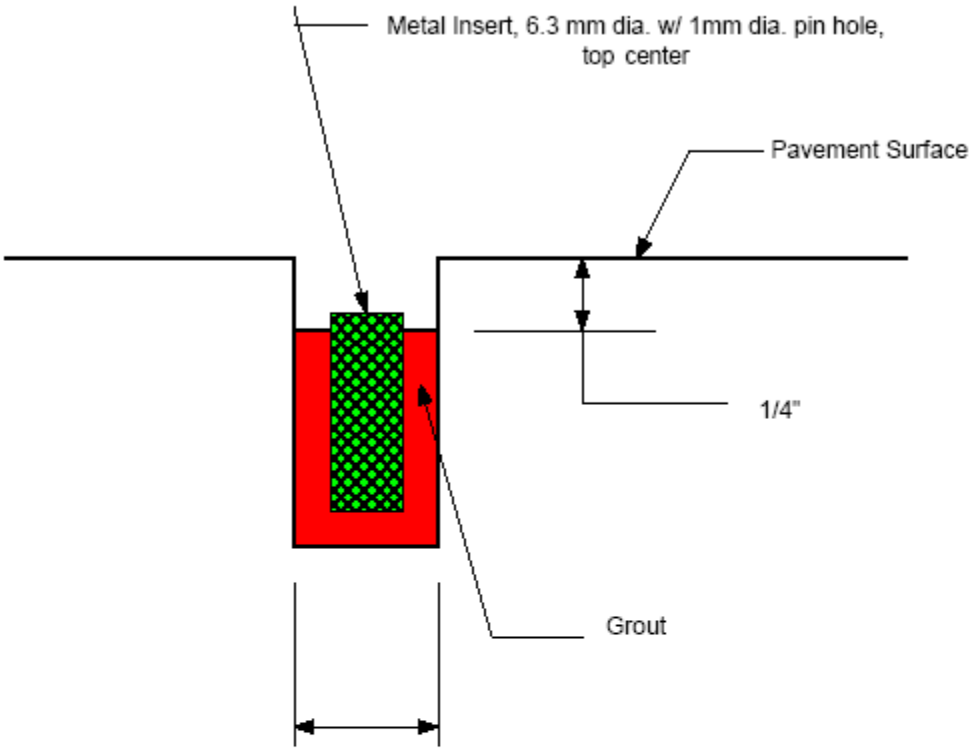
Saw Cut Detail
No Scale
Figure No. 2





Notes:
1.) All saw cuts shall be full depth.
2.) Panel size: 9' x 9'.
3.) Test point locations to be determined in the field.

Instrumentation Plan
No Scale
Figure No. 3



Pavement Insert (DeMac Point) Detail
(no scale)

Figure No. 4

APPENDIX II

TABLES

Table No. 1 – Concrete Mix Design	
Material	**Quantity**
Type I Portland Cement	564 Lbs.
Class C Fly Ash	100 Lbs.
47B Sand & Gravel*	2050 Lbs.
Water Reducer	900 Lbs.
47B Limestone	12 oz.
Air Entrainment	2 oz.
Water	24 gal.

Table No. 2 - Splitting Tensile Strengths				
Panel No.	**Dia. (in.) x Length (in.)**	**Ultimate Load (Lbs.)**	**Tensile Strength (PSI)**	**Treated/Untreated**
1	4.03 x 9.42	50,300	844	Treated
2	4.00 x 9.14	44,900	782	Untreated
17	4.00 x 4.58	9,320	324	Untreated
18	4.00 x 10.36	43,400	665	Treated

Date Tested: 27 Feb. 2004

Table No. 3a – Impact Echo Data (Panel 6, Control Phase II)					
October 2002			**May 2004**		
Point	**Wave Speed (m/s)**	**Modulus (GPa)**	**Point**	**Wave Speed (m/s)**	**Modulus (GPa)**
1	2240	11.6	1	3120	22.5
2	2470	14.1	2	3350	26
3	2290	12.2	3	3300	25.3
4	2290	12.2	4	3120	22.5
5	2470	14.1	5	2890	19.3
6	2060	9.8	6	3350	26
7	2240	11.6	7	3390	26.6
8	2240	11.6	8	3350	26
9	2240	11.6	9	3390	26.6
10	2020	9.5	10	3350	26
11	2020	9.5	11	3210	23.8
12	2020	9.5	12	3530	28.9
13	2060	9.8	13	3120	22.5
14	2200	11..2	14	3440	27.4
15	1830	7.8	15	3530	28.9
16	1830	7.8	16	3440	27.4
17	2200	11.2	17	3350	26
18	2020	9.5	18	3300	25.2
19	2020	9.5	19	3440	27.4
20	2290	12.2	20	3350	26
21	----------	----------	21	3120	22.5
22	----------	----------	22	3570	29.5
23	2020	9.5	23	3390	26.6
24	2290	12.2	24	3350	26
25	1970	9.0	25	3250	24.5
Average		**10.74**	**Average**		**25.5**

Table No. 3b – Impact Echo Data (Panel 7, Treated Phase II)					
October 2002			May 2004		
Point	**Wave Speed (m/s)**	**Modulus (GPa)**	**Point**	**Wave Speed (m/s)**	**Modulus (GPa)**
1	3340	25.9	1	3160	23.2
2	3340	25.9	2	3120	22.5
3	3110	22.4	3	2930	19.9
4	2890	19.4	4	3800	33.4
5	------	-------	5	2890	19.4
6	2890	19.4	6	3250	24.5
7	3110	22.4	7	3350	26
8	3110	22.4	8	3300	25.2
9	3160	23.1	9	3480	28.1
10	2520	14.7	10	3530	28.9
11	3160	23.1	11	3350	26
12	3160	23.1	12	3390	26.6
13	------	-------	13	3300	25.2
14	2930	19.9	14	3350	26
15	3070	21.8	15	3440	27.4
16	2980	20.6	16	3350	26
17	2890	19.4	17	3250	24.5
18	3070	21.8	18	3160	23.2
19	3110	22.4	19	3300	25.2
20	3110	22.4	20	3530	28.9
21	3070	21.8	21	2930	19.9
22	3110	22.4	22	3020	21.2
23	------	------	23	2890	19.4
24	------	------	24	3160	23.2
25	2840	18.7	25	2930	19.9
Average		**26.6**	**Average**		**24.5**

Table No. 3c – Impact Echo Data (Panel 17, Control Phase I)					
October 2002			May 2004		
Point	**Wave Speed (m/s)**	**Modulus (GPa)**	**Point**	**Wave Speed (m/s)**	**Modulus (GPa)**
1	3620	30.4	1	3530	28.9
2	3340	25.9	2	2890	19.4
3	3570	29.5	3	3440	27.4
4	2840	18.7	4	2930	19.9
5	2430	13.7	5	3530	28.9
6	1790	7.4	6	2930	19.9
7	2560	15.2	7	3530	28.9
8	3440	27.4	8	3300	25.2
9	3340	25.9	9	3390	26.6
10	------	-------	10	3480	28.1
11	3570	29.5	11	------	------
12	3110	22.4	12	3710	31.9
13	3570	29.5	13	3760	32.8
14	-------	-------	14	3390	26.6
15	2020	9.5	15	3300	25.3
16	2240	11.6	16	3620	30.4
17	-------	-------	17	3760	32.8
18	3110	22.4	18	3300	25.3
19	3570	29.5	19	3530	28.9
20	3570	29.5	20	3210	23.9
21	-------	-------	21	3350	26
22	3570	29.5	22	3620	30.4
23	3800	33.5	23	3760	32.8
24	2700	16.9	24	3570	29.5
25	2700	16.9	25	3480	28.1
Average		**22.6**	**Average**		**27.4**

Table No. 3d – Impact Echo Data (Panel 18,Treated, Phase I)					
October 2002			May 2004		
Point	**Wave Speed (m/s)**	**Modulus (GPa)**	**Point**	**Wave Speed (m/s)**	**Modulus (GPa)**
1	3570	29.5	1	2890	19.4
2	3300	25.2	2	2930	19.9
3	3020	21.1	3	3350	26
4	2700	16.9	4	3020	21.2
5	2890	19.4	5	3120	22.5
6	2890	19.4	6	3160	23.2
7	2610	15.8	7	3350	26
8	3340	25.9	8	3390	26.6
9	3340	25.9	9	3160	23.2
10	3530	28.9	10	3120	22.5
11	3390	26.6	11	3390	26.6
12	3300	25.2	12	-------	-------
13	3340	25.9	13	3480	28.1
14	2890	19.4	14	3160	23.2
15	2890	19.4	15	3530	28.9
16	2930	19.9	16	2980	20.6
17	2890	19.4	17	3160	23.2
18	3070	21.8	18	3250	24.5
19	3390	26.6	19	-------	-------
20	3340	25.9	20	2890	19.4
21	2890	19.4	21	2890	19.4
22	3300	25.2	22	3300	25.2
23	2890	19.4	23	3300	25.2
24	2840	18.7	24	3300	25.2
25	2700	16.9	25	3020	21.2
Average		**22.3**	**Average**		**23.5**

Table No. 4a – V-Meter Data (Panel 6, Control Phase II)							
October 2002				June 2005			
Point	Time (micro-sec)	Wave Speed (m/s)	Modulus (GPa)	Point	Time (micro-sec)	Wave Speed (m/s)	Modulus (GPa)
1	14.2			1	12.9		
		4510	47.2			3760	32.8
2	31.1			2	33.2		
		3930	35.8			4650	50.1
3	50.5			3	49.6		
4	12.3			4	13.6		
		4080	38.6			3610	30.2
5	31			5	34.7		
		4280	42.5			4510	47.1
6	48.8			6	51.6		
7	13.8			7	13.9		
		4770	52.7			3670	31.2
8	29.8			8	34.7		
		3890	35.1			3830	34
9	49.4			9	54.6		
Average			**42**	**Average**			**37.6**

Table No. 4b – V-Meter Data (Panel 7, Treated Phase II)							
October 2002				June 2005			
Point	Time (micro-sec)	Wave Speed (m/s)	Modulus (GPa)	Point	Time (micro-sec)	Wave Speed (m/s)	Modulus (GPa)
1	13.4			1	13.8		
		4980	57.5			4280	42.5
2	28.7			2	31.6		
		4080	38.6			4190	40.7
3	47.4			3	49.8		
4	12.5			4	15.6		
		3830	35.8			3700	31.7
5	31.9			5	36.2		
		4140	39.7			4280	42.5
6	50.3			6	54		
7	14.6			7	16.3		
		4380	44.5			3910	35.4
8	32			8	35.8		
		4590	48.8			4280	42.5
9	48.6			9	53.6		
Average			**44.1**	**Average**			**39.2**

Table No. 4c – V-Meter Data (Panel 17, Control Phase I)							
October 2002				June 2005			
Point	Time (micro-sec)	Wave Speed (m/s)	Modulus (GPa)	Point	Time (micro-sec)	Wave Speed (m/s)	Modulus (GPa)
1	13.9			1	24,7		
		3100	22.3			1630	6.2
2	38.5			2	71.5		
		2920	19.8			1810	7.6
3	64.6			3	113.6		
4	12.9			4	23.6		
		2980	20.6			2590	15.5
5	38.5			5	53		
		2510	14.6			3510	28.6
6	68.9			6	74.7		
7	18.9			7	12.1		
		3810	33.7			2220	11.4
8	38.9			8	46.5		
		3370	26.3			3190	23.6
9	61.5			9	70.4		
Average			**22.9**	**Average**			**15.5**

Table No. 4d – V-Meter Data (Panel 18,Treated, Phase I)							
October 2002				June 2005			
Point	Time (micro-sec)	Wave Speed (m/s)	Modulus (GPa)	Point	Time (micro-sec)	Wave Speed (m/s)	Modulus (GPa)
1	14.5			1	17.4		
		4140	39.7			3180	23.4
2	32.9			2	41.4		
		3890	35.1			2670	16.5
3	52.5			3	70		
4	11.4			4	13.5		
		4190	40.7			3140	22.9
5	29.6			5	37.8		
		3200	23.7			3810	33.6
6	53.4			6	57.8		
7	14.6			7	18		
		3850	34.4			3470	27.9
8	34.4			8	40		
		3790	33.3			2890	19.4
9	54.5			9	66.4		
Average			**34.5**	**Average**			**24**

Table 5a – Schmidt Hammer Data (Panel 6, Control Phase II)							
October 2002				June 2005			
Point	Ave Rebound #	Wave Speed (m/s)	Modulus (GPa)	Point	Ave Rebound #	Wave Speed (m/s)	Modulus (GPa)
1	45	4070	38.3	1	46	4070	38.3
2	45	4070	38.3	2	51	3940	36
3	44	4010	37.3	3	42	4070	38.3
4	45	4070	38.3	4	45	3720	32
5	46	4120	39.3	5	45	3770	32.9
6	44	4010	37.3	6	42	3940	36
7	43	3870	36.5	7	39	3440	27.4
8	42	3940	36	8	41	3780	33.2
9	45	4070	38.3	9	46	3770	32.9
10	44	4010	37.3	10	42	3940	36
11	41	3890	35.2	11	39	3610	30.1
12	47	4160	40	12	48	3080	22
13	45	4070	38.3	13	51	3770	32.9
14	46	4120	39.3	14	49	3140	22.8
15	47	4160	40	15	46	3250	24.5
16	45	4070	38.3	16	46	3620	30.5
Average	**44.6**		**38**	**Average**	**46**		**31.6**

Table 5b – Schmidt Hammer Data (Panel 7, Treated Phase II)							
October 2002				June 2005			
Point	Ave Rebound #	Wave Speed (m/s	Modulus (GPa)	Point	Ave Rebound #	Wave Speed (m/s	Modulus (GPa)
1	47	4160	40	1	48	4070	37.9
2	43	3970	36.5	2	45	3940	36
3	42	3940	36	3	46	4070	37.9
4	45	4070	38.3	4	45	3720	32
5	44	4010	37.3	5	43	3770	32.9
6	44	4010	37.3	6	40	3940	36
7	44	4010	37.3	7	41	3440	27.4
8	43	3970	36.5	8	39	3780	33.2
9	43	3970	36.5	9	41	3770	32.9
10	44	4010	37.3	10	40	3940	36
11	43	3970	36.5	11	45	3610	30.1
12	43	3970	36.5	12	48	3080	22
13	45	4070	38.3	13	44	3770	32.9
14	46	4120	39.3	14	44	3140	22.8
15	45	4070	38.3	15	46	3250	24.5
16	44	4010	37.3	16	44	3620	30.5
Average	44		37.4	Average	46		31.6

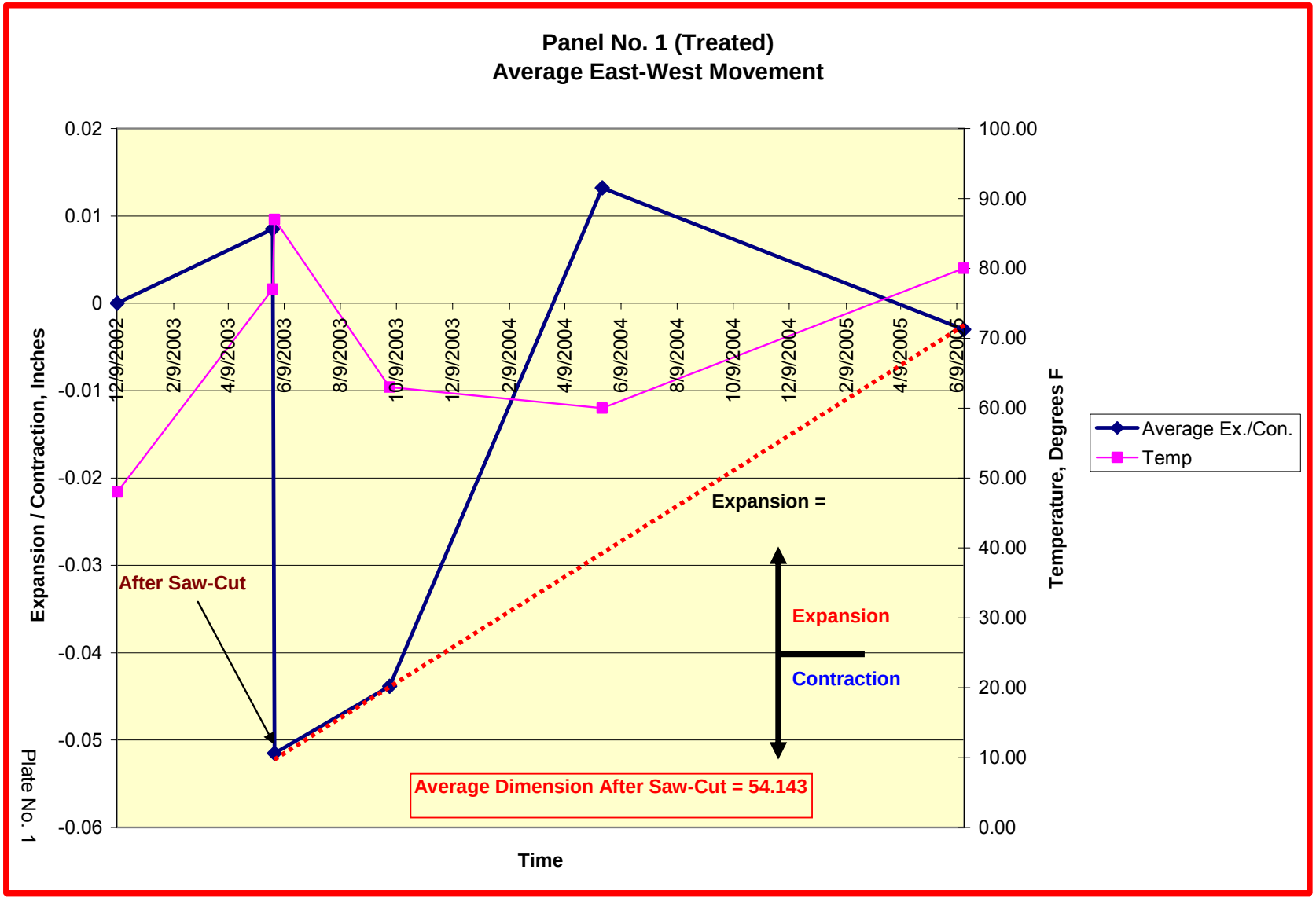
Table 5c – Schmidt Hammer Data (Panel 17, Control Phase I)							
October 2002				June 2005			
Point	Ave Rebound #	Wave Speed (m/s)	Modulus (GPa)	Point	Ave Rebound #	Wave Speed (m/s)	Modulus (GPa)
1	39	3780	33.2	1	45	4070	38.3
2	39	3780	33.2	2	42	3940	36
3	36	3640	30.8	3	45	4070	38.3
4	37	3720	32	4	37	3720	32
5	37	3720	32	5	38	3770	32.9
6	36	3640	30.8	6	42	3940	36
7	35	3620	30.4	7	31	3440	27.4
8	36	3640	30.8	8	39	3780	33.2
9	36	3640	30.8	9	38	3770	32.9
10	37	3720	32	10	42	3940	36
11	36	3640	30.8	11	34	3610	30.1
12	34	3610	30.1	12	24	3080	22
13	36	3640	30.8	13	38	3770	32.9
14	34	3610	30.1	14	25	3140	22.8
15	25	3140	22.8	15	27	3250	24.5
16	34	3530	28.8	16	35	3620	30.5
Average	**35.4**		**30.6**	**Average**	**36**		**31.6**

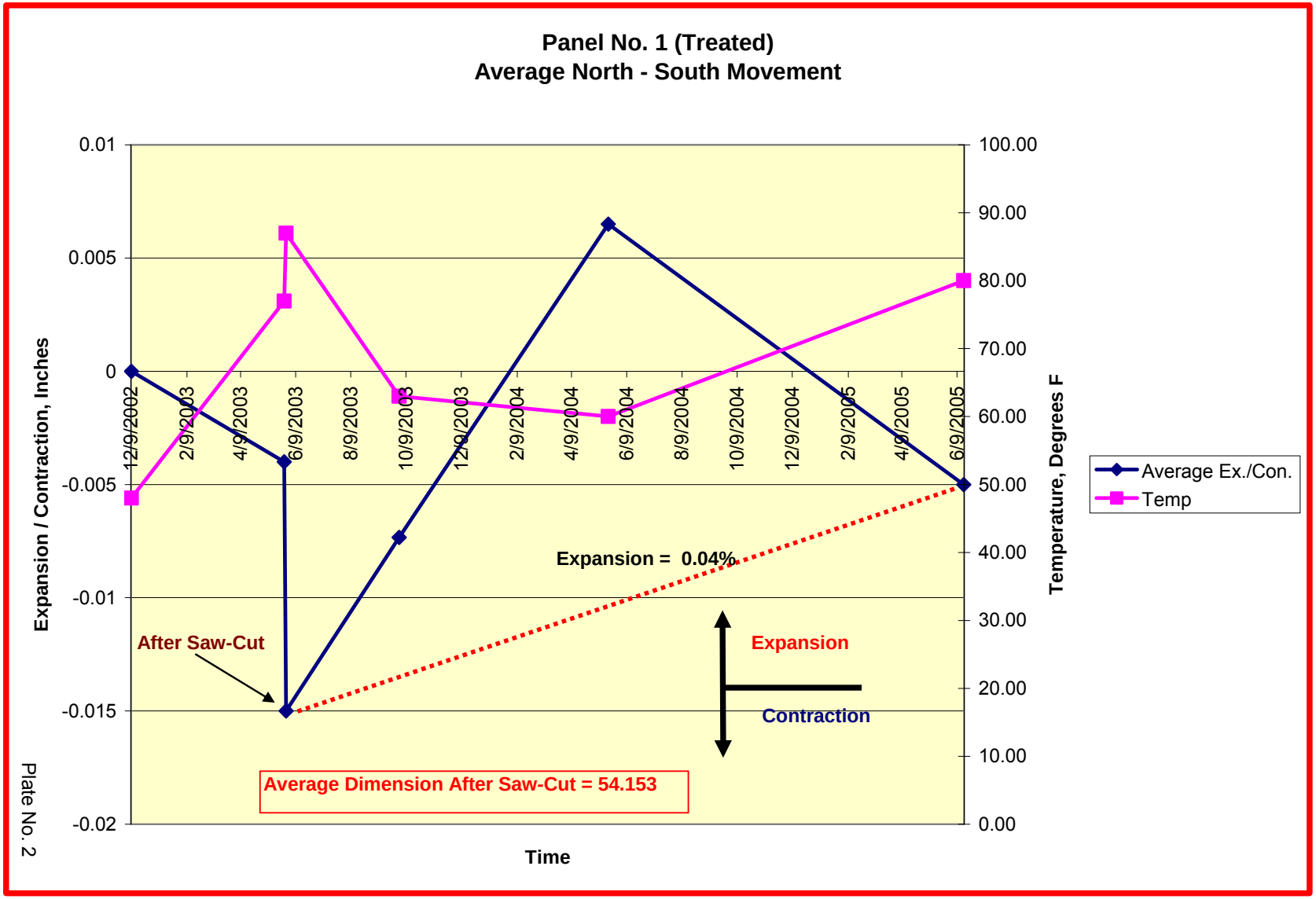
Table 5d – Schmidt Hammer Data (Panel 18,Treated, Phase I)							
October 2002				June 2005			
Point	Ave Rebound #	Modulus (GPa)	Wave Speed (m/s)	Point	Ave Rebound #	Modulus (GPa)	Wave Speed (m/s)
1	44	4010	37.3	1	41	3890	35.2
2	42	3940	36	2	43	3970	36.5
3	42	3940	36	3	37	3720	32
4	39	3780	33.2	4	43	3970	36.5
5	43	3970	36.5	5	43	3970	36.5
6	43	3970	36.5	6	43	3970	36.5
7	39	3780	33.2	7	43	3970	36.5
8	48	4210	41	8	40	3850	34.3
9	44	4010	37.3	9	44	4010	37.3
10	42	3940	36	10	44	4010	37.3
11	49	4240	41.7	11	44	4010	37.3
12	47	4160	40	12	43	3970	36.5
13	45	4070	38.3	13	44	4010	37.3
14	45	4070	38.3	14	44	4010	37.3
15	44	4010	37.3	15	42	3940	36
16	44	4010	37.3	16	40	3850	34.3
Average	43.8		37.2	Average	44		36.1

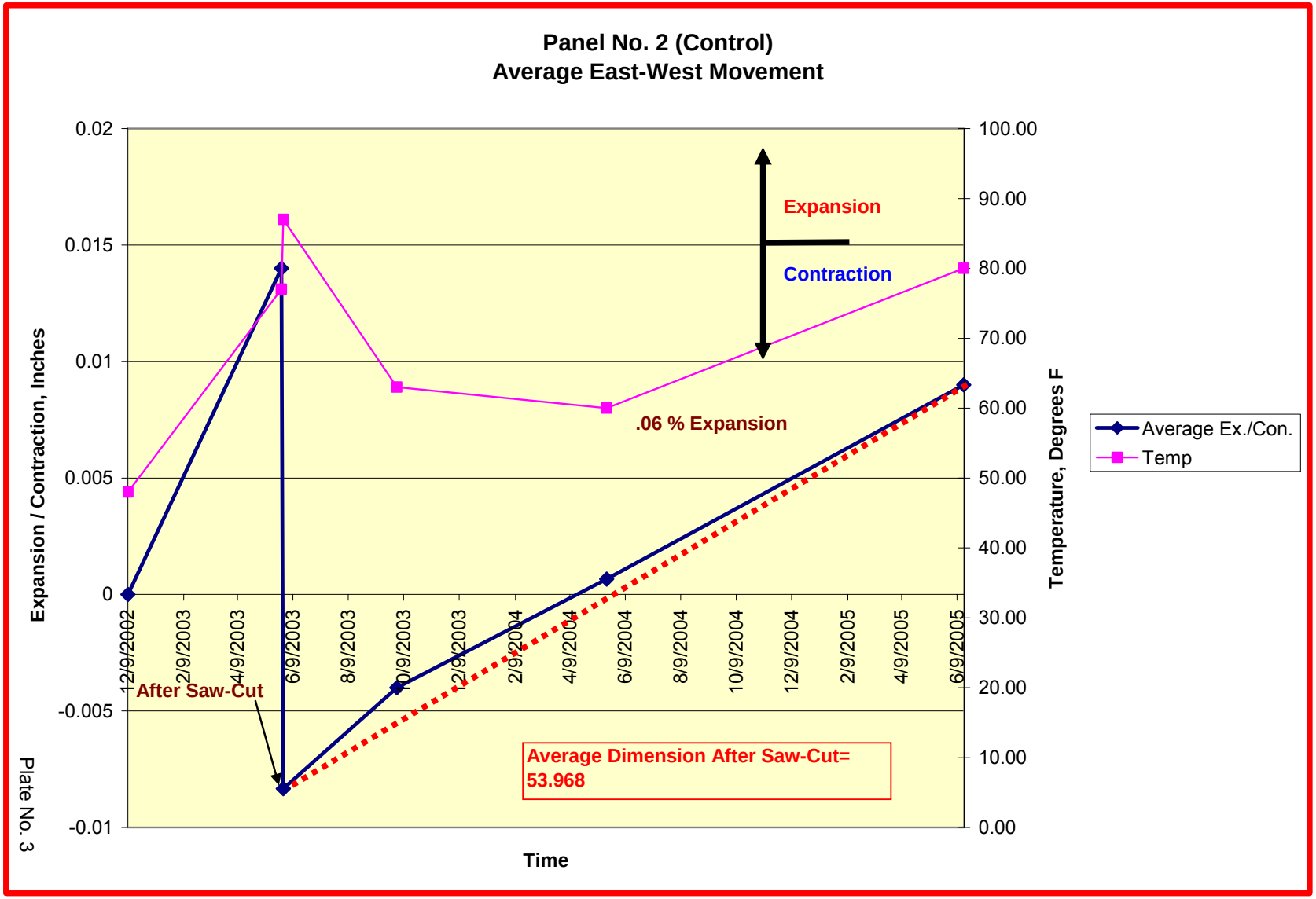
APPENDIX III

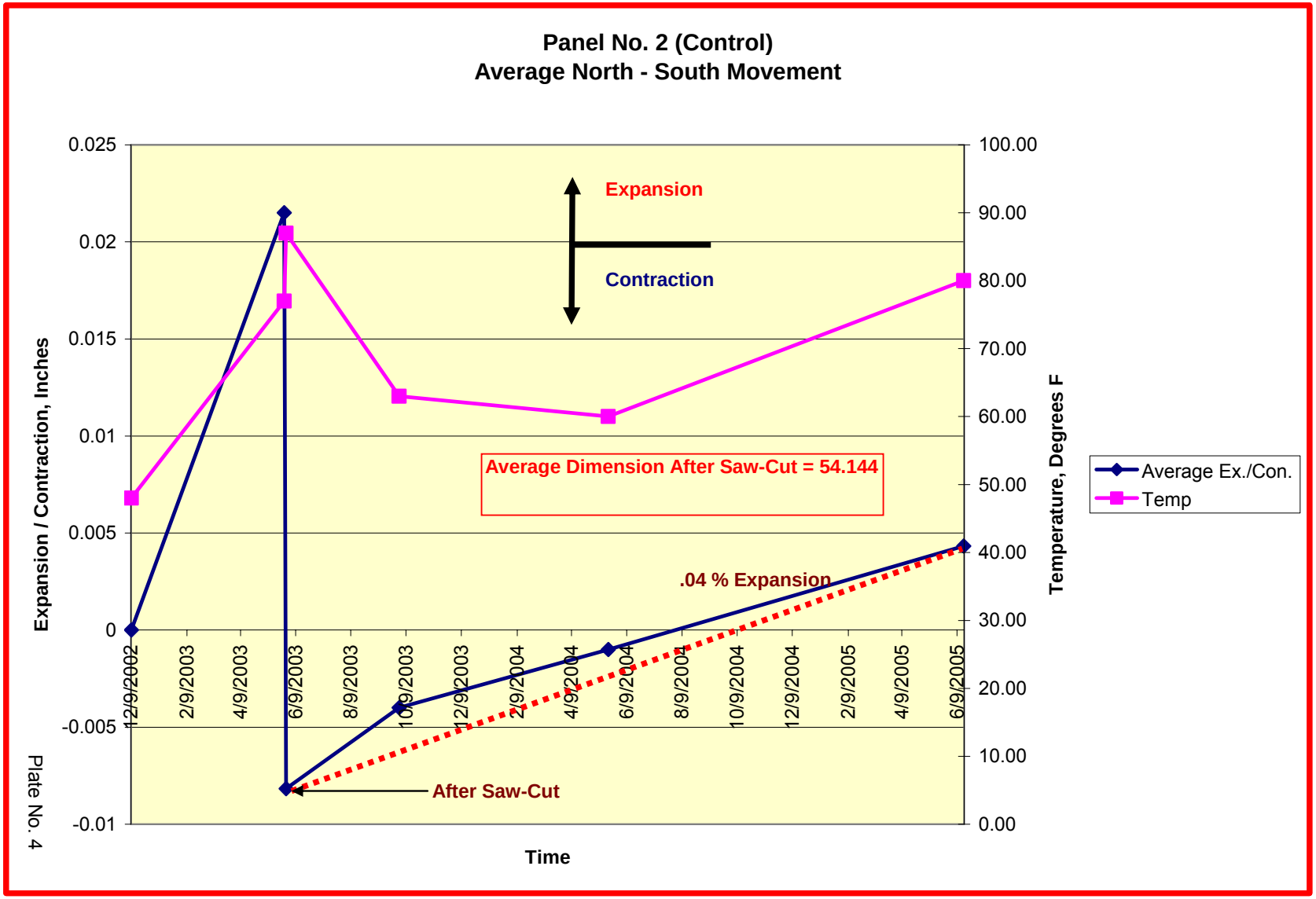
DATA PLOTS

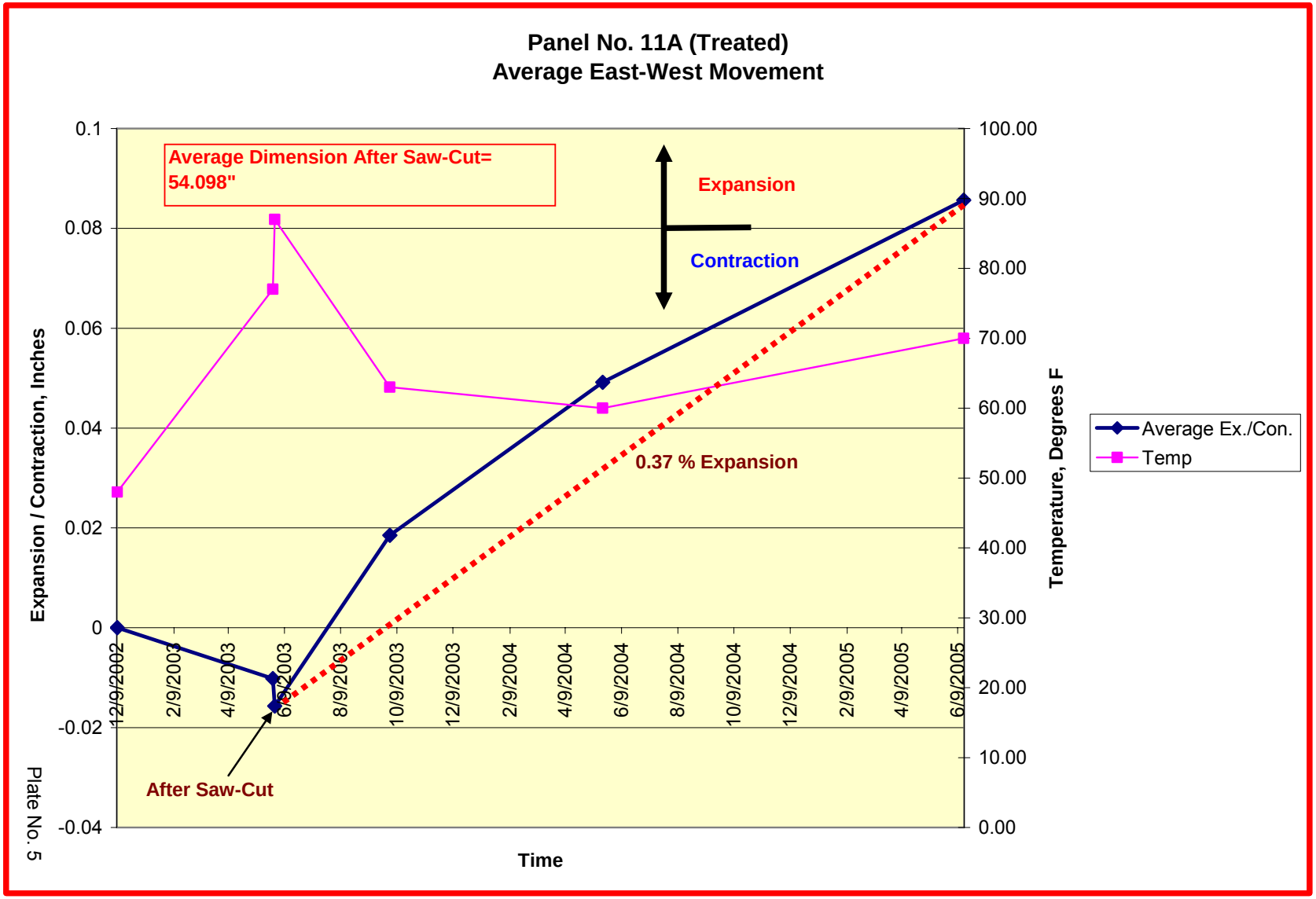
EXHIBIT NO. 1


Panel No. 1 (Treated)
Average East-West Movement
Expansion / Contraction, Inches
Temperature, Degrees F
Time
Plate No. 1
0.02
0.01
0
-0.01
-0.02
-0.03
-0.04
-0.05
-0.06
100.00
90.00
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
12/9/2002
2/9/2003
4/9/2003
6/9/2003
8/9/2003
10/9/2003
12/9/2003
2/9/2004
4/9/2004
6/9/2004
8/9/2004
10/9/2004
12/9/2004
2/9/2005
4/9/2005
6/9/2005
Average Ex./Con.
Temp
Expansion =
Expansion
Contraction
After Saw-Cut
Average Dimension After Saw-Cut = 54.143


Panel No. 1 (Treated)
Average North - South Movement
Expansion / Contraction, Inches
Temperature, Degrees F
Time
Plate No. 2
0.01
0.005
0
-0.005
-0.01
-0.015
-0.02
100.00
90.00
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
12/9/2002
2/9/2003
4/9/2003
6/9/2003
8/9/2003
10/9/2003
12/9/2003
2/9/2004
4/9/2004
6/9/2004
8/9/2004
10/9/2004
12/9/2004
2/9/2005
4/9/2005
6/9/2005
Average Ex./Con.
Temp
Expansion = 0.04%
After Saw-Cut
Expansion
Contraction
Average Dimension After Saw-Cut = 54.153


Panel No. 2 (Control)
Average East-West Movement
Expansion / Contraction, Inches
Temperature, Degrees F
Time
Plate No. 3
Expansion
Contraction
.06 % Expansion
After Saw-Cut
Average Dimension After Saw-Cut= 53.968
Average Ex./Con.
Temp
0.02
0.015
0.01
0.005
0
-0.005
-0.01
100.00
90.00
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
12/9/2002
2/9/2003
4/9/2003
6/9/2003
8/9/2003
10/9/2003
12/9/2003
2/9/2004
4/9/2004
6/9/2004
8/9/2004
10/9/2004
12/9/2004
2/9/2005
4/9/2005
6/9/2005


Panel No. 2 (Control)
Average North - South Movement
Expansion
Contraction
Average Dimension After Saw-Cut = 54.144
.04 % Expansion
After Saw-Cut
Expansion / Contraction, Inches
Temperature, Degrees F
Time
Plate No. 4
Average Ex./Con.
Temp
0.025
0.02
0.015
0.01
0.005
0
-0.005
-0.01
100.00
90.00
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
12/9/2002
2/9/2003
4/9/2003
6/9/2003
8/9/2003
10/9/2003
12/9/2003
2/9/2004
4/9/2004
6/9/2004
8/9/2004
10/9/2004
12/9/2004
2/9/2005
4/9/2005
6/9/2005


Panel No. 11A (Treated)
Average East-West Movement
Average Dimension After Saw-Cut= 54.098"
Expansion
Contraction
0.37 % Expansion
After Saw-Cut
Expansion / Contraction, Inches
Temperature, Degrees F
Time
Plate No. 5
Average Ex./Con.
Temp
0.1
0.08
0.06
0.04
0.02
0
-0.02
-0.04
100.00
90.00
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
12/9/2002
2/9/2003
4/9/2003
6/9/2003
8/9/2003
10/9/2003
12/9/2003
2/9/2004
4/9/2004
6/9/2004
8/9/2004
10/9/2004
12/9/2004
2/9/2005
4/9/2005
6/9/2005

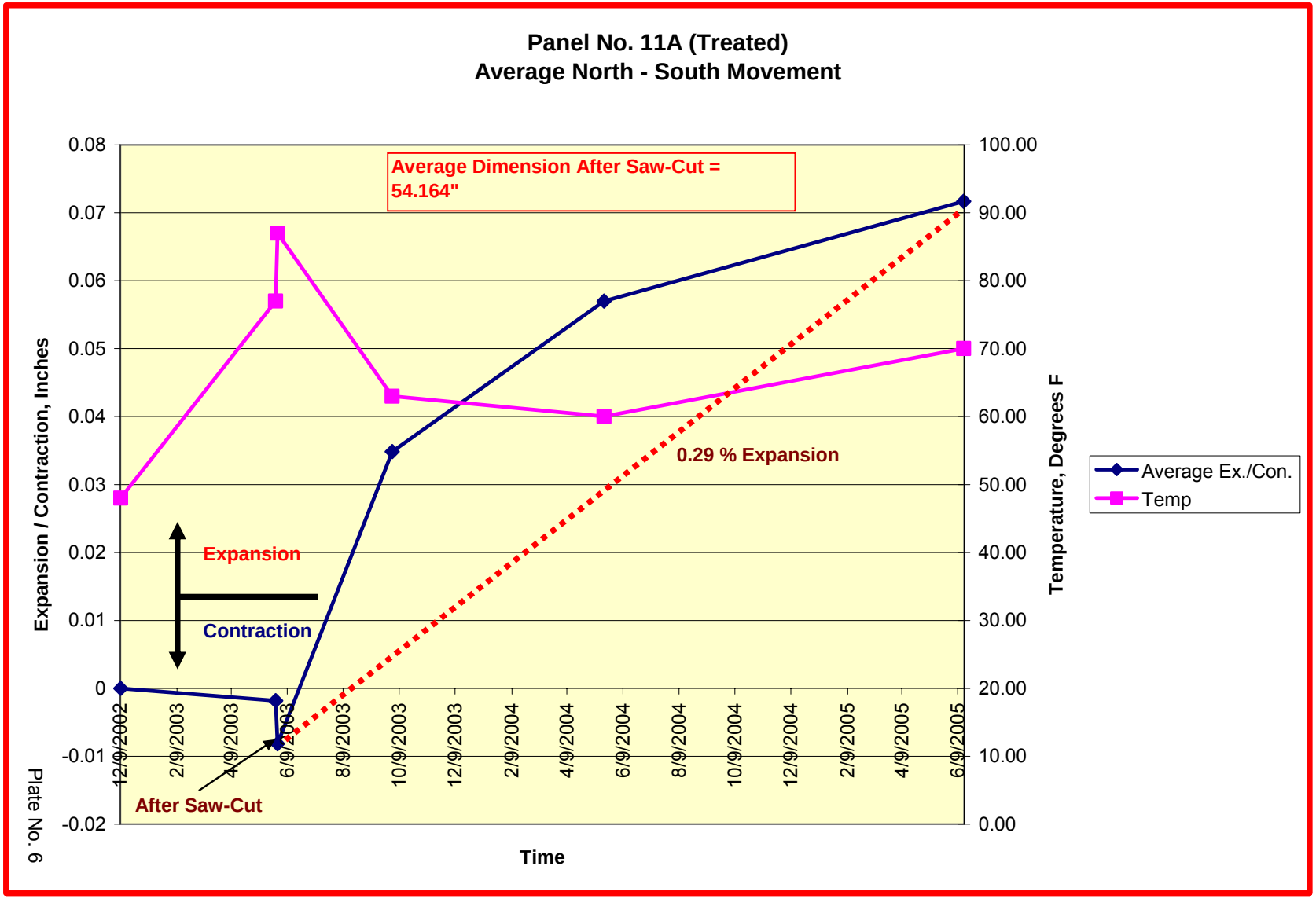
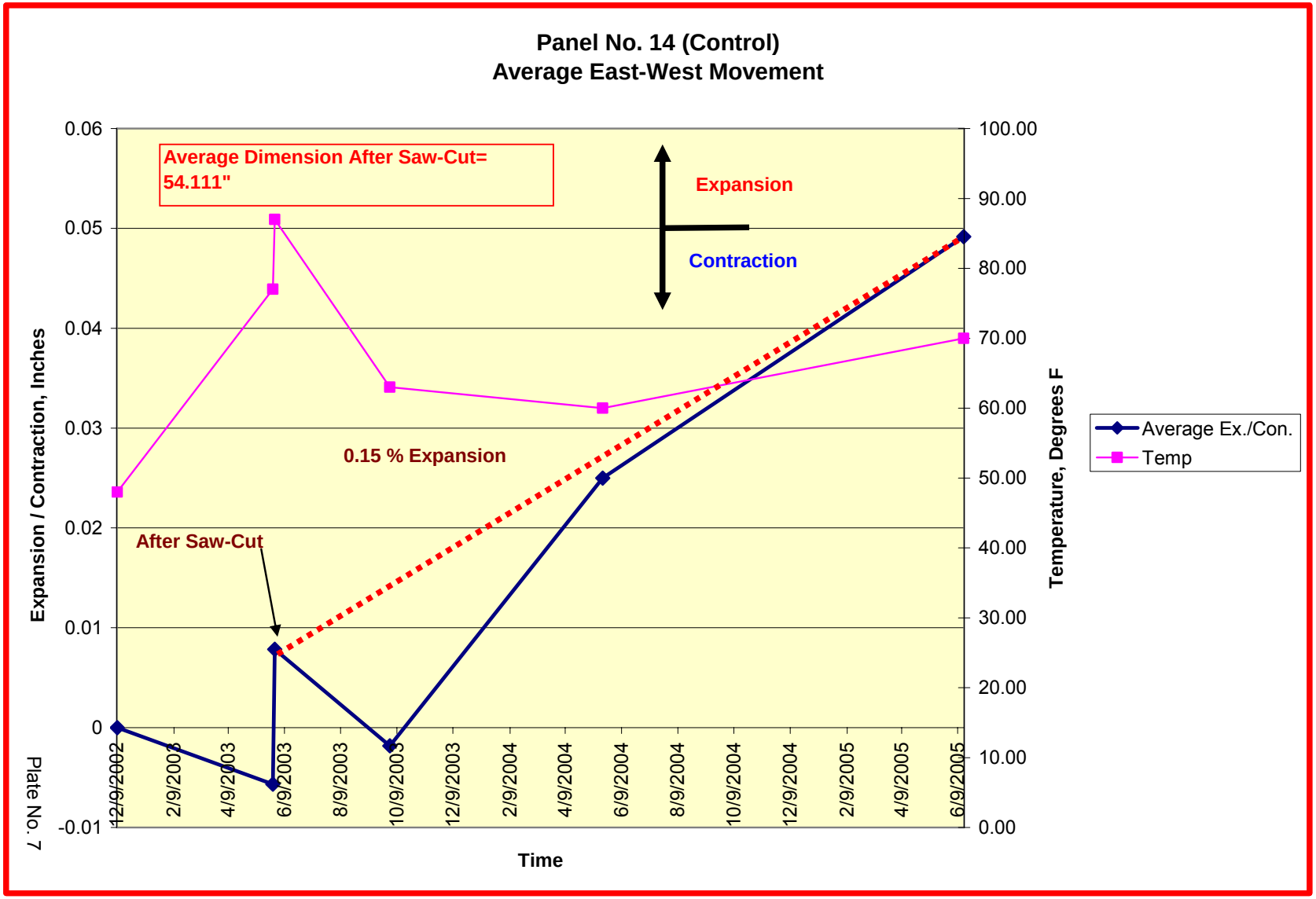

Panel No. 11A (Treated)
Average North - South Movement
Average Dimension After Saw-Cut = 54.164"
0.29 % Expansion
Expansion
Contraction
After Saw-Cut
Expansion / Contraction, Inches
Temperature, Degrees F
Time
Average Ex./Con.
Temp
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
-0.01
-0.02
100.00
90.00
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
12/9/2002
2/9/2003
4/9/2003
6/9/2003
8/9/2003
10/9/2003
12/9/2003
2/9/2004
4/9/2004
6/9/2004
8/9/2004
10/9/2004
12/9/2004
2/9/2005
4/9/2005
6/9/2005

Plate No. 6


Panel No. 14 (Control)
Average East-West Movement
Average Dimension After Saw-Cut= 54.111"
Expansion
Contraction
0.15 % Expansion
After Saw-Cut
Expansion / Contraction, Inches
Temperature, Degrees F
Time
Plate No. 7
Average Ex./Con.
Temp
0.06
0.05
0.04
0.03
0.02
0.01
0
-0.01
100.00
90.00
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
12/9/2002
2/9/2003
4/9/2003
6/9/2003
8/9/2003
10/9/2003
12/9/2003
2/9/2004
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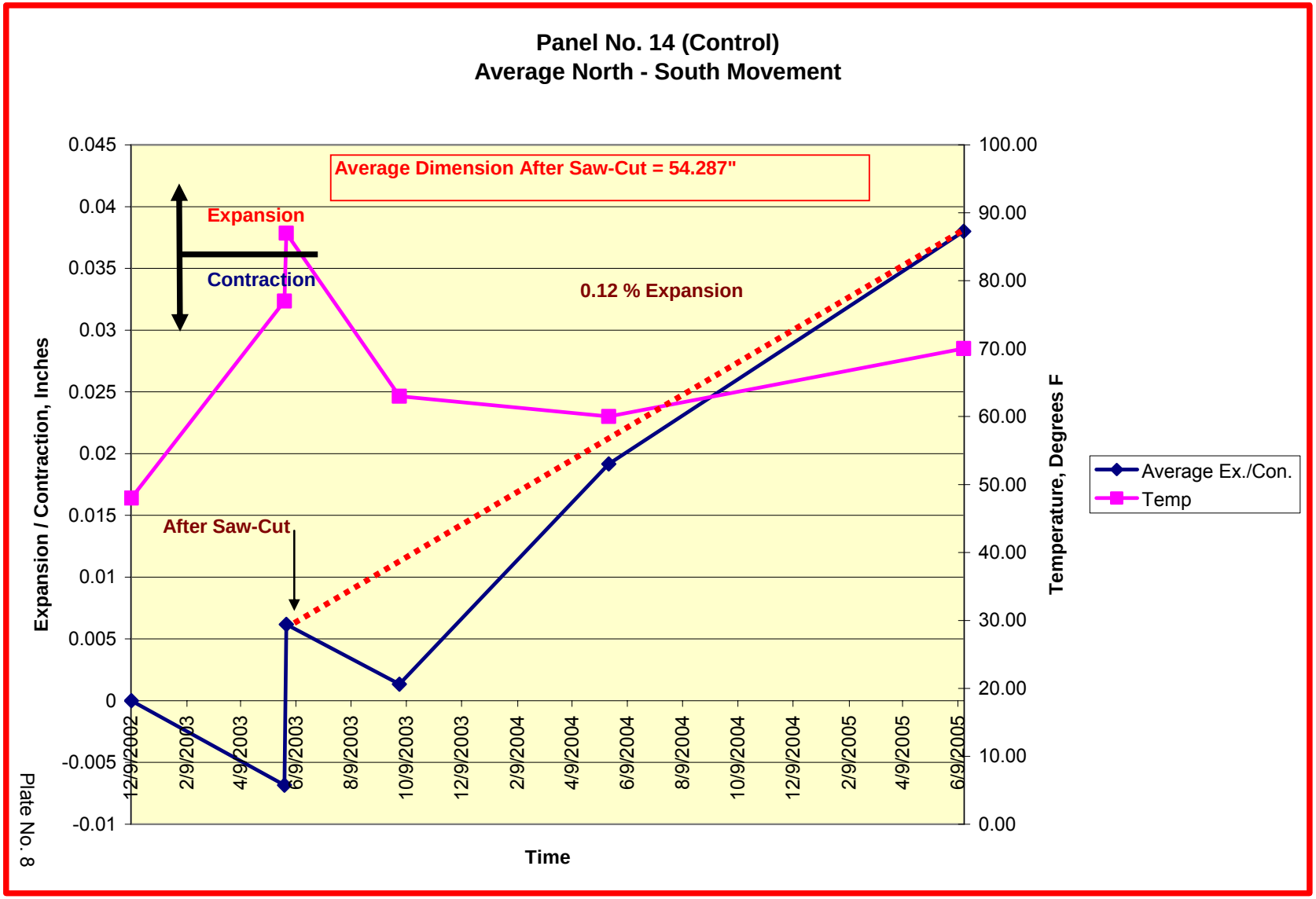
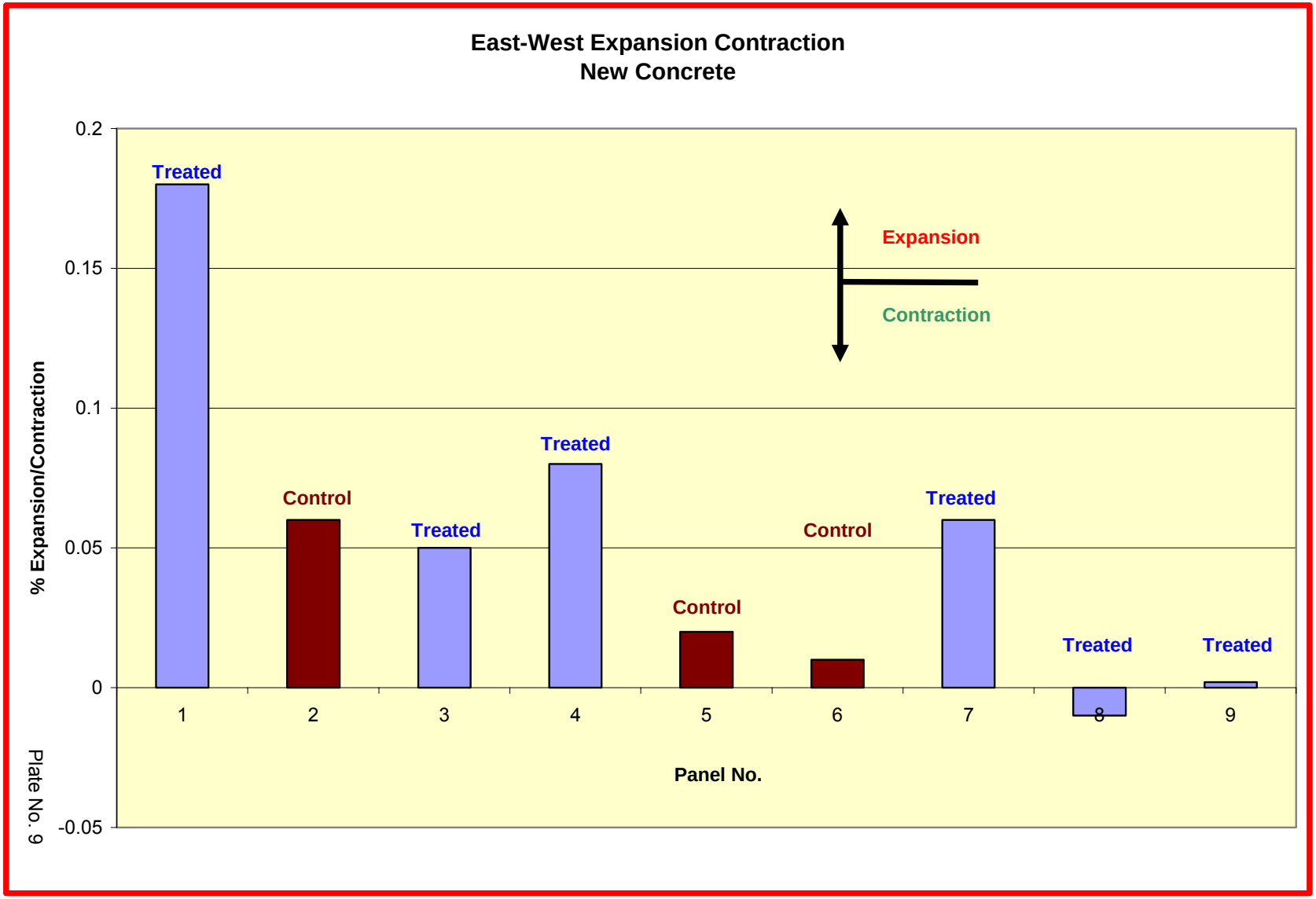
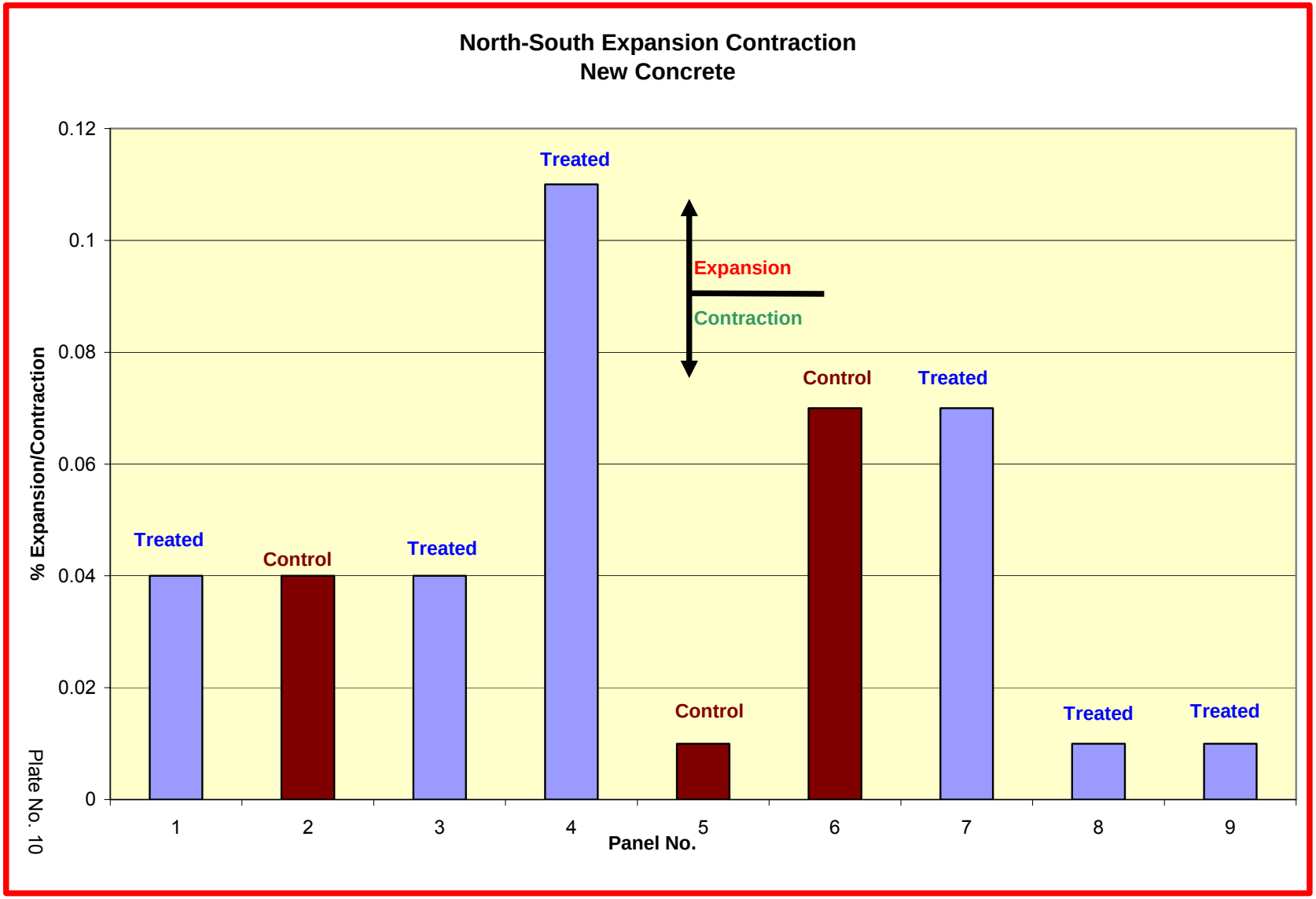
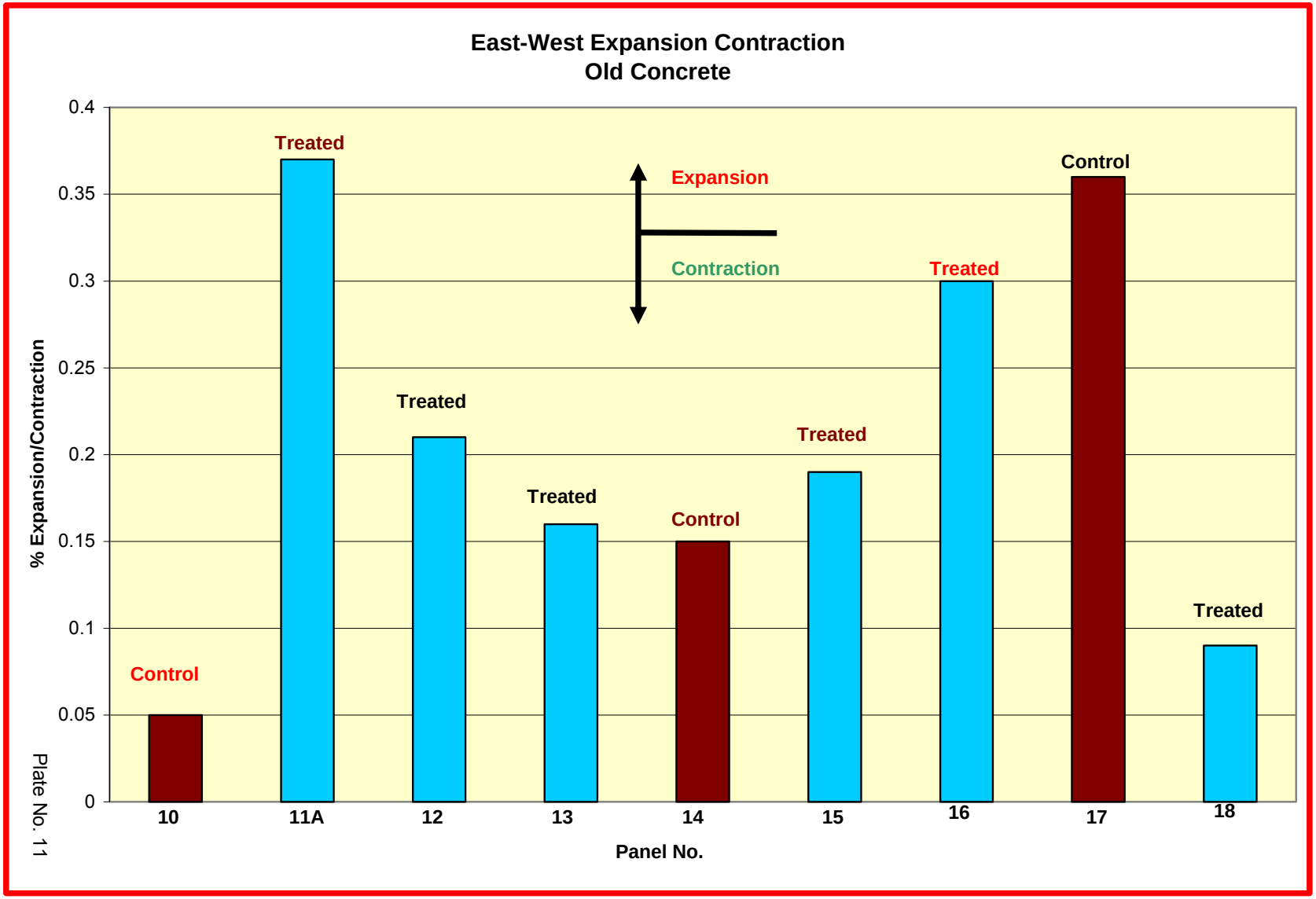
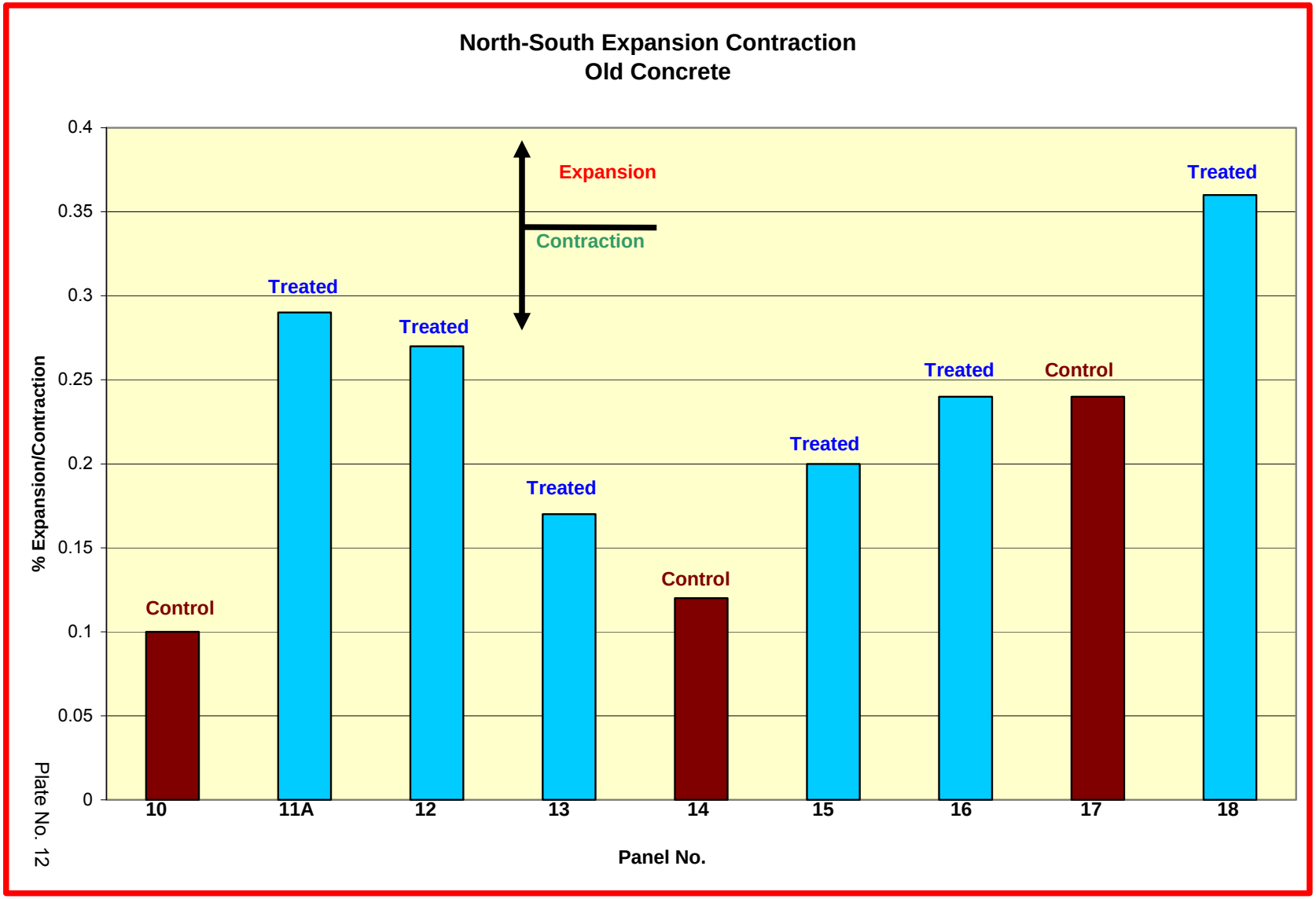
12/9/2004
2/9/2005
4/9/2005
6/9/2005

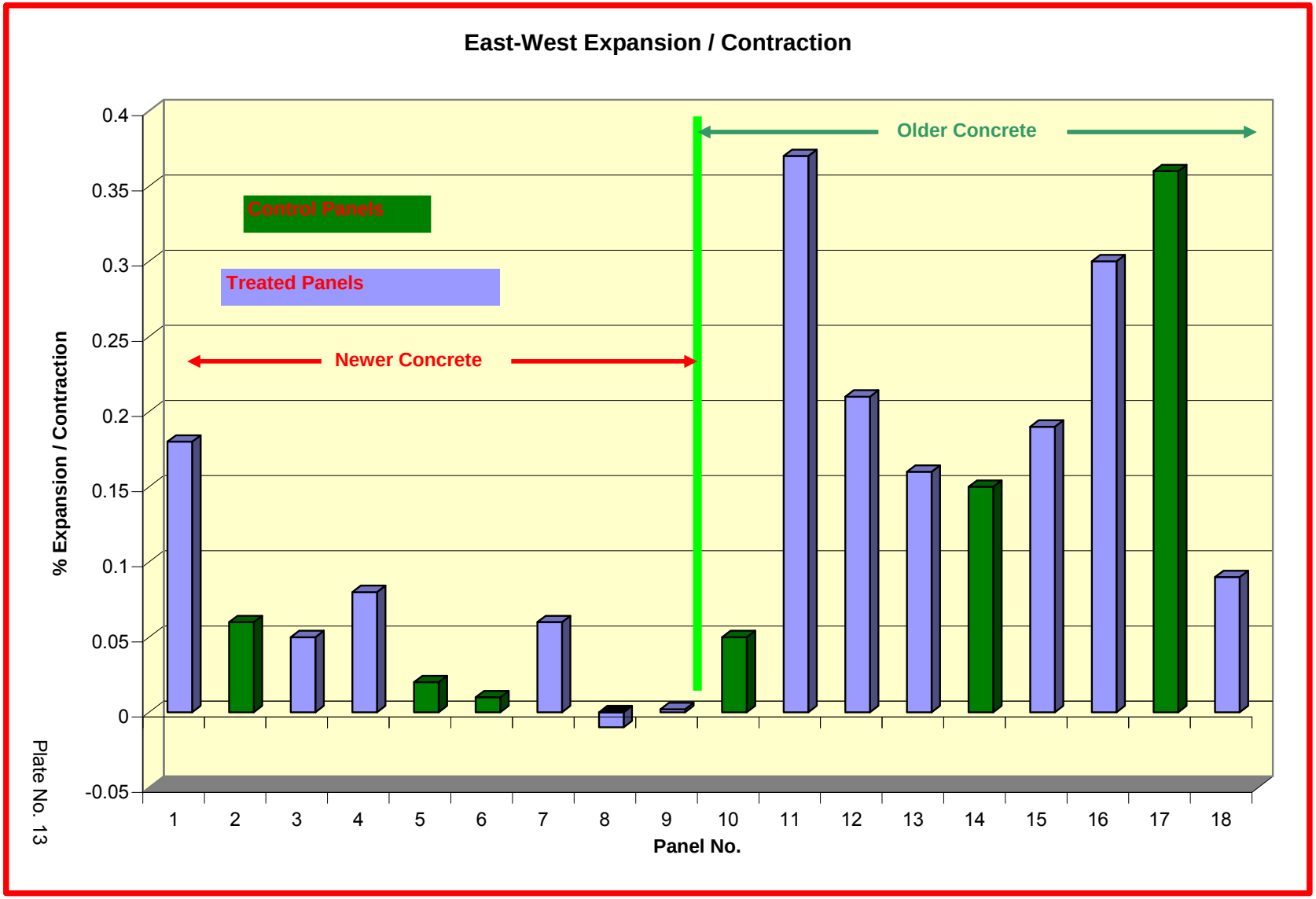

Panel No. 14 (Control)
Average North - South Movement
Average Dimension After Saw-Cut = 54.287"
Expansion
Contraction
0.12 % Expansion
After Saw-Cut
Expansion / Contraction, Inches
Temperature, Degrees F
Time
Average Ex./Con.
Temp
0.045
0.04
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
-0.005
-0.01
100.00
90.00
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
12/9/2002
2/9/2003
4/9/2003
6/9/2003
8/9/2003
10/9/2003
12/9/2003
2/9/2004
4/9/2004
6/9/2004
8/9/2004
10/9/2004
12/9/2004
2/9/2005
4/9/2005
6/9/2005
Plate No. 8


East-West Expansion Contraction
New Concrete
0.2
0.15
0.1
0.05
0
-0.05
% Expansion/Contraction
Plate No. 9
Expansion
Contraction
Treated
Control
Treated
Treated
Control
Control
Treated
Treated
Treated
1
2
3
4
5
6
7
8
9
Panel No.


North-South Expansion Contraction
New Concrete
% Expansion/Contraction
Plate No. 10
0.12
0.1
0.08
0.06
0.04
0.02
0
Expansion
Contraction
Treated
Control
Treated
Treated
Control
Control
Treated
Treated
Treated
1
2
3
4
5
6
7
8
9
Panel No.


East-West Expansion Contraction
Old Concrete
% Expansion/Contraction
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
Expansion
Contraction
Control
Treated
Treated
Treated
Control
Treated
Treated
Control
Treated
10
11A
12
13
14
15
16
17
18
Panel No.
Plate No. 11


North-South Expansion Contraction
Old Concrete
Expansion
Contraction
% Expansion/Contraction
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
Control
Treated
Treated
Treated
Control
Treated
Treated
Control
Treated
10
11A
12
13
14
15
16
17
18
Panel No.
Plate No. 12


East-West Expansion / Contraction
Older Concrete
Control Panels
Treated Panels
Newer Concrete
% Expansion / Contraction
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
-0.05
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
Panel No.
Plate No. 13

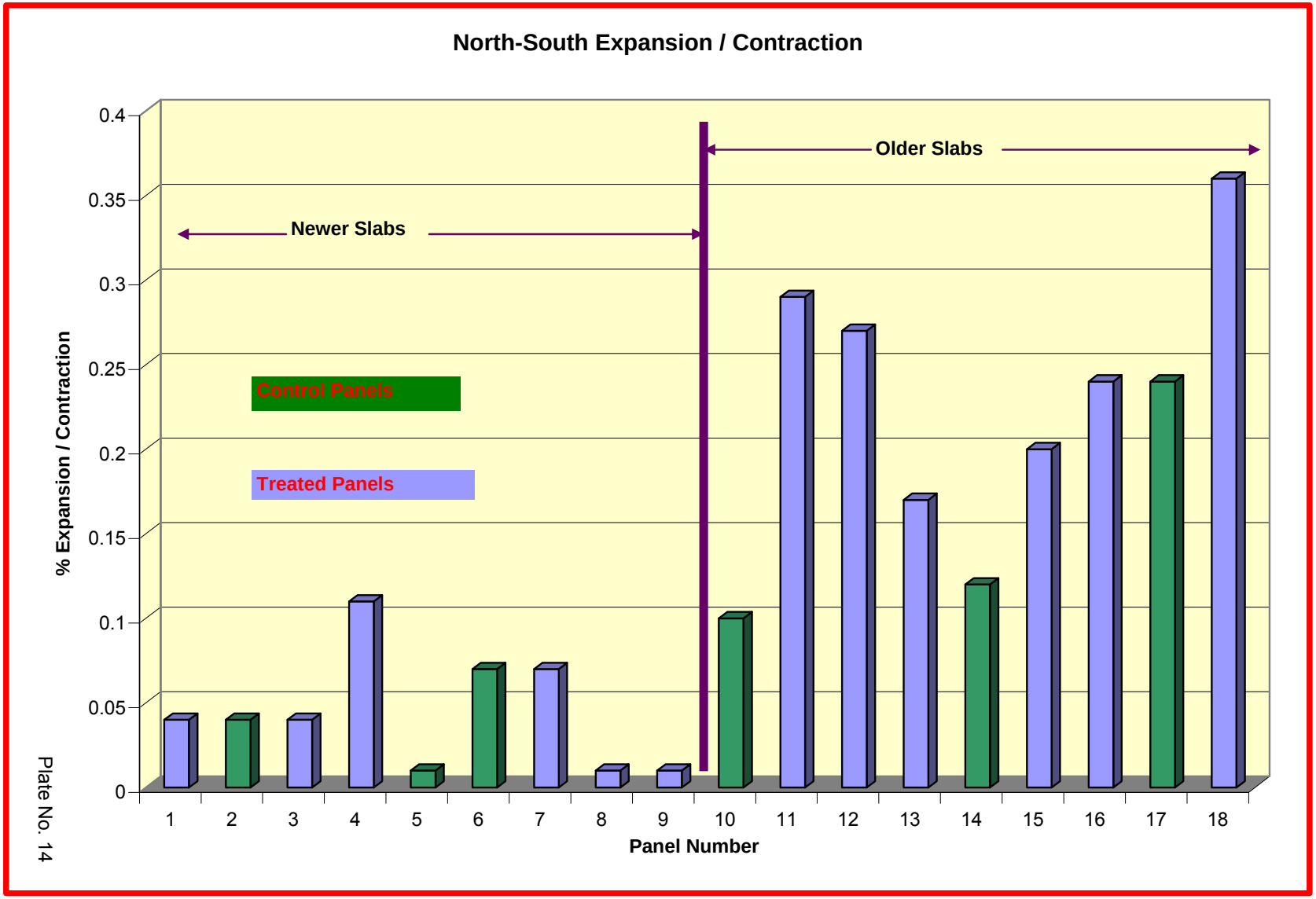
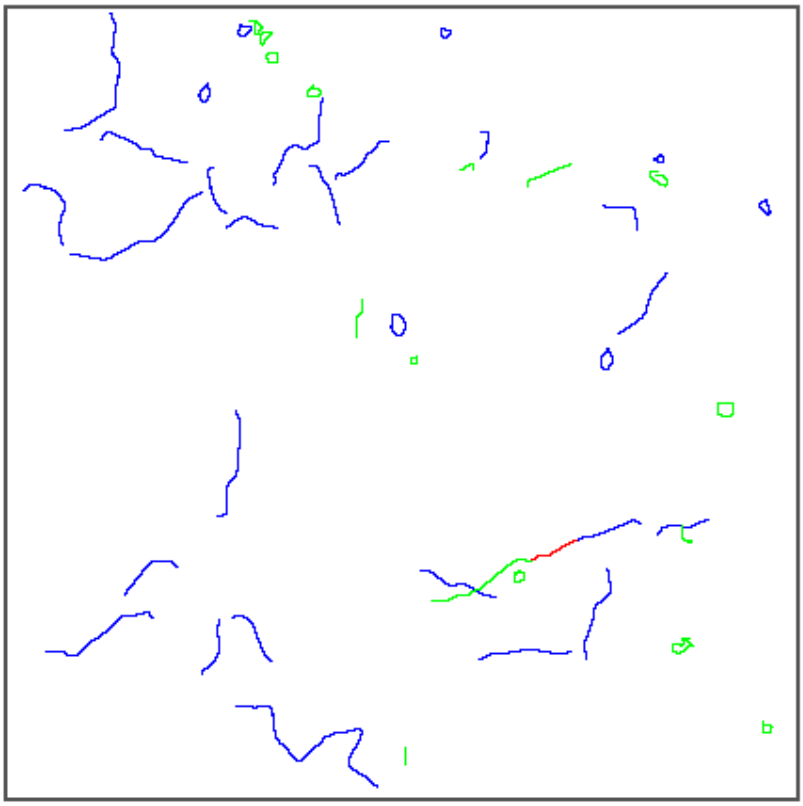

North-South Expansion / Contraction
% Expansion / Contraction
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
Newer Slabs
Older Slabs
Control Panels
Treated Panels
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
Panel Number
Plate No. 14

EXHIBIT NO. 2

CONTROL



—JUNE 05
— MAY 04
— OCTOBER 02

PANEL 6 NO. 2

N

Plate No. 1

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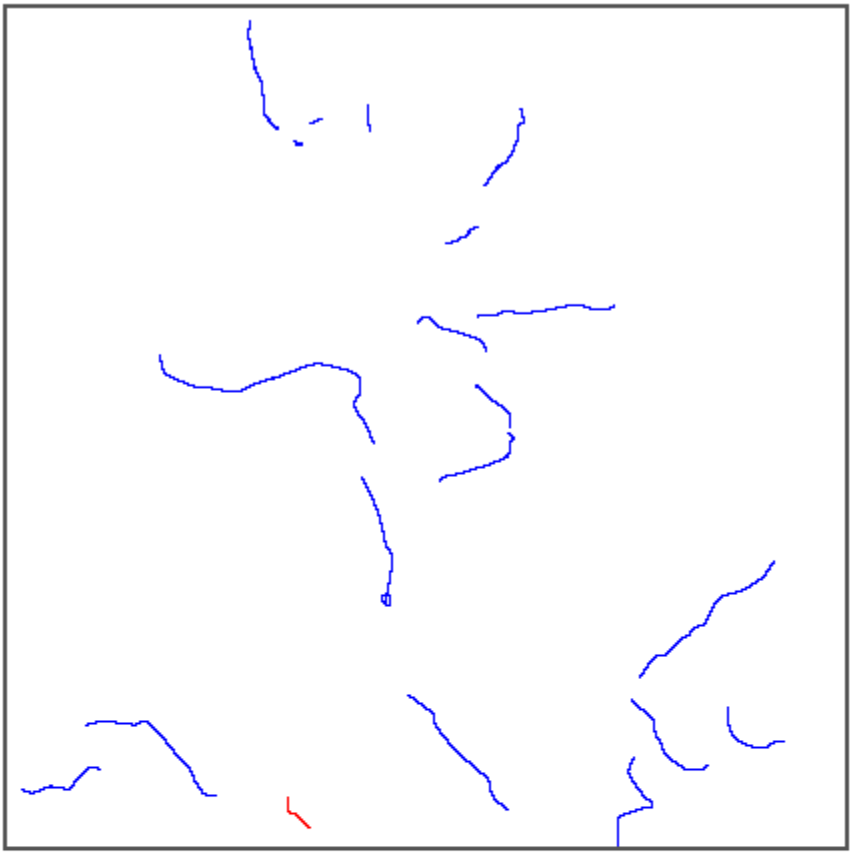
CONTROL



JUNE 05
MAY 04
OCTOBER 02

PANEL 6 NO. 3

N

Plate No. 2

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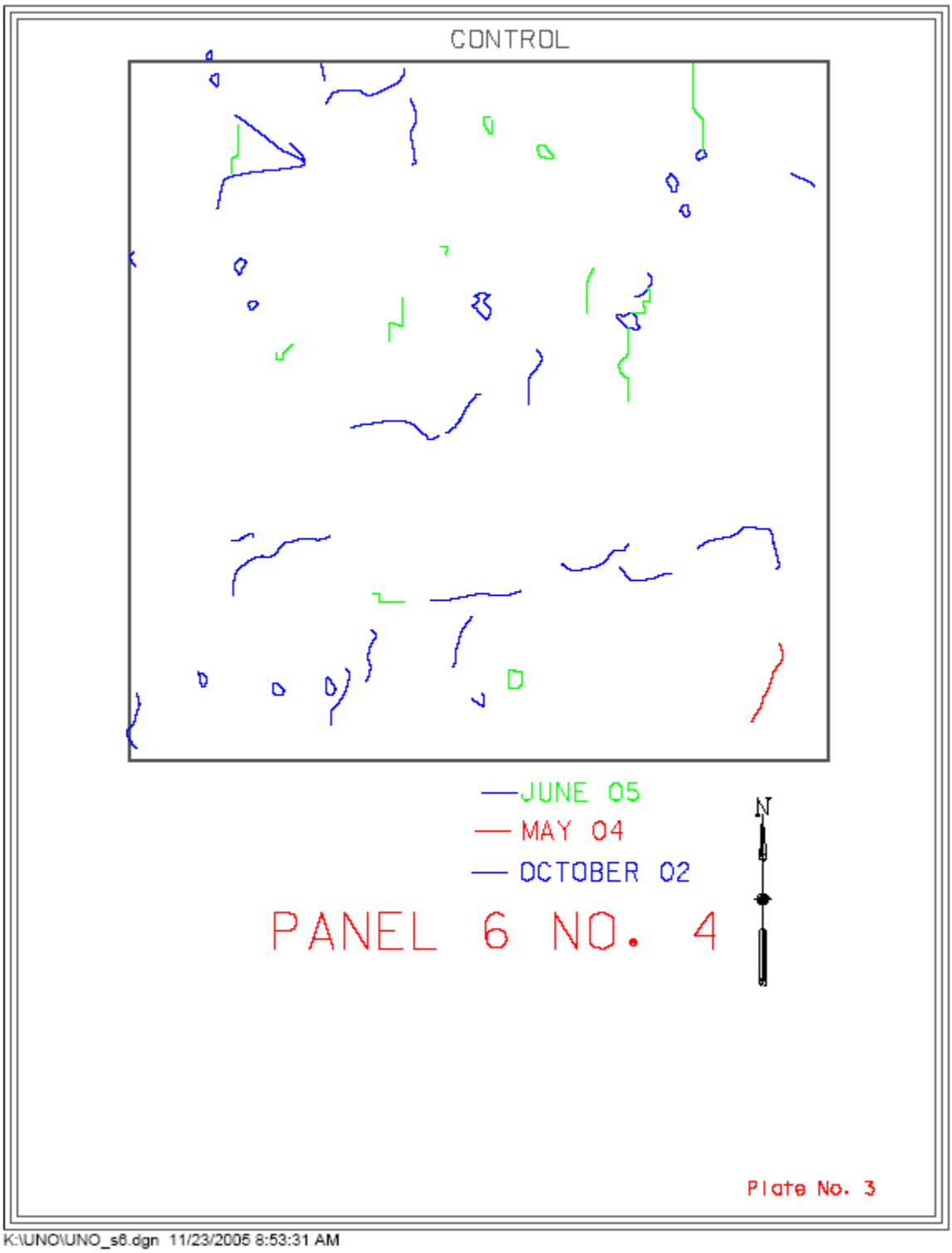
CONTROL
JUNE 05
MAY 04
OCTOBER 02
N
PANEL 6 NO. 4
Plate No. 3
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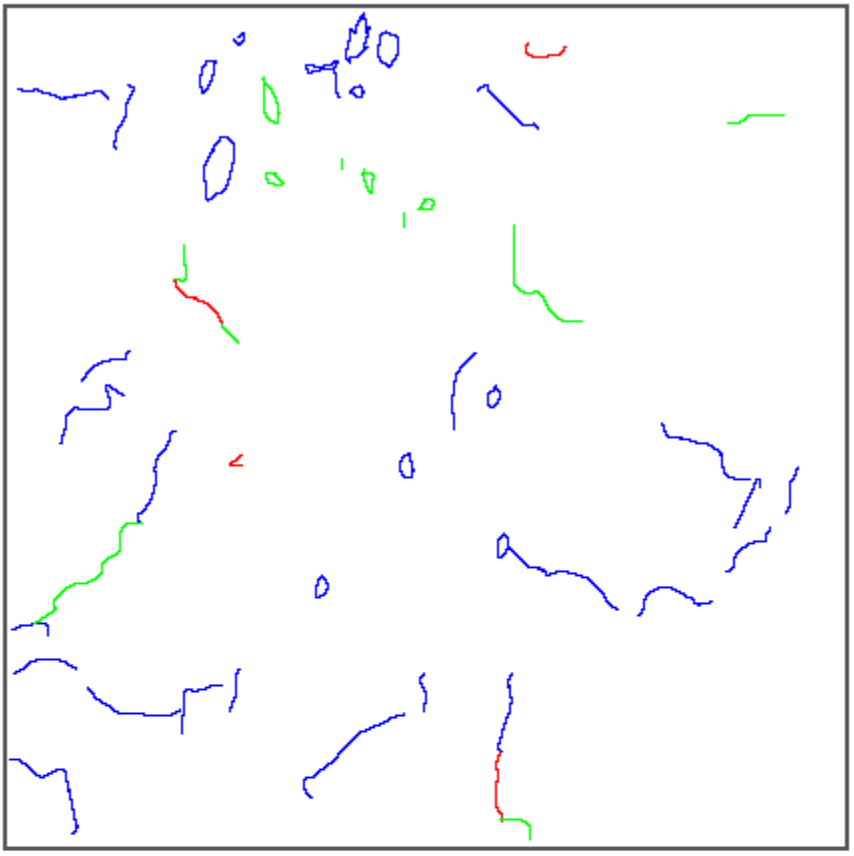
CONTROL



CONTROL

—JUNE 05

— MAY 04

— OCTOBER 02

PANEL 6 NO. 5

N

US Army Corps of Engineers
Omaha District

University of Nebraska Lincoln

Nebraska Department of Roads

Plate No. 4

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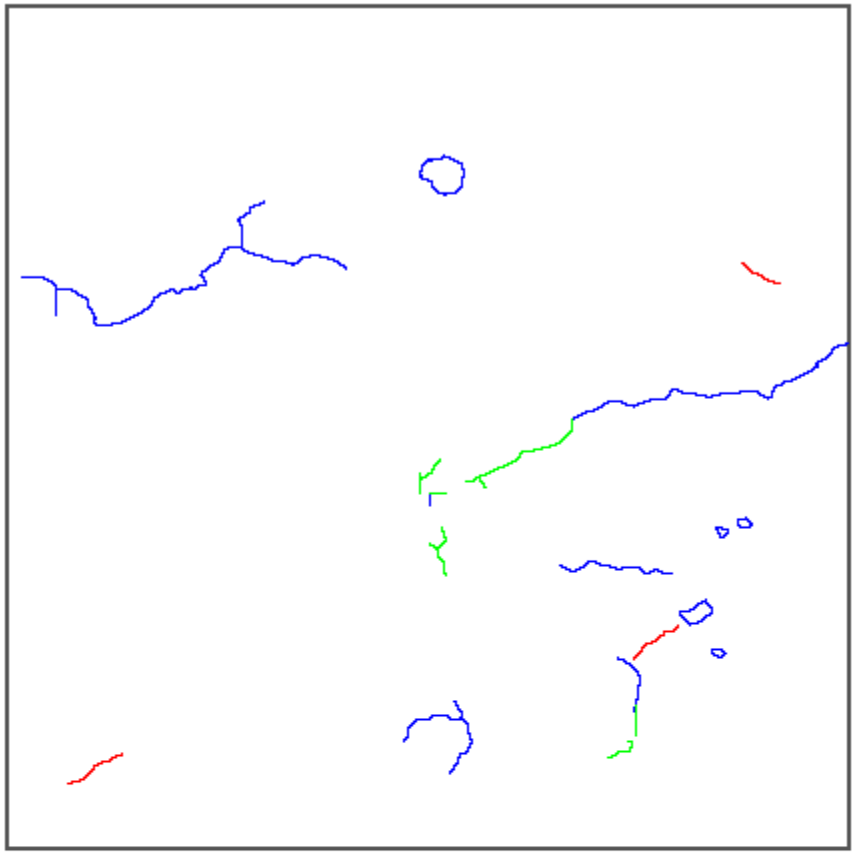
TREATED



JUNE 05
MAY 04
OCTOBER 02

N

PANEL 7 NO. 1

PLATE NO. 5

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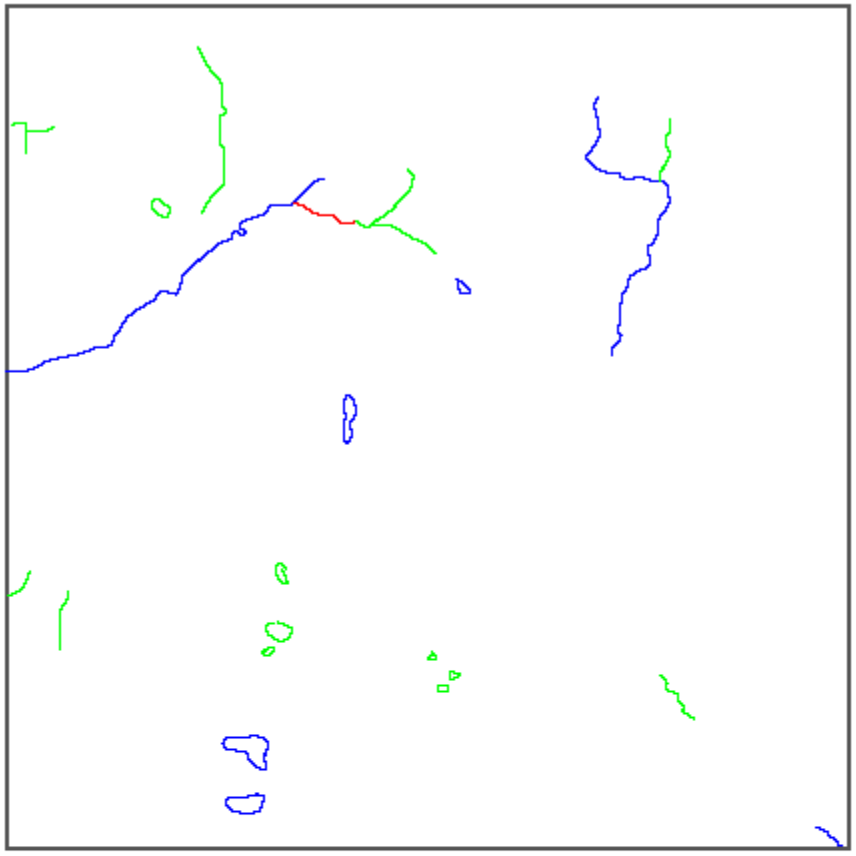

—JUNE 05
— MAY 04
— OCTOBER 02

PANEL 7 NO. 2

N

PLATE NO. 6

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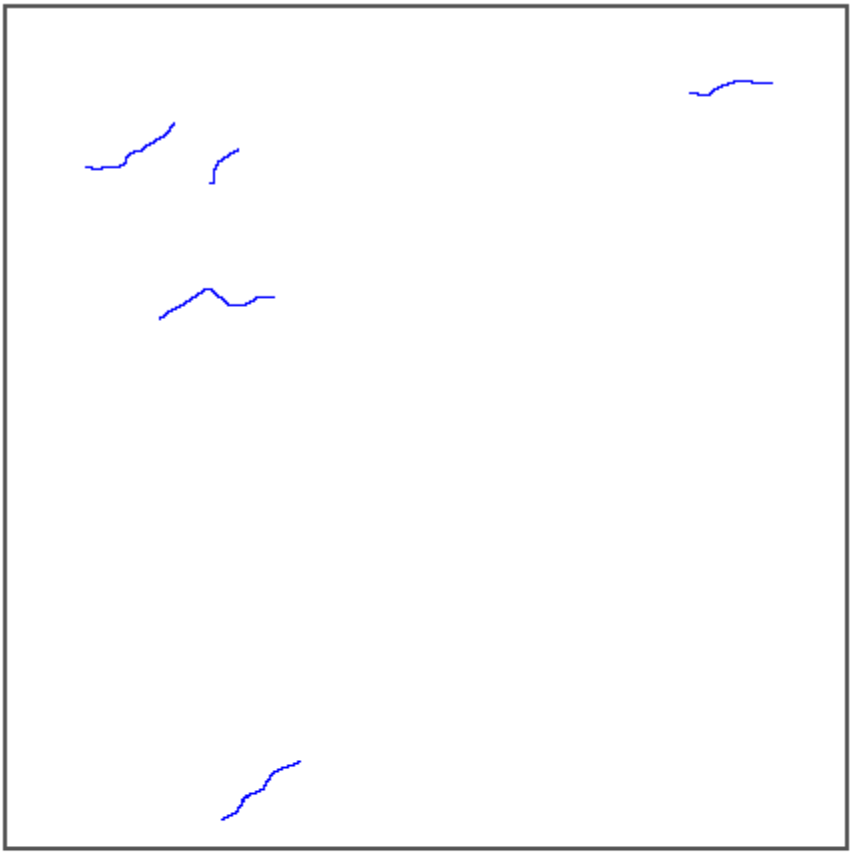

—JUNE 05
— MAY 04
— OCTOBER 02

PANEL 7 NO. 3

N

US Army Corps of Engineers
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PLATE NO. 7

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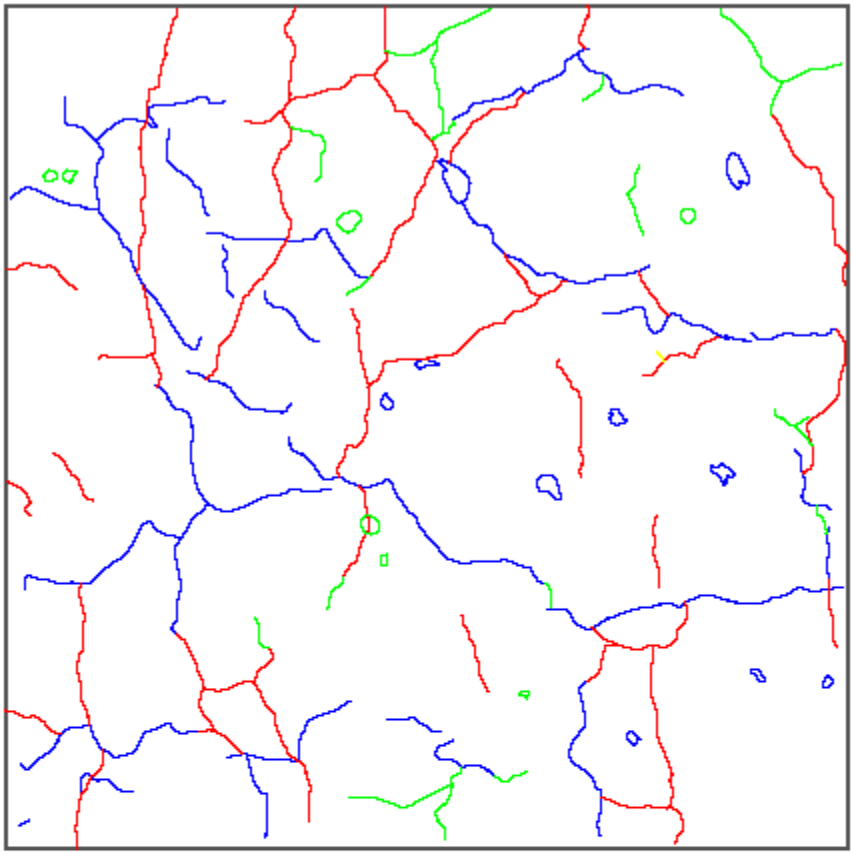
CONTROL



JUNE 05
MAY 04
OCTOBER 02

N

PANEL 17 NO. 1

PLATE NO. 8

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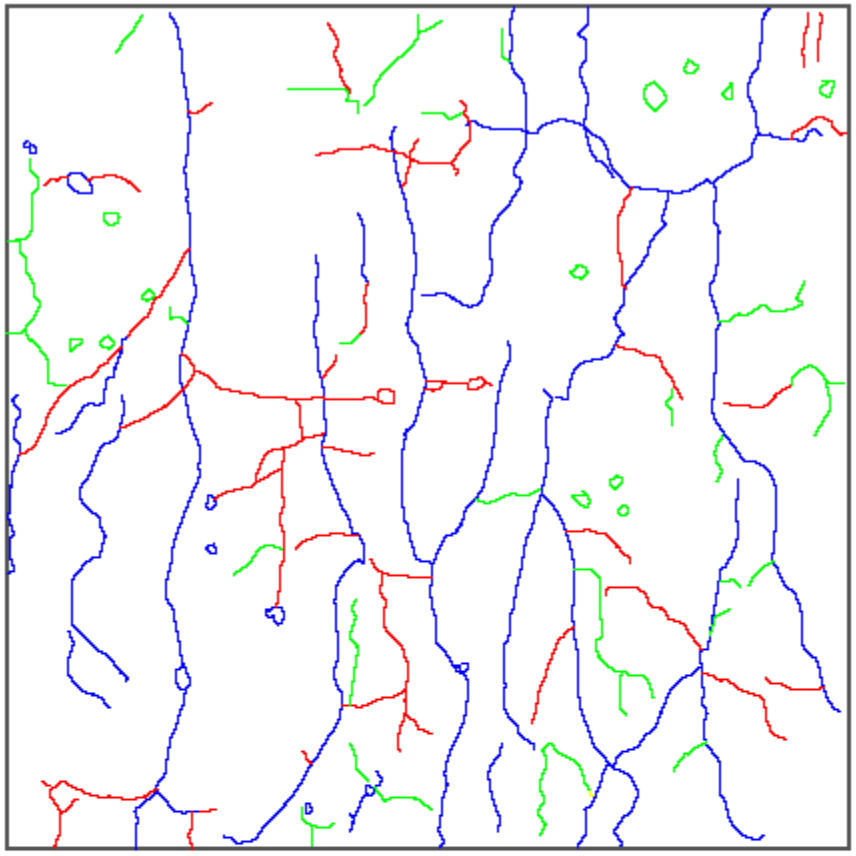

JUNE 05
MAY 04
OCTOBER 02

PANEL 17 NO. 2

N

PLATE NO. 9

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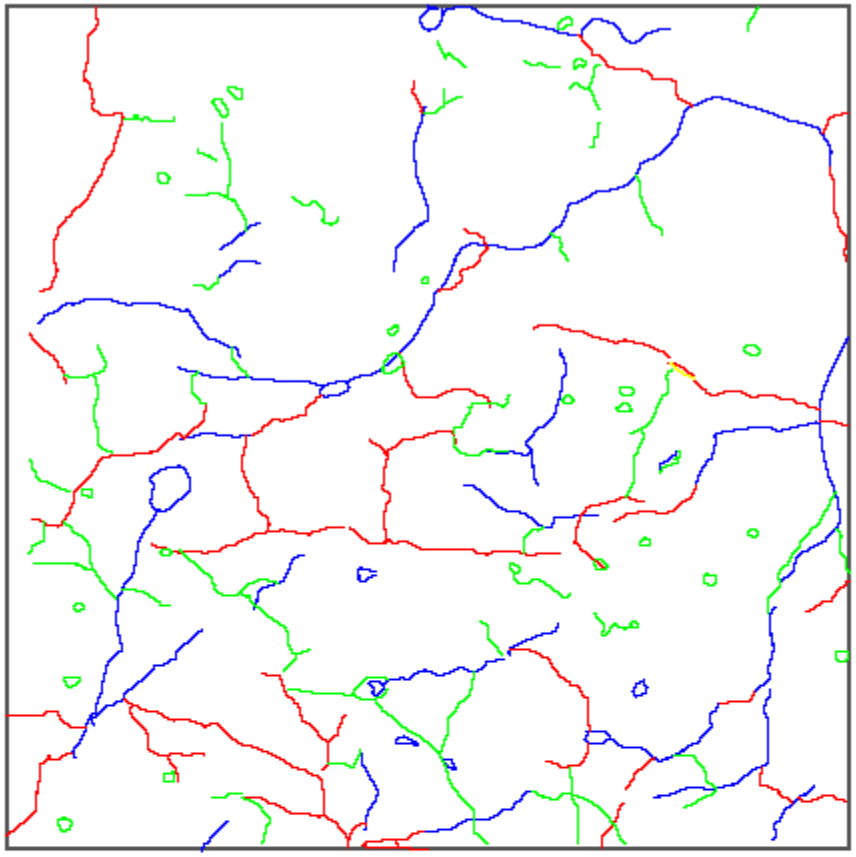

—JUNE 05
—MAY 04
—OCTOBER 02

PANEL 17 NO. 3

N

PLATE NO. 10

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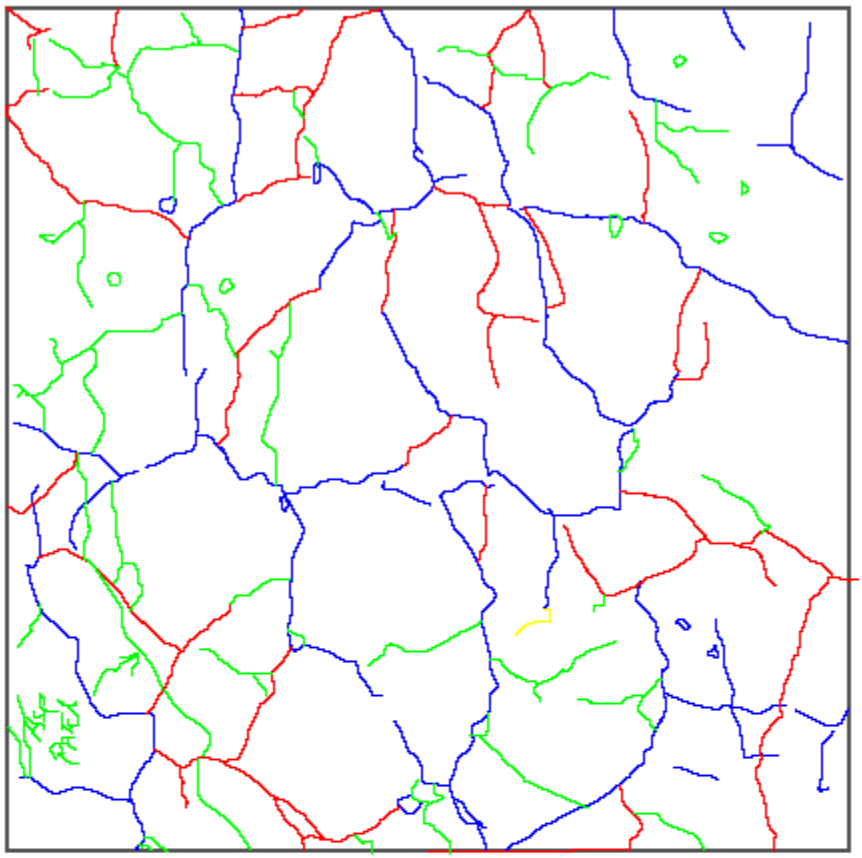

JUNE 05
MAY 04
OCTOBER 02

N

PANEL 17 NO. 4

US Army Corps of Engineers
Omaha District

University of Nebraska Lincoln

Nebraska Department of Roads

PLATE NO. 11

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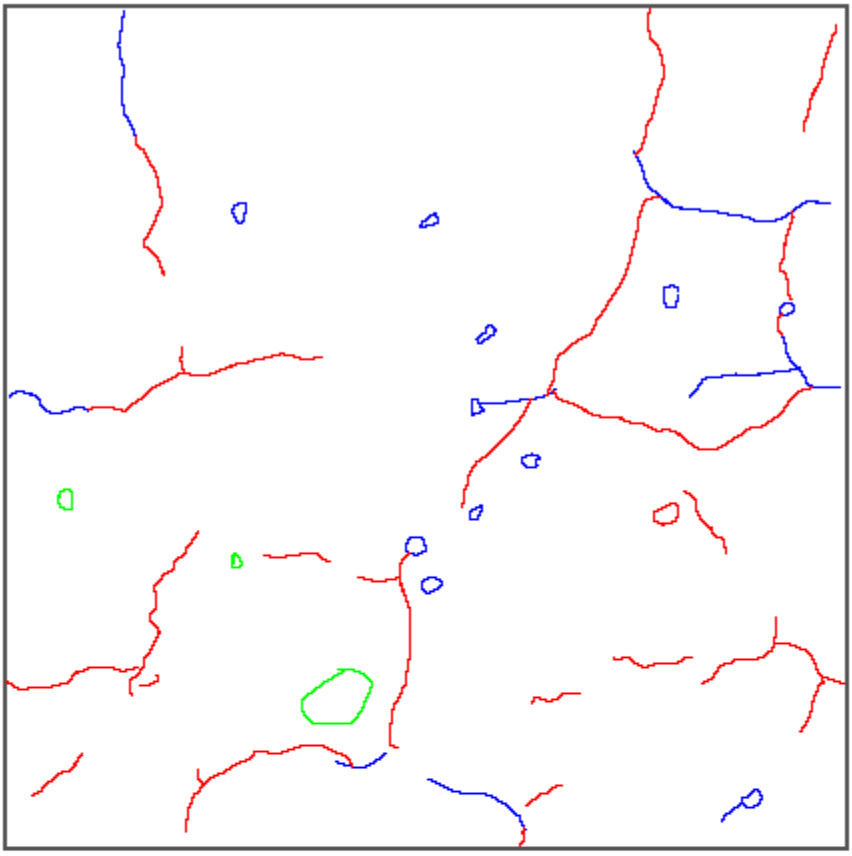
TREATED



JUNE 05
MAY 04
OCTOBER 02

N

PANEL 18 NO. 3

US Army Corps of Engineers
Omaha District

University of Nebraska Lincoln

Nebraska Department of Roads

PLATE NO. 12

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EXHIBIT NO. 3

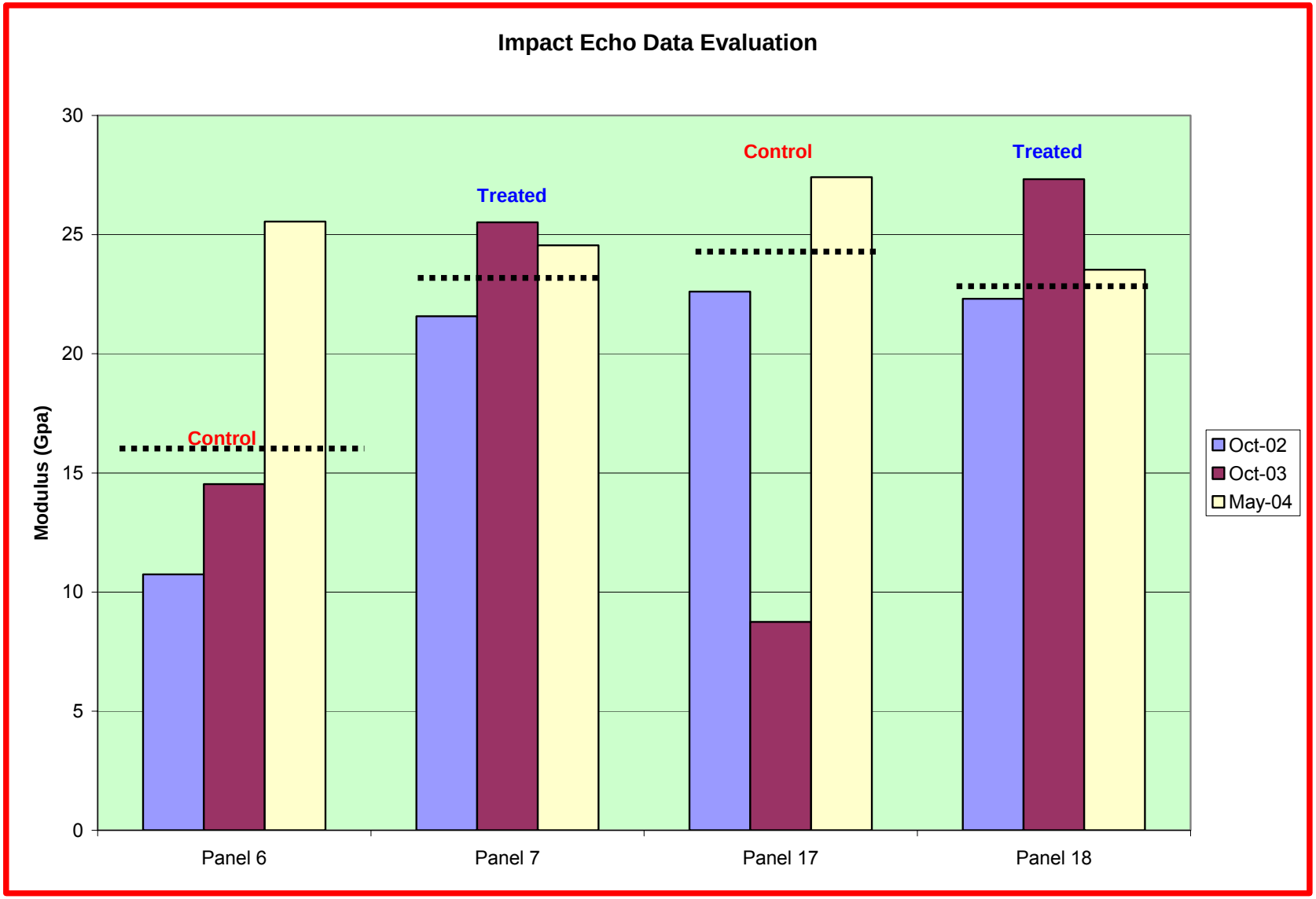

Impact Echo Data Evaluation
Modulus (Gpa)
30
25
20
15
10
5
0
Control
Treated
Control
Treated
Panel 6
Panel 7
Panel 17
Panel 18
Oct-02
Oct-03
May-04

EXHIBIT NO. 4

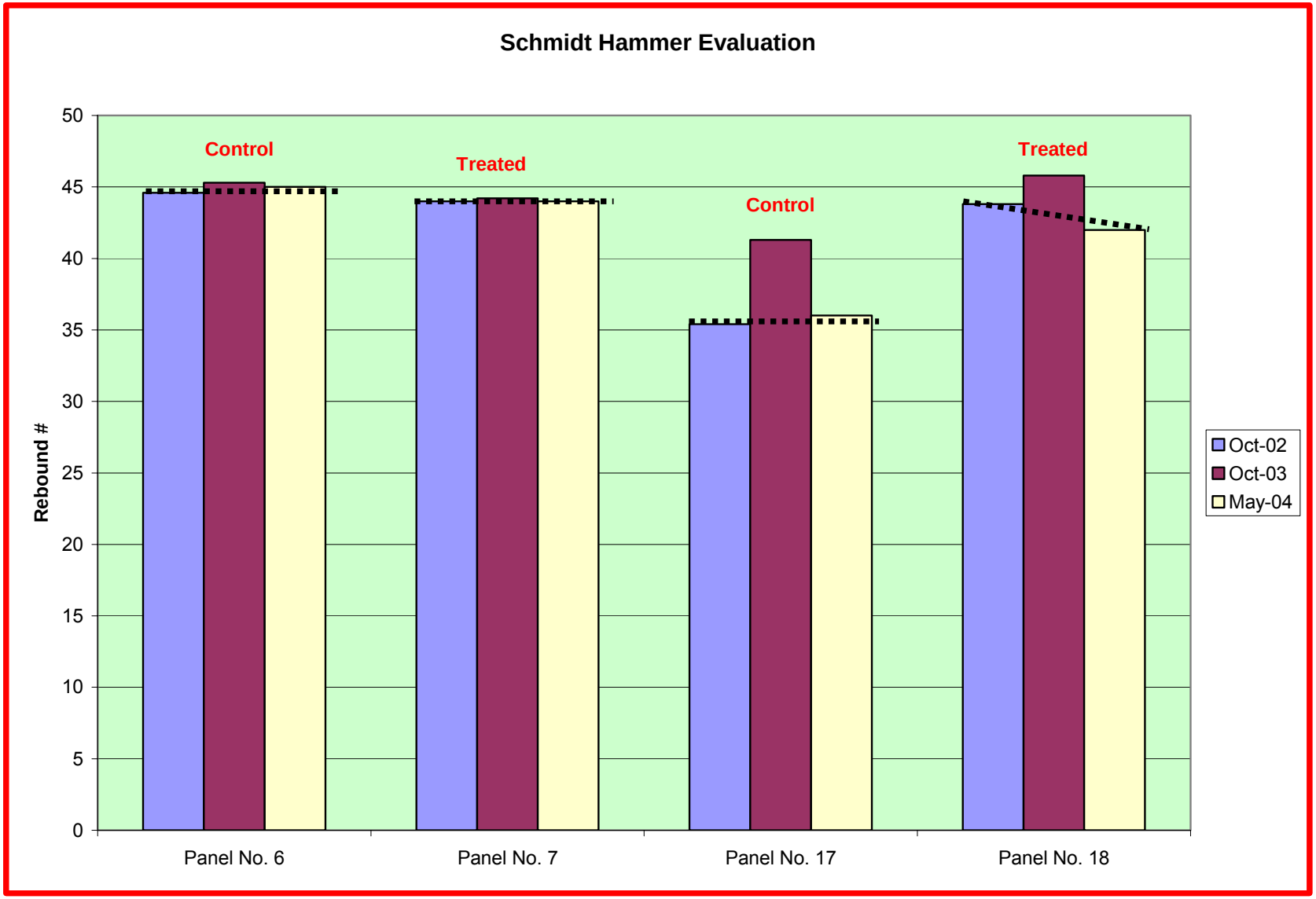

Schmidt Hammer Evaluation
Rebound #
50
45
40
35
30
25
20
15
10
5
0
Control
Treated
Control
Treated
Panel No. 6
Panel No. 7
Panel No. 17
Panel No. 18
Oct-02
Oct-03
May-04

EXHIBIT NO. 5

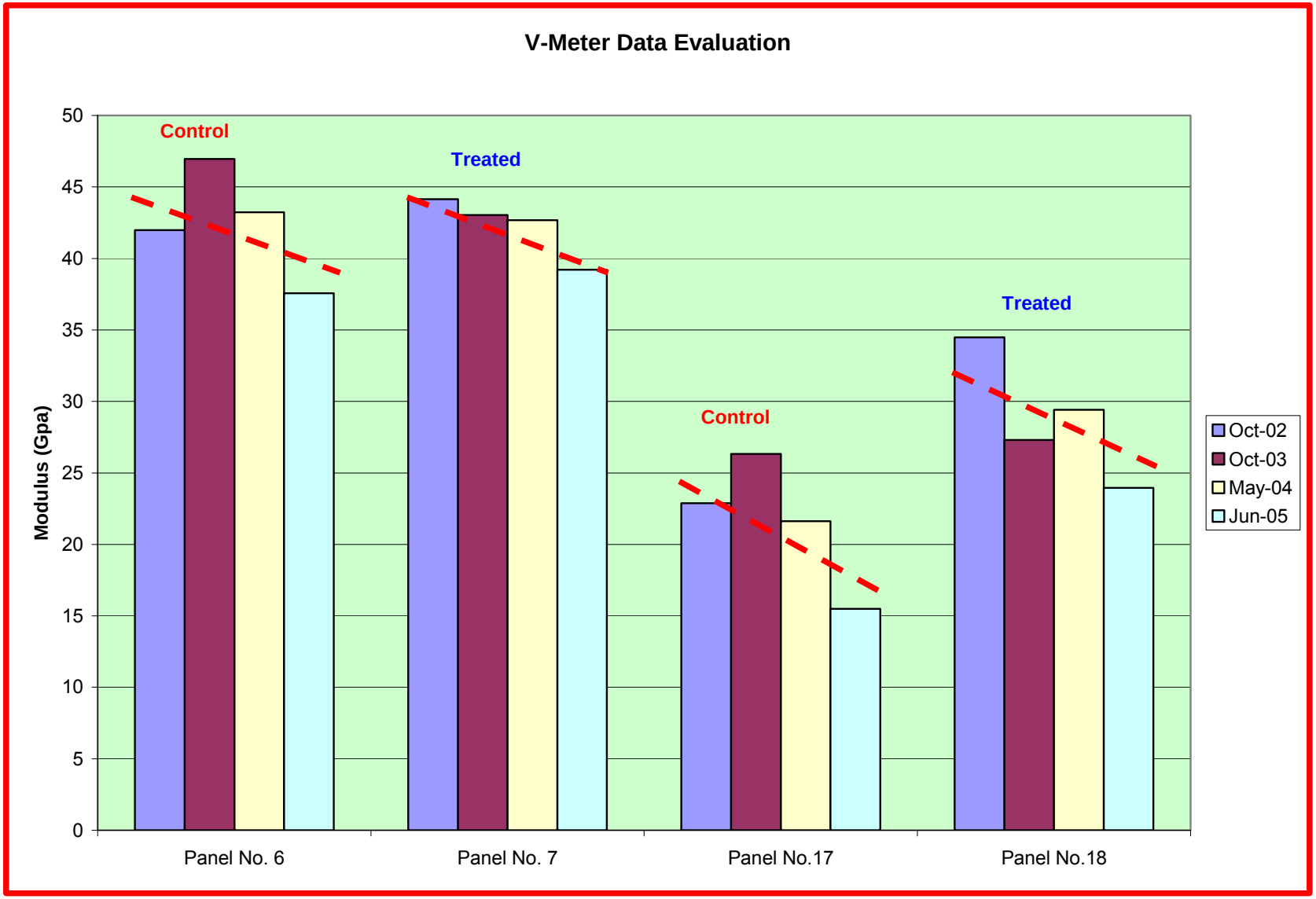
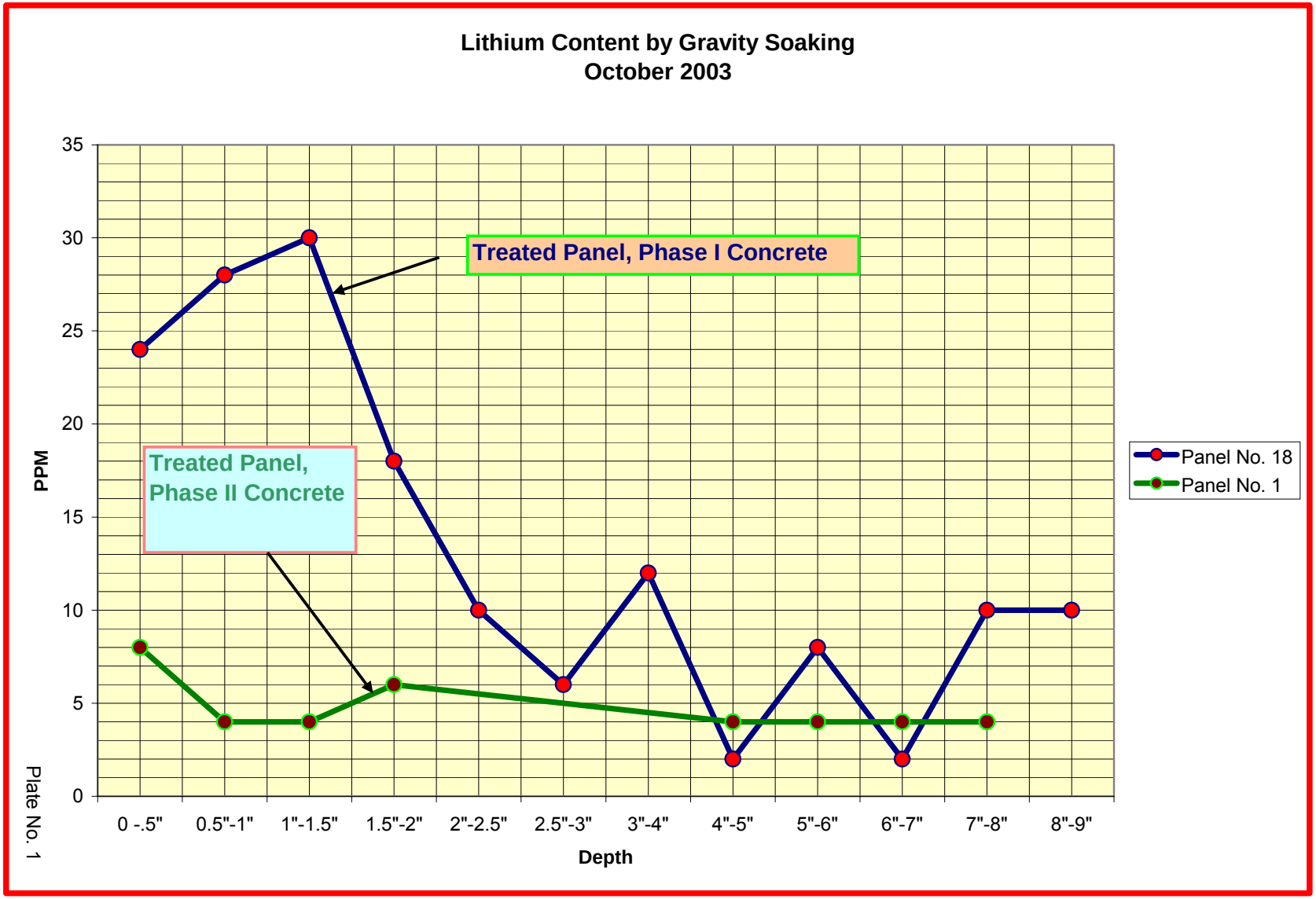
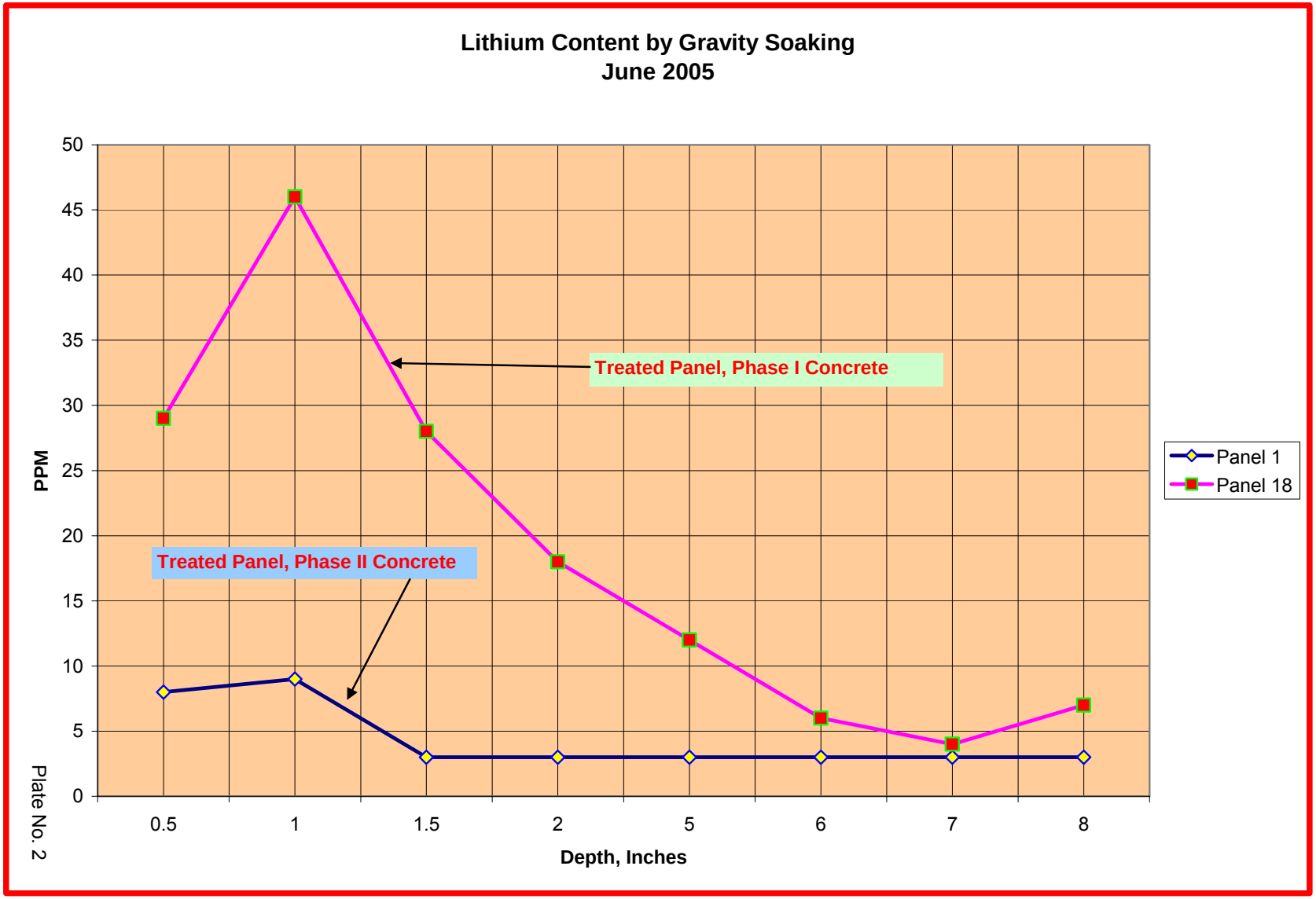
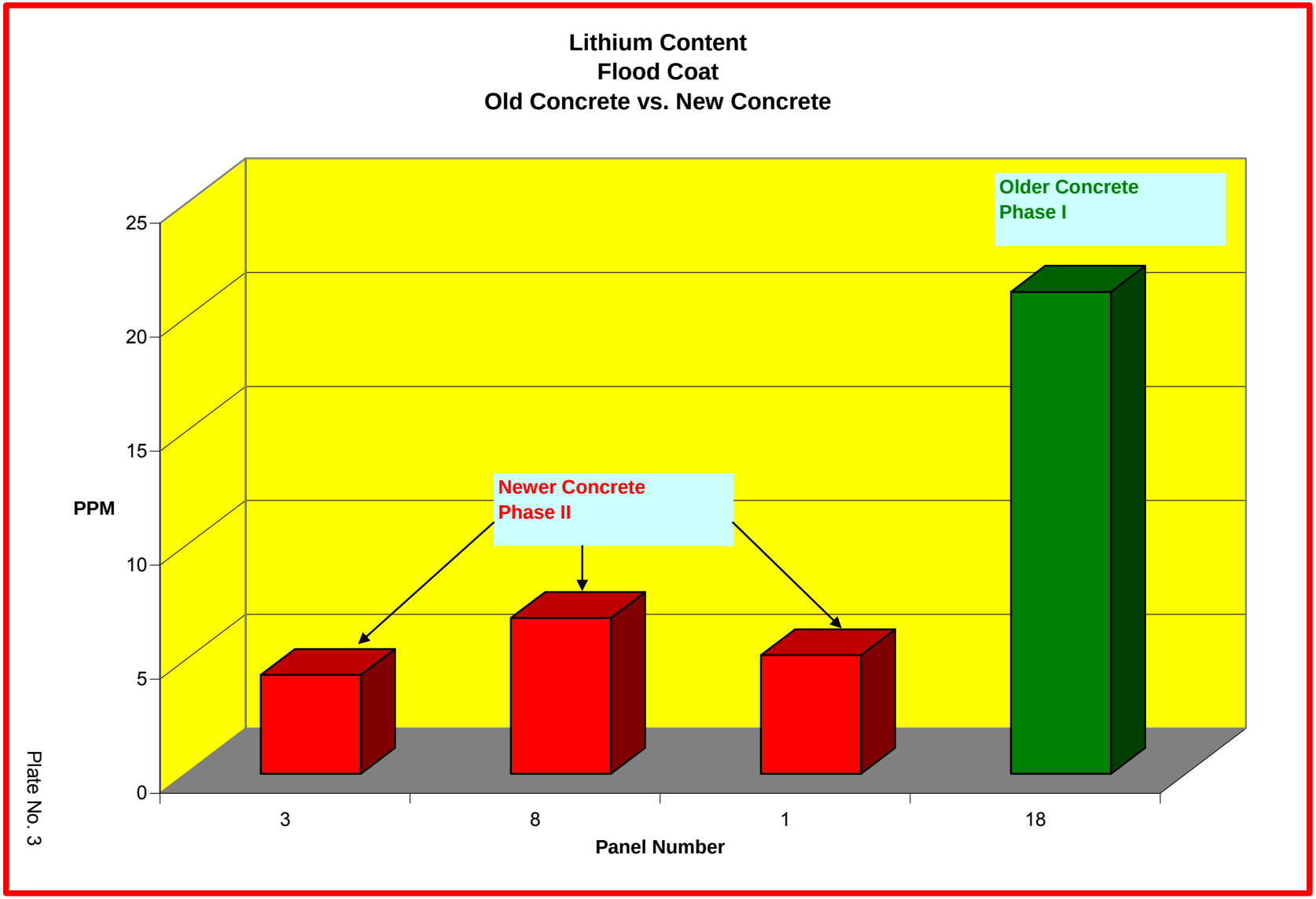
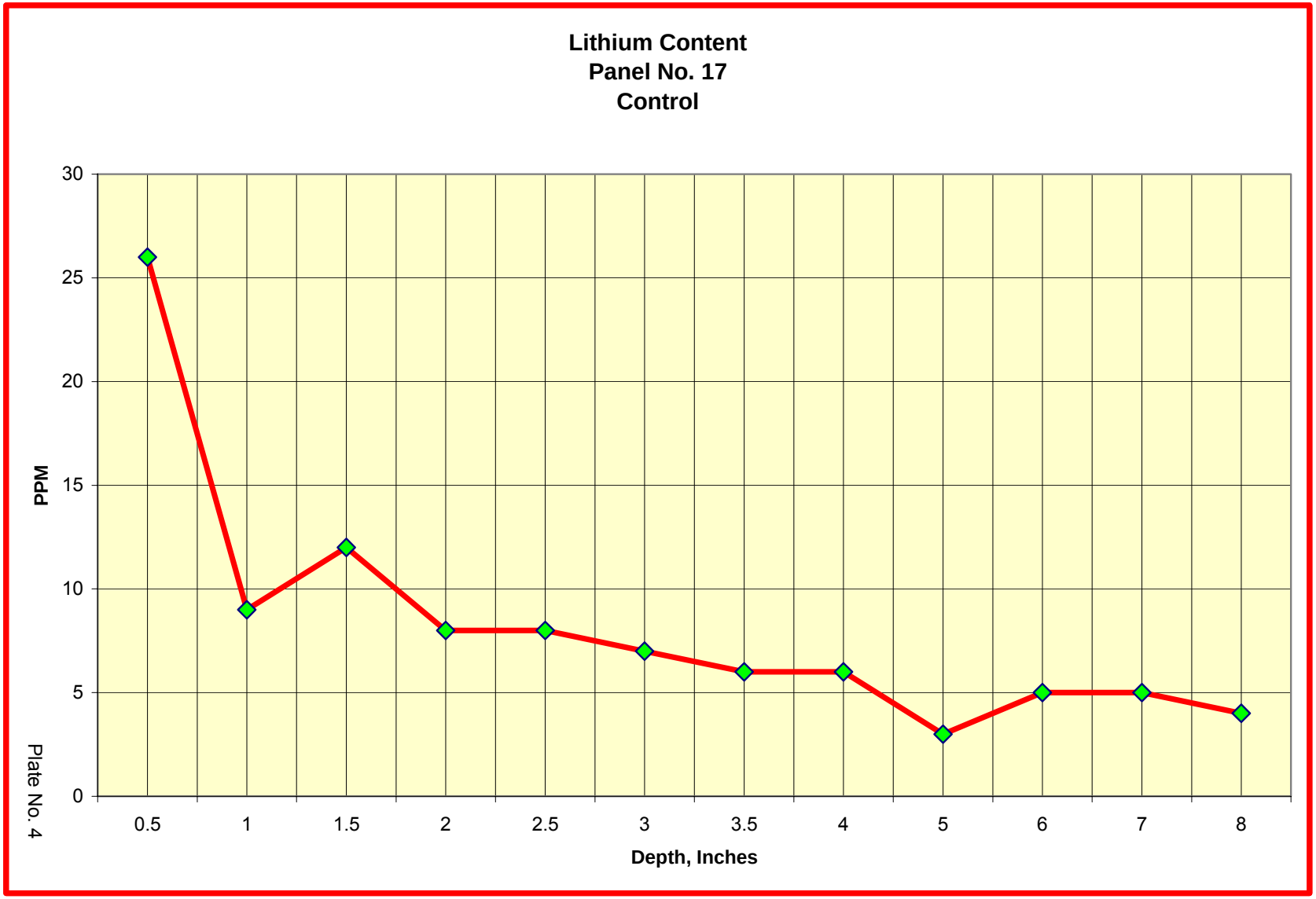

V-Meter Data Evaluation
Modulus (Gpa)
50
45
40
35
30
25
20
15
10
5
0
Control
Treated
Control
Treated
Panel No. 6
Panel No. 7
Panel No.17
Panel No.18
Oct-02
Oct-03
May-04
Jun-05

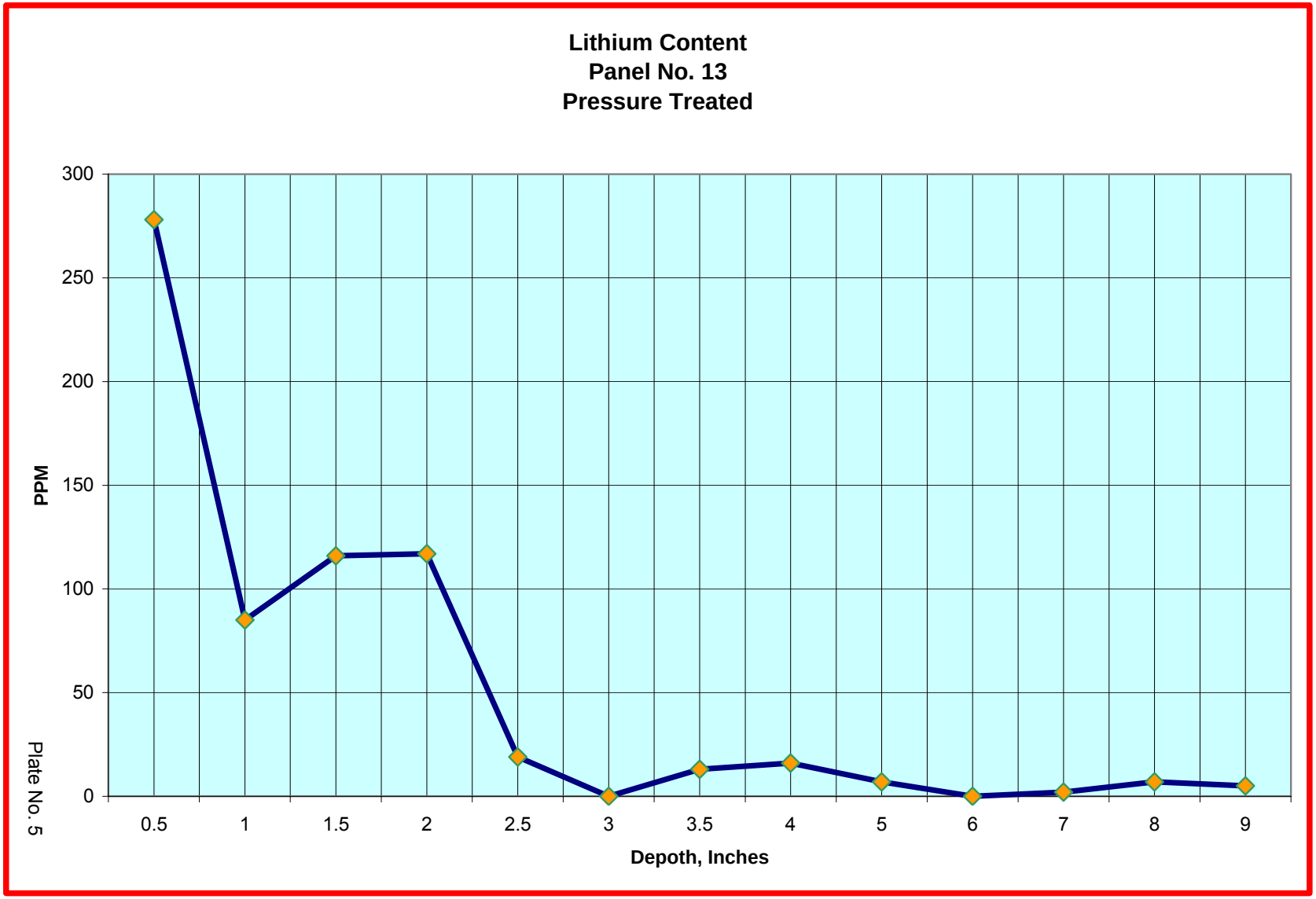
EXHIBIT NO. 6

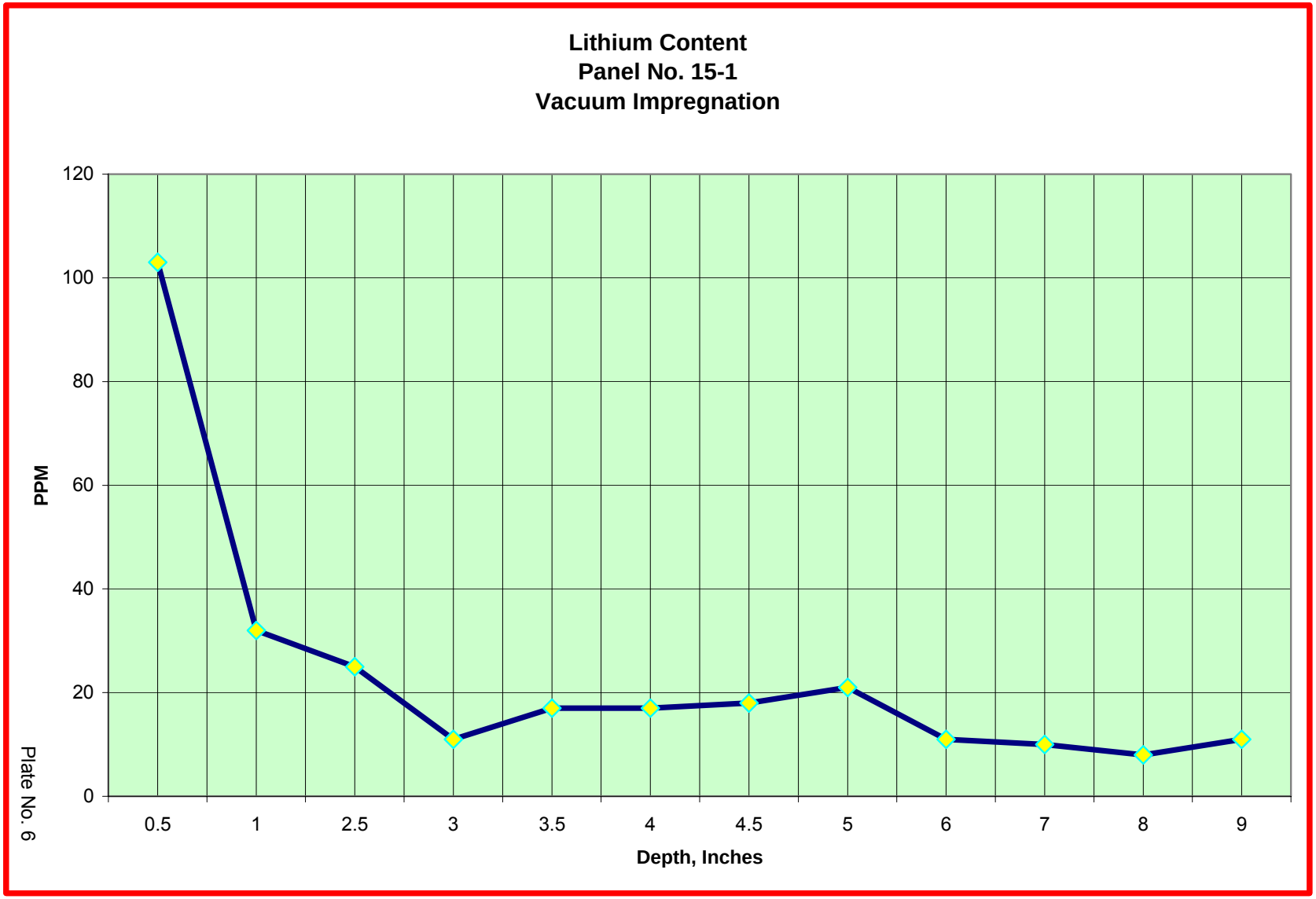

Lithium Content by Gravity Soaking
October 2003
Treated Panel, Phase I Concrete
Treated Panel, Phase II Concrete
PPM
35
30
25
20
15
10
5
0
0 -.5"
0.5"-1"
1"-1.5"
1.5"-2"
2"-2.5"
2.5"-3"
3"-4"
4"-5"
5"-6"
6"-7"
7"-8"
8"-9"
Depth
Panel No. 18
Panel No. 1
Plate No. 1

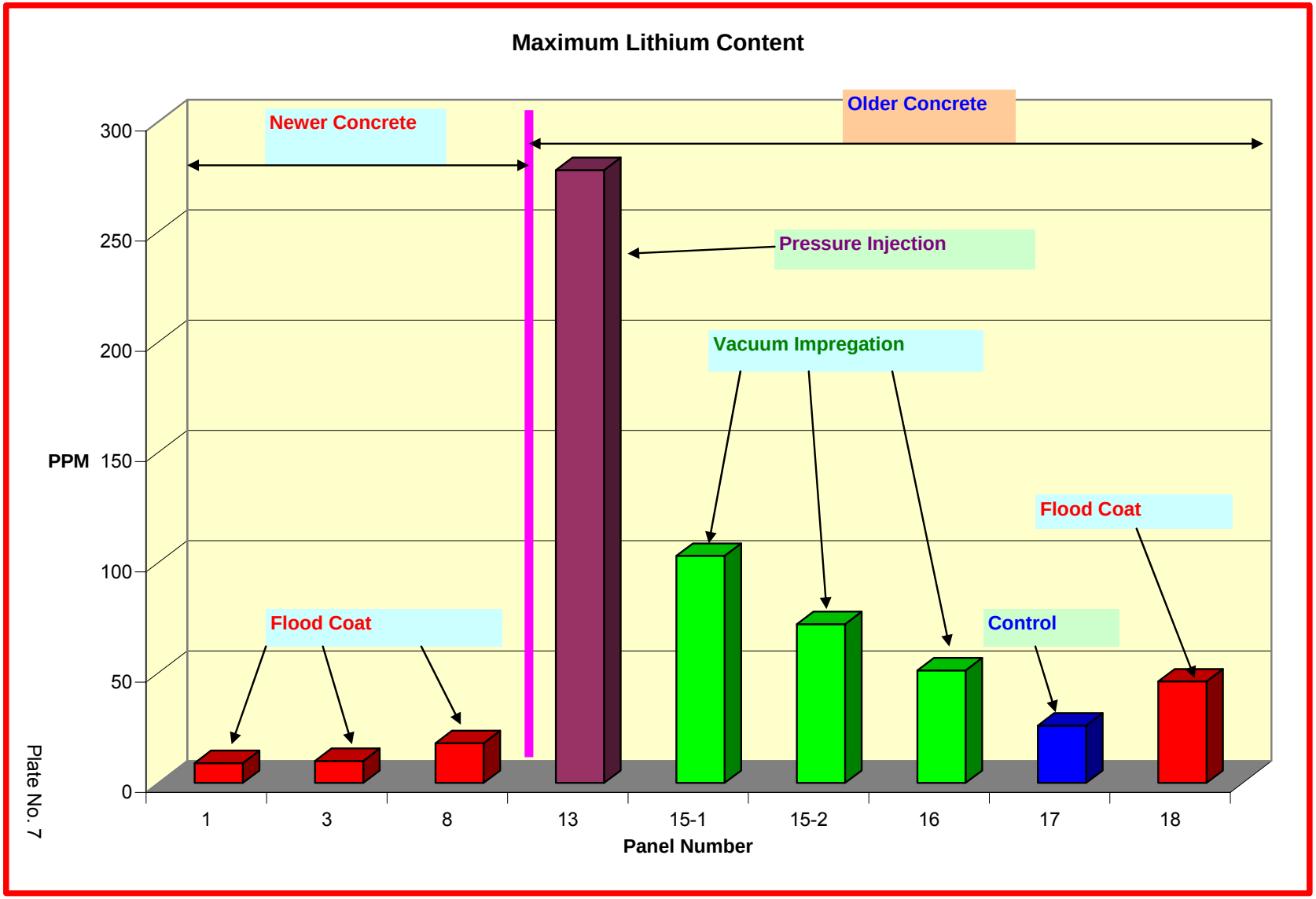

Lithium Content by Gravity Soaking
June 2005
PPM
50
45
40
35
30
25
20
15
10
5
0
0.5
1
1.5
2
5
6
7
8
Depth, Inches
Treated Panel, Phase I Concrete
Treated Panel, Phase II Concrete
Panel 1
Panel 18
Plate No. 2

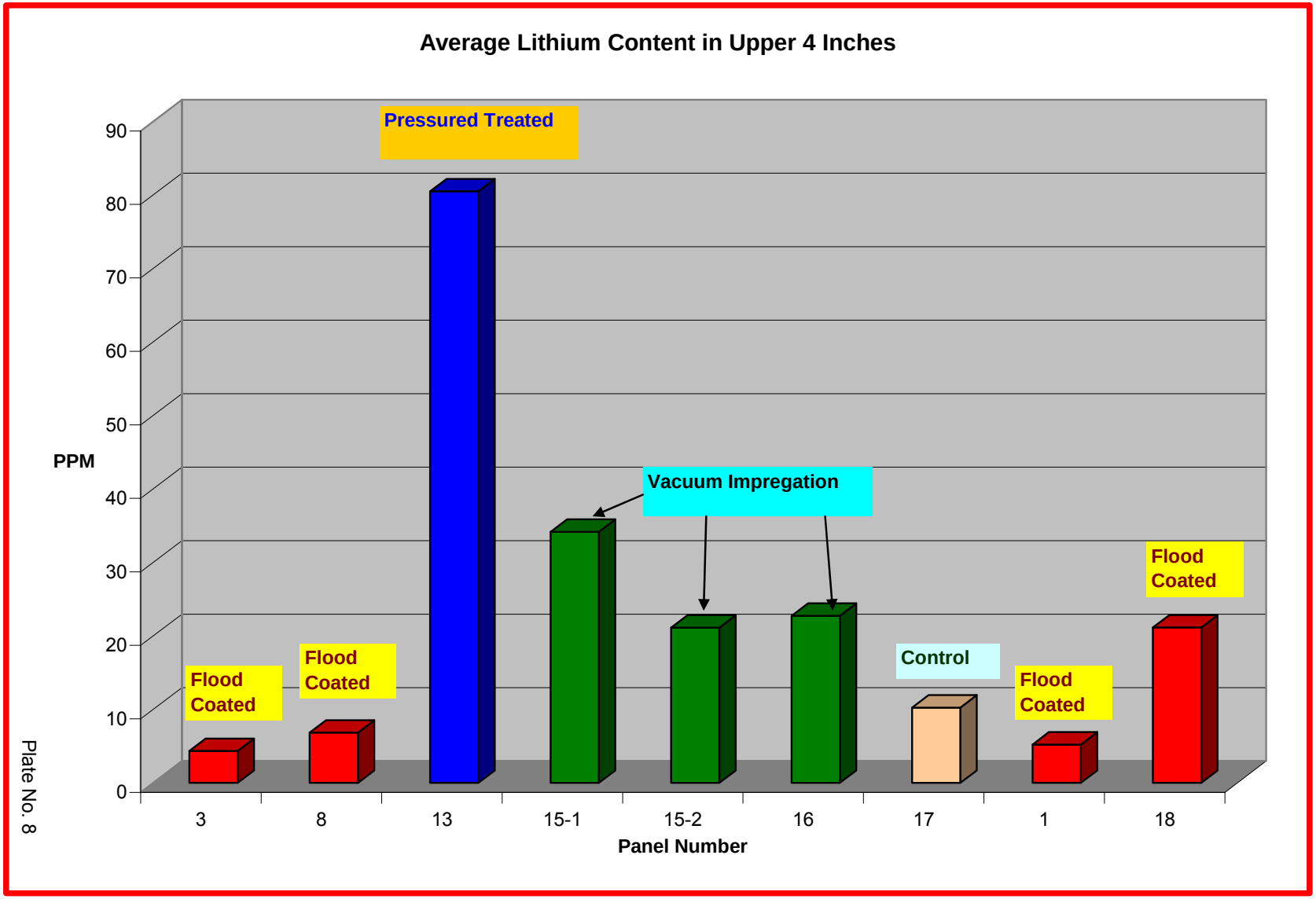

Lithium Content
Flood Coat
Old Concrete vs. New Concrete
Older Concrete
Phase I
Newer Concrete
Phase II
PPM
25
20
15
10
5
0
3
8
1
18
Panel Number
Plate No. 3


Lithium Content
Panel No. 17
Control
PPM
30
25
20
15
10
5
0
0.5
1
1.5
2
2.5
3
3.5
4
5
6
7
8
Depth, Inches
Plate No. 4


Lithium Content
Panel No. 13
Pressure Treated
300
250
200
150
100
50
0
PPM
Plate No. 5
0.5
1
1.5
2
2.5
3
3.5
4
5
6
7
8
9
Depoth, Inches


Lithium Content
Panel No. 15-1
Vacuum Impregnation
PPM
120
100
80
60
40
20
0
0.5
1
2.5
3
3.5
4
4.5
5
6
7
8
9
Depth, Inches
Plate No. 6


Maximum Lithium Content
Newer Concrete
Older Concrete
Pressure Injection
Vacuum Impregation
Flood Coat
Flood Coat
Control
PPM
300
250
200
150
100
50
0
1
3
8
13
15-1
15-2
16
17
18
Panel Number
Plate No. 7


Average Lithium Content in Upper 4 Inches
Pressured Treated
Vacuum Impregation
Flood Coated
Flood Coated
Flood Coated
Control
Flood Coated
PPM
90
80
70
60
50
40
30
20
10
0
3
8
13
15-1
15-2
16
17
1
18
Panel Number
Plate No. 8