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Final Report

EVALUATION OF PRESTRESS CABLE STRAIN IN MULTIPLE BEAM CONFIGURATIONS

Jeffrey A. Frantzen, David A. Meggers, David G. Alt and Christopher R. Wilkens

August 1996

KANSAS DEPARTMENT OF TRANSPORTATION

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16 Abstract

A system to measure prestress cable strain was fabricated, software written, and the unit calibrated. Strain measurements were made by attaching four Linear Variable Differential Transformers (LVDT) to prestress cables before they were stressed. Due to limited test data and problems with the data collection, no conclusions were drawn about the loss of cable tension due to cable depressors.

Due to the cooperation between the Kansas department of Transportation and the supplier of the prestressed beams, this project resulted in a change in the casting bed configuration which will likely result in more consistent prestress cable tension. The casting bed configuration was changed from casting five beams simultaneously to casting three beams simultaneously.

Other linear movements, such as bridge beam deflection, can be measured using the method and instrumentation developed in this project.

17 Key Words Prestressed concrete, prestress cables, strain, deflection, cable depressors, LVDT, stress, multiple beam configurations.	**18 Distribution Statement** No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161

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by

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INTRODUCTION

This project was initiated due to concern expressed by Kansas Department of Transportation (KDOT) inspectors as to the uniformity of prestress strand tension in multiple beam configurations.

Prestressed concrete beam producers use prestressing beds that are long enough to allow for the production of multiple prestressed concrete beams at one time to increase production.

In most prestressed beams, a number of the prestressing strands are depressed into the lower portion of the beam to allow for additional positive moment carrying capacity. In multiple beam configurations it is necessary for the prestressing strands to be raised at the ends of the each beam (negative moment capacity) and depressed in the middle of each beam (positive moment capacity). To accomplish this, strand depressors with steel wheels are used to displace the strands in the vertical direction. The steel wheels on the strand depressors are to allow free movement of the prestressing strands during prestressing operations. The strand depressors become part of the completed beam.

During prestressing operations of several multiple beam configurations, indentations of the strands were visible on the surface of the rollers of the strand depressors. The indentations indicated that the rollers might not have allowed free movement of the strands through the depressors, causing a variation of prestressing force in the strands during the prestressing operation. The producer was jacking (prestressing) the strands from both ends of the bed and calculating the appropriate upward deflection in the middle of the bed to induce required stress in the prestressing strands. The upward deflection in the middle of the prestressing bed was accomplished by use of a crane cable attached to the prestressing cable.

Directly determining the stress in the prestress strands at various points along the prestressing strand during prestressing is difficult, but measuring strain at various points along the continuous strand could be done with relative ease and safety. Knowing the actual strains induced in the strand would allow calculations of the stresses being imparted to the strand during the prestressing operation. Knowing the stress level at various points in the prestressing bed would allow evaluation of the affect of the depressors on the prestressing operation. The effect that multiple beam configurations have on prestressing forces throughout the length of the bed could also be evaluated. If significant differences in the stress levels were found between the bulkheads of the same beam or between individual beams the operation could be evaluated to determine if the depressors were the cause of the differences or if the method used to stress multiple beam configurations should be changed. The prestressing beds were stressed and left overnight for placement of the concrete the following day. By leaving the strain testing equipment on the strand overnight any changes in stress levels due to being exposed overnight could be determined.

NOTE: The DataPAC portable data collection and processing unit operating instructions and the strain readout programs were written previous to the Kansas Department of Transportation adopting the metric system. Rewriting the program would be required to allow the DataPAC to express values equal to metric units. Values in the body of the report have been converted to metric units.

WORK PLAN

Equipment Description:

Devices to measure the strain in the strand during prestressing operations were designed by KDOT personnel. The devices consisted of Lucas Schaevitz type MP 300 Linear Variable Differential Transformers (LVDT) mounted in a frame to allow for attachment to the prestressing strand and to protect the LVDT should the strand break during stressing. Targets were designed to be attached to the strand near the LVDT. A metal rod attached to the LVDT actuator rod extended to a target block with a 50 mm diameter target. Originally the target was a block approximately 32 mm square. During the initial testing the target block twisted as the strand was loaded and the actuator rod lost contact with the target block. Deeper more stable target blocks were developed and the 50 mm round target was added. The metal rod was attached to the LVDT to provide a gauge length of 355 mm. This longer gauge length was used to facilitate a more accurate measurement of the strain of the cable during loading. Both the LVDT frame and the target block were attached to the prestressing strand by set screws. The prestressing strand was protected from being nicked by the set screws by use of copper shims. The LVDT frame and the target block were attached to the strand after the initial pre-load was applied to the strand. Both the LVDT frame and the target block were attached in such a way as to ensure elongation over the entire gauge length (Appendix A).

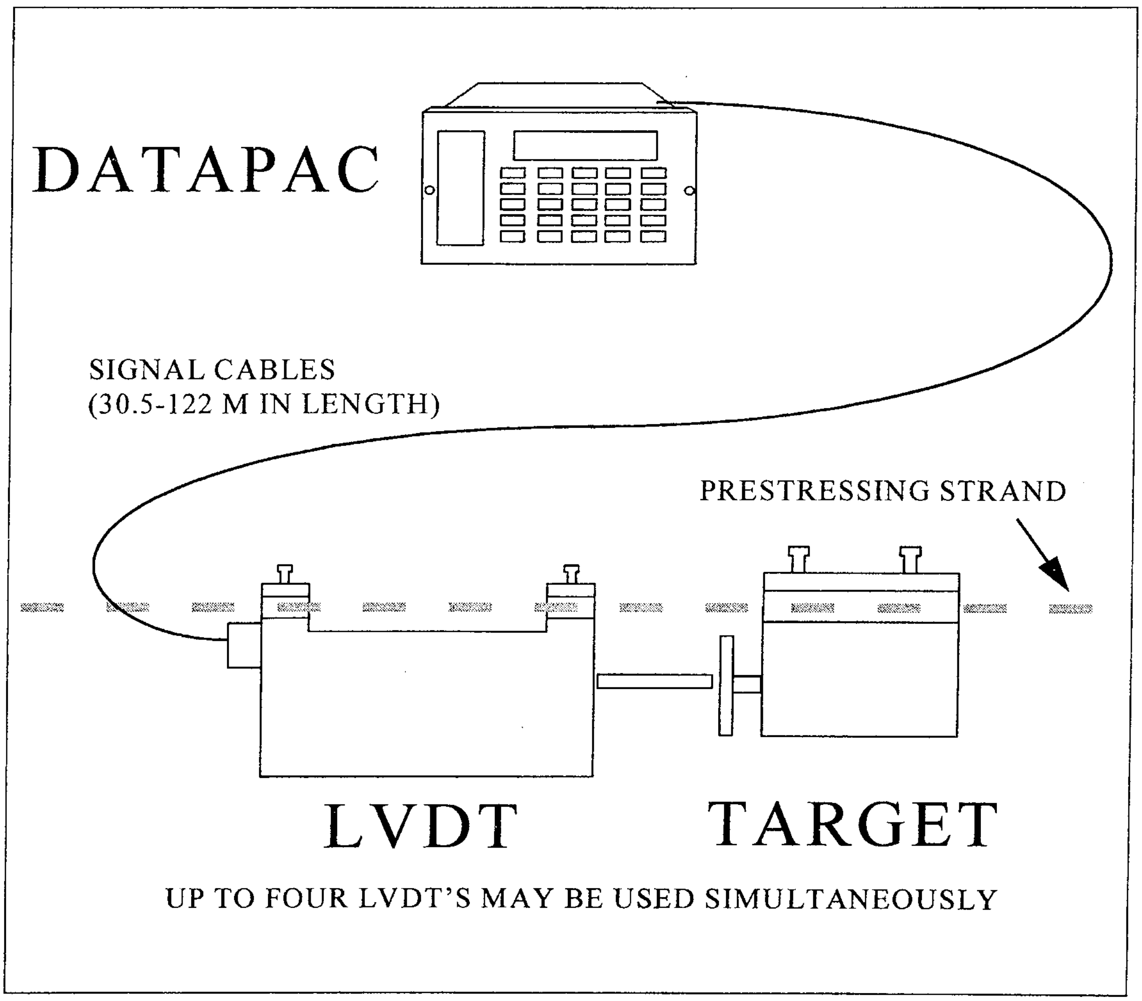

FIGURE 1 SYSTEM CONFIGURATION

The LVDTs were connected to a Daytronic model 10KU-KD DataPAC portable data collection and processing unit with two model 10A30-2 dual LVDT conditioners. Data was transmitted from the LVDTs to the DataPAC using four Belton 8725 instrumentation cables of 30.5, 61.0, 91.5, and 122 m in length (Figure 1). Simultaneous readouts of strain measurement were available at up to four locations along the prestressing strand.

RESULTS

Laboratory Testing:

Initially it was incorrectly assumed that the DataPAC interpretation of the LVDT output voltage was a direct displacement measurement. However early laboratory tests indicated that a correction factor would be required. Using a micrometer, increments of 2.5 mm were measured and average correction factors were calculated for LVDT 4105 and each cable length. A field test was performed at Wilson Concrete, Kansas City, KS using LVDT 4105 and the 30.5 m cable and the data was found to be unacceptable.

A laboratory test was performed to determine if the problem was poor data evaluation or slippage of the LVDT and/or target. The laboratory test was performed using LVDT 4105 and the 30.5 m cable just as in the field. A section of prestressing strand was placed in the universal testing machine and the LVDT attached. The strand was then stressed and the elongation was measured both with the LVDT and the universal testing machine. Strain was also calculated using the loading of the testing machine. This test indicated that the LVDT output voltage changes were nonlinear with respect to the displacement and a single correction factor used over the full range of movement was not adequate.

The manufacturer of the LVDTs was contacted concerning the problem and suggested several combinations of resistors and capacitors be added to the LVDT circuitry to increase linearity. No combination was found to improve the signal linearity significantly. The nonlinear response was caused by a combination of the resistance created by the long signal cables required to perform the field-testing and by varied response from each LVDT. Response also varied for each LVDT and cable length combination.

Lab testing was conducted with the LVDTs configured with 0.01 microFarad capacitors. The LVDTs and cable were matched and each set was tested for accuracy. Displacements were measured at increments of 0.635 mm over a range of 0.0 to 15.8 mm using a micrometer table. The range varied due to LVDT and cable length interaction. Using the test data, curves representing the error in measurement were plotted. The error plot for LVDT 1 and the 30.5 m cable can be seen in Figure 2. An acceptable error bandwidth was determined and the graphs were divided into linear segments. Due to programming limitations of the DataPAC, the corrections were limited to only six segments. Slopes of the segments were used as the correction factors. Each segment varied in length due to the non-linearity of the error.

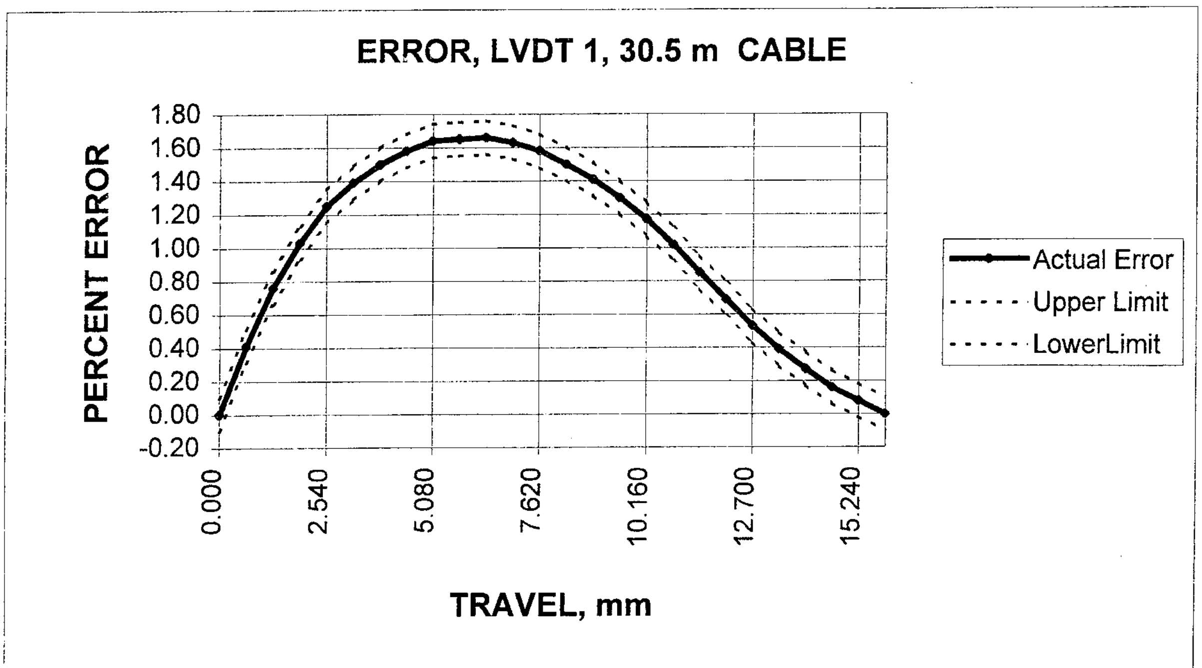

FIGURE 2 EXAMPLE ERROR GRAPH

Four programs were written and stored in the DataPAC processing unit to convert LVDT output voltage to displacement (Appendix B). Each program corresponds to a specific cable length and LVDT. The displacements measured by the LVDTs using the programs to condition the signal input produced an accuracy of 2.6% over the measurable range of 0.0 to 15.8 mm.

Field Testing:

After the data acquisition programs were completed, field tests were performed on May 28 and 29, 1992, at Wilson Concrete. The 91.5 m long placement bed was configured to cast three beams simultaneously. LVDTs were placed at four locations along the continuous 13 mm diameter ASTM A 416 grade 270 low relaxation strands (Figure 3). Each beam was configured with multiple strands. A 13 345 N pre-load was applied to each prestressing strand to take up slack in the strand, at which time initial LVDT readings were recorded. The design load was then applied to the strands, one at a time, by hydraulic jacks, first from one end of the placement bed and then the other. Each jack had a gauge that indicated the jacking force applied to the strand. Final LVDT readings were then recorded. The configuration tested on May 28, 1992 was allowed to sit overnight, approximately seventeen hours until the morning of May 29, 1992, at which time LVDT readings were again recorded. Another beam was tested during the day of May 29, 1992. Note that the two beam part numbers were not recorded. They may or may not have been KDOT beams. The purpose of the testing was to check the manufacturing process.

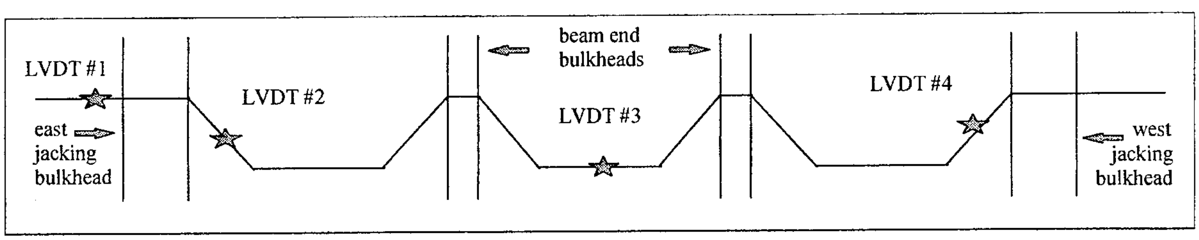

FIGURE 3 FIELD PLACEMENT OF LVDTS

The May 28, 1992 testing resulted in LVDTs two, three and four falling off the strand (Appendix C). LVDT #1 remained in place between the east hydraulic jack and the east jacking bulkhead. It was also east of the strand depressors. The output of this LVDT indicated a force in the strand of 131 939 N, 95% of the 138 785 N jack gauge reading. As stated previously, the LVDT was left in place on the strand overnight to determine if any significant loss of prestressing force would be experienced. When the DataPAC output was checked the next morning there was no significant change in the strain readout indicating very little, if any, change in stresses due to be exposed overnight.

The May 29, 1992 testing (Appendix C) resulted in invalid readings from LVDT #2 and LVDT #3. LVDT #2 found to have been poorly attached and moved, and LVDT #3 malfunctioned. LVDTs #1 and #4 showed strand forces of 124 768 N and 160 421 N, respectively; 89% and 115%, respectively, of the 139 674 N jack gauge reading.

On both testing dates the LVDTs were left in place and readings were taken as the additional prestressing strands in the beam were stressed to the required level. Some variations of strain were noted in the monitored strand as the additional strands were stressed (Appendix C). Variations in the testing data could have been caused by the geometry of the test bed or by movement of the LVDTs or the targets during stressing of the strand.

Plans were made to perform additional testing to determine the cause of the variations later in 1992. Due to Wilson Concrete's busy production schedule, this never occurred. Plans were then modified to test in 1993, but once again the busy production schedule prevented this. The same problem occurred in 1994 and 1995. As of the date of this report, KDOT is unlikely to have the opportunity to collect additional data for some time in the future.

CONCLUSIONS

Before KDOT made the decision to conduct field tests on the prestressing strands, Wilson Concrete configured their bed to cast five beams simultaneously. In addition to the jack used at each end to stress the strands, a crane was used between beds to lift the strands, previous to anchoring. The additional stress was needed to overcome the unknown friction in the rollers of the depressor mechanisms and to overcome stress losses due to the geometry changes in the multiple beam placements. Since the actual friction loss and strand tension at these points were not known, KDOT decided to conduct tests to measure strand tension.

As a result of the cooperation between KDOT and Wilson Concrete, three beams are being cast simultaneously instead of five, and the crane is no longer used to lift the strands, thus the prestress strands are more likely to have consistent tension.

Due to the limited amount of test data and problems that occurred during the collection, little was learned about the affects of the strand depressors on strand tension. The problems encountered and variations between the jacking force and the measured strain during testing indicated that a more positive LVDT attachment system should be developed. Accuracy of the system may also be improved if the cables or the LVDTs were changed such that the correction program could be simplified or eliminated.

IMPLEMENTATION

As a result of this project, equipment has been purchased, manufactured, and calibrated for a system to measure small linear movements. The equipment was used to modify fabrication procedures at Wilson Concrete. In addition to the prestressing strand stress measurement, other linear movement problems can be studied with this test equipment. For example, bridge beam deflections can be measured, provided a suitable method of anchoring the LVDT and target can be found.

APPENDIX A

INSTRUCTIONS FOR USE OF LVDTs WITH DataPAC

INSTRUCTIONS FOR USE OF LVDTs WITH DataPAC

1. Locate DataPAC near power source, 110V, A.C. Ensure that the "Write Protect Switch" is in the down position. This switch is located at the back of the DataPAC near the bottom and is silver in color. This switch should always be down and should not be moved. Loss of all programming could otherwise occur.

2. Layout all cables which will be used and connect to DataPAC. Be sure to connect each cable to its corresponding outlet, i.e. 100 ft. cable to outlet labeled 100, etc.

3. Connect LVDTs to each cable. Be sure to connect each LVDT to its proper cable. LVDTs are labeled 100, 200, etc.

NOTE: Failure to connect proper cables to LVDTs and outlet at DataPAC will result in false readings.

4. Plug in and turn on DataPAC, switch is located on rear panel of DataPAC. Allow unit to warm up for 30 minutes. Unit may be used with less than 30 minutes warm up, but accuracy may be slightly lower.

5. Raise front of DataPAC, hinge will drop down and the unit will remain angled upward. If "E2" light is on in the front window of the DataPAC refer to step 1. Access to each output channel is obtained by pushing the (CHAN) button on the front at the unit, followed by the corresponding number for the cable you wish to monitor, 11 for the 100 ft. cable, 12 for 200 ft. cable, 13 for 300 ft. cable and 14 for the 400 ft. cable. Press the [CHAN] button followed by 11, now press [ENTER] and observe the bottom line of the LCD display. The channel number should be at the bottom left of the display. The LVDT reading, at the center of the display, is thousandths of an inch, anything to the right of the decimal is ten-thousandths of an inch. For example, 253.0 is 0.253" and 253.5 is 0.2535" and should be rounded to 0.254". Ignore the "MVV" on the right of the display.

6. After the preload has been applied hang the LVDT from the strand using 3/8" x 16 socket head bolts. Be sure to protect the strand!

Use the curved conduit sections, placed between the bolt and the strand, to prevent marring.

NOTE: The body of the LVDT assembly and target blocks are made of magnesium. **DO NOT** over tighten-bolts or you may strip the threads.

Tighten the bolt at the cable connection end securely, the bolt at the end with the protruding brass rod should be only finger tightened Lightly.

7. Rotate target clockwise into target block until finger tight. Hang target block from strand, opposite brass rod, using socket head bolts and protecting the strand in the same manner as previously described, target faces LVDT. Slide target toward LVDT until brass rod is depressed approximately 1/8". Tighten bolt farthest from LVDT. LIGHTLY finger tighten the bolt closest to LVDT.

8. Ensure LVDT and target are aligned with the strand. Ensure that the bolt on the LVDT closest to the target and the bolt on the target closest to the LVDT are just barely touching the piece protecting the strand, no tighter.

9. Rotate the target counter-clockwise until a reading of between 50 and 500 is obtained on the corresponding channel at the DataPAC.

10. Carefully measure and record the distance between centers of the two bolts which you tightened securely (the two bolts farthest apart). This distance should be approximately 14 inches. This is your gauge length.

11. Repeat steps 6 through 10 for each cable/LVDT.

12. Read and record each output channel you are using. Readings should be between 50 and 500.

13. After the final load has been applied to the strand, read and record each output channel.

The difference between readings taken in steps 12 and 13 is the elongation of the strand along the gauge length.

14. Loosen and remove LVDTs and targets.

15. Check the front window of the DataPAC to ensure the "E2" light is not visible and the write protect switch is in the down position prior to turning off power to the DataPAC.

FOR FURTHER INFORMATION CONTACT
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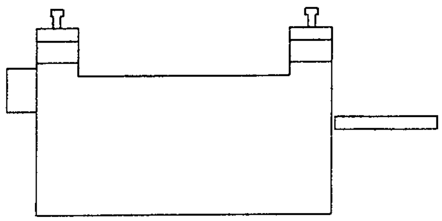
Topeka, Kansas 66611-1195
Tel. (785) 291-3845

LVDT

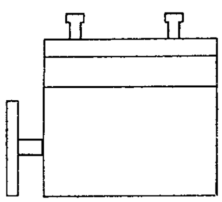
LINEAR VARIABLE DIFFERENTIAL TRANSFORMER



SCHAEVITZ TYPE 300 MP
CUSTOM BUILT HOUSING

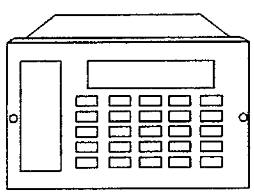
MODIFIES SIGNAL TO
INDICATE MOVEMENT

TARGET



PROVIDES AN ADJUSTABLE
REFERENCE POINT FOR LVDT

DataPAC



DAYTRONIC SYSTEM 10
PROCESSES SIGNAL FROM LVDT'S
PROGRAMMED TO LINEARIZE INPUT

FIGURE 4. DATA ACQUISITION SYSTEM

APPENDIX B

DataPAC COMPUTER PROGRAMS

DataPAC PROGRAM

CHN 1 LVDT1 100' CABLE .01μF CAPACITOR

```
CLC20=.06234(CHN1)+0.00
     21=1(CHN20)-50
     22=1(ABS CHN21)+0
     23=.020330(CHN21+CHN22)+0.00
     24=1(CHN20+CHN23)+0
     25=1(CHN24)-125
     26=1(ABS CHN25)+0
     27=.015150(CHN25+CHN26)+0.00
     28=1(CHN24+CHN27)+0
     29=1(CHN28)-200
     30=1(ABS CHN29)+0
     31=.012679(CHN29+CHN30)+0.00
     32=1(CHN28+CHN31)+0
     33=1(CHN32)-300
     34=1(ABS CHN33)+0
     35=.11212(CHN33+CHN34)+0.00
     36=1(CHN32+CHN35)+0
     37=1(CHN36)-400
     38=1(ABS CHN37)+0
     39=.006267(CHN37+CHN38)+0.00
     40=1(CHN36+CHN39)+0
     41=1(CHN40)-550
     42=1(ABS CHN41)+0
     43=-.007914(CHN41+CHN42)+0.00
     44=1(CHN40+CHN43)+0
     11=1(CHN44)+0.0
```

DataPAC PROGRAM

CHN2 LVDT2 200' CABLE .01μF CAPACITOR

```
CLC50=.079618(CHN99)+0
    51=1(CHN50)-50
    52=1(ABS CHN51)+0.0
    53=.028619(CHN51+CHN52)+0.00
    54=1(CHN50+CHN53)+0.0
    55=1(CHN54)-100
    56=1(ABS CHN55)+0.0
    57=.024735(CHN55+CHN56)+0.00
    58=1(CHN54+CHN57)+0.0
    59=1(CHN58)-150
    60=1(ABS CHN59)+0.0
    61=.021499(CHN59+CHN60)+0.00
    62=1(CHN58+CHN61)+0.0
    63=1(CHN62)-225
    64=1(ABS CHN63)+0.0
    65=.017318 (CHN63+CHN64)+0.00
    66=1(CHN62+CHN65)+0.0
    67=1(CHN66)-325
    68=1(ABS CHN67)+0.0
    69=.008236(CHN67+CHN68)+0.00
    70=1(CHN66+CHN69)+0.0
    71=1(CHN70)-575
    72=1(ABS CHN71)+0.0
    73=-.008883(CHN71+CHN72)+0.00
    74=1(CHN70+CHN73)+0.0
    12=1(CHN74)+0.0
```

DataPAC PROGRAM

LVDT3 300' CABLE CHN3 .01μF CAPACITOR

```
CLC80=.095238(CHN3)+0.0
     81=1(CHN80)-50
     82=1(ABS CHN81)+0.0
     83=.032454(CHN81+CHN82)+0.00
     84=1(CHN80+CHN83)+0.0
     85=1(CHN84)-100
     86=1(ABS CHN85)+0.0
     87=.027838(CHN85+CHN86)+0.00
     88=1(CHN84+CHN87)+0.0
     89=1(CHN88)-150
     90=1(ABS CHN89)+0.0
     91=.021982(CHN89+CHN90)+0.00
     92=1(CHN88+CHN91)+0.0
     93=1(CHN92)-225
     94=1(ABS CHN93)+0.0
     95=.017747(CHN93+CHN94)+0.00
     96=1(CHN92+CHN95)+0.0
     97=1(CHN96)-300
     98=1(ABS CHN97)+0.0
     99=.012388(CHN97+CHN98)+0.00
     100=1(CHN96+CHN99)+0.0
     101=1(CHN 100)-525
     102=1(ABS CHN101)+0.0
     103=-.014337(CHN101+CHN102)+0.00
     104=1(CHN100+CHN103)+0.0
     13=1(CHN104)+0.0
```

DataPAC PROGRAM

CHN4 LVDT5 400' CABLE .01μF CAPACITOR

```
CLC120=.09276(CHN99)+0.0
    121=1(CHN120)-50
    122=1(ABS CHN121)+0
    123=.04966(CHN121+CHN122)+0.00
    124=1(CHN120+CHN123)+0
    125=1(CHN124)-100
    126=1(ABS CHN125)+0
    127=.05996(CHN125+CHN126)+0.00
    128=1(CHN124+CHN127)+0
    129=1(CHN128)-175
    130=1(ABS CHN129)+0
    131=.04816(CHN129+CHN130)+0.00
    132=1(CHN128+CHN131)+0
    133=1(CHN132)-250
    134=1(ABS CHN133)+0
    135=.03448(CHN133+CHN134)+0.00
    136=1(CHN132+CHN135)+0
    137=1(CHN136)-350
    138=1(ABS CHN137)+0
    139=.026496(CHN137+CHN138)+0.00
    140=1(CHN136+CHN139)+0
    141=1(CHN140)-600
    142=1(ABS CHN141)+0
    143=-.017449(CHN141+CHN142)+0.00
    144=1(CHN140+CHN143)+0
    14=1(CHN144)+0.0
```

APPENDIX C

FIELD TEST DATA

Table 1 Field Test Data Collected At Wilson Concrete 5-28-92.

Measured Strand Strain, mm/mm

Description	LVDT #1	LVDT #2	LVDT #3	LVDT #4
3000 lb. preload, west end	0.0	0.0	0.0	0.0
final load, test strand	0.004 91	**	**	**
after second strand stressed	0.005 17	**	**	**
after third strand stressed	0.005 19	**	**	**
after fourth strand stressed	0.005 25	**	**	**
after fifth strand stressed	0.005 26	**	**	**
after sixth strand stressed	0.005 27	**	**	**
test strand, stressed from east	0.007 42	**	**	**
after five top strands stressed	0.007 18	**	**	**
Reading next day	0.007 27	**	**	**

Calculated Strand Force, N

Description	LVDT #1	LVDT #2	LVDT #3	LVDT #4
3000 lb. preload, west end	0.0	0.0	0.0	0.0
final load, test strand	90 223	**	**	**
after second strand stressed	95 000	**	**	**
after third strand stressed	95 370	**	**	**
after fourth strand stressed	96 473	**	**	**
after fifth strand stressed	96 665	**	**	**
after sixth strand stressed	96 838	**	**	**
test strand, stressed from east	136 347	**	**	**
after five top strands stressed	131 939	**	**	**
reading next day	133 589	**	**	**

Note:
1) Final force at jack gauge, 138 785 N.
2) Strand was stressed from the west end of the bed and then from the east end of the bed.
3) ** LVDTs 2, 3, and 4 fell off.

Table 2 Field Test Data Collected At Wilson Concrete 5-29-92.

Measured Strand Strain, mm/mm

Description	LVDT #1	LVDT #2	LVDT #3	LVDT #4
3000 lb. preload, east end	0.0	0.0	0.0	0.0
final load, test strand	0.007 04	0.009 09	0.008 94	0.010 19
after second strand stressed	0.007 02	**	0.009 64	0.007 79
after third strand stressed	0.006 94	**	0.009 63	0.007 87
after fourth strand stressed	0.006 93	**	0.009 69	0.007 95
after fifth strand stressed	0.006 92	**	0.009 69	0.007 95
after sixth strand stressed	0.006 90	**	0.009 65	0.008 02
after seventh strand stressed	0.006 88	**	0.009 61	0.008 01
after eighth strand stressed	0.006 86	**	0.009 62	0.008 02
after bottom strands stressed	0.006 69	**	**	0.008 02
test strand, stressed from west	0.006 74	**	**	0.008 93
after top strands stressed	0.006 79	**	**	0.008 73

Calculated Strand Force, N

Description	LVDT #1	LVDT #2	LVDT #3	LVDT #4
3000 lb. preload, west end	0.0	0.0	0.0	0.0
final load, test strand	129 363	167 035	164 277	187 248
after second strand stressed	128 998	**	177 142	143 144
after third strand stressed	127 526	**	176 959	144 616
after fourth strand stressed	127 344	**	178 058	146 084
after fifth strand stressed	127 161	**	178 058	146 822
after sixth strand stressed	126 792	**	177 324	147 374
after seventh strand stressed	126 423	**	176 590	147 187
after eighth strand stressed	126 058	**	176 772	147 374
after bottom strands stressed	122 931	**	**	147 374
test strand, stressed from west	123 851	**	**	164 095
after top strands stressed	124 768	**	**	160 421

Note:

1) Final force at jack gauge, 139 674 N.
2) Strand was stressed from the east end of the bed and then from the west end of the bed.
3) ** LVDT 2 fell off, LVDT 3 had error.