Seismic, Creep, and Tensile Testing of Various Epoxy Bonded Rebar Products in Hardened Concrete

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This project was performed in cooperation with the US Department of Transportation, Federal Highway Administration, under the research project titled "Seismic, Creep, and Tensile Testing of Various Epoxy Bonded Rebar Products in Hardened Concrete"

The objective of this project was to evaluate the performance of currently specified epoxy adhesive anchor systems on various epoxy-coated rebar under seismic, creep and tensile loading. Previous testing of dowel bonding materials for use in hardened concrete was performed on plain rebar, raising the question of their performance on epoxy coated rebar.

The epoxy-coated rebar was found to meet the requirements of ICBO-AC58, Section 5.3.7.2.4, "Conditions of Acceptance" for tension and seismic loading when bonded into hardened concrete using an epoxy adhesive. However, the epoxy-coated rebar did not meet the requirements of the Caltrans Augmentation/Revisions to ICBO-AC58, Section 5.3.3.2, "Conditions of Acceptance" for creep loading when bonded into hardened concrete. The rebar bonded with Covert Operations CIA-Gel 7000 was found to meet the creep requirements, whereas the rebar bonded with Simpson SET22 and Red Head Epcon C6 did not meet the conditions of acceptance for creep loading.

It was also noticed that, when compared to the manufacturer test data, the epoxy-coated rebar outperformed uncoated rebar in allowable tensile loads for two of the three epoxies tested. Simpson SET22 adhesive under performed the manufacturer test data. Revision (2007): Upon further review of the creep data for the rebar bonded with Simpson SET, it was determined that the adhesive met the creep requirement. Due to the load fluctuations, only the first 26 days of data were used for the logarithmic curve fit.

Epoxy-Coated Rebar, Rebar Testing, Creep, Seismic, Tensile, Dowel Testing, Concrete.
Seismic, Creep, and Tensile Testing of Various Epoxy Bonded Rebar Products in Hardened Concrete

Final Report
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SEISMIC, CREEP, AND TENSILE TESTING OF VARIOUS EPOXY BONDED REBAR PRODUCTS IN HARDENED CONCRETE

Supervised by…………………………………………………..Tom Hoover, P.E.
Principal Investigator…………………………………………Robert Meline, P.E.
Report Prepared by………………………………………………..Jacob Duane, P.E. & Malinda Gallaher
Research Performed……………………………………………….. Jacob Duane, P.E. & Malinda Gallaher
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Other persons who made important contributions are Bill Poroshin, Martin Zanotti, and Mike Said with excellent machine shop services, and Fred McWhorter with instrumentation support. Student assistants John Means, Steve Kiyama, Natane Clarke, and John Black also lent aid in completing this project.
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1. INTRODUCTION

1.1 Problem Statement

For certain applications, the California Department of Transportation (Caltrans) uses epoxy cartridge adhesives for bonding rebar into holes that are drilled in hardened concrete. Caltrans started using these adhesives on plain rebar since previous research and testing was completed on them. At some point, Caltrans used a large quantity of epoxy-coated rebar for earthquake retrofitted bridge structure rehabilitation projects. Concern was expressed about using epoxy-coated rebar with epoxy cartridge adhesives. Problems that could occur are long-term creep under sustained tensile loading and slip or strength loss during cyclic loading that takes place during a seismic event. The International Conference of Building Officials (ICBO) had suggested that bars with any coatings should be treated as a new, different bar and would require a new set of tests. These tests have yet to be completed.

Caltrans’ Division of Materials Engineering and Testing Services recommended to Structures Design that a separate set of ICBO seismic tests be performed on epoxy-coated bars with epoxy cartridge adhesives. These tests would have to pass Caltrans’ Augmentation to ICBO-AC58 [1] to be permitted for use in concrete structures. They also recommended that a considerable reduction in allowable loads be imposed on untested coated bars until the effects of coatings could be determined.

1.2 Objective

The objective of this project is to evaluate the performance of currently specified epoxy adhesive anchor systems on various epoxy-coated rebar under seismic, creep and tensile loading.

1.3 Background

Epoxy-coated reinforcing bars are used in concrete structures where corrosion protection is important. The epoxy-coated bars have a lower bond strength to concrete than the uncoated bars. An improved understanding of bond behavior is needed with the increasing application of epoxy-coated reinforcement, the conservative design guides, and the limited data on which those provisions are based. The goal is to improve economy and constructability, while maintaining an adequate margin of safety.

A large scale study, “Bond of Epoxy-Coated Reinforcement: Bar Parameters” [2], was carried out by Oan Chul Choi, Hossain Hadje-Ghaffari, David Darwin, and Steven L. McCabe to determine the effects of coating thickness, deformation pattern, and bar size on the reduction in bond strength between reinforcing bars and concrete caused by epoxy coating. In general, their conclusion was that the reduction in bond strength caused by epoxy coating increases with bar size.

Adhesive-bonded anchors are increasingly used as structural fasteners for connections to hardened concrete. Due to their reliance on chemical and mechanical bond, adhesive anchors are uniquely susceptible to a number of potentially adverse
conditions that cause these factors can occur during installation and throughout the service life of the anchor.

Twenty different epoxy products (for a total of 765 tests) were evaluated by Ronald A. Cook and Robert C. Konz in their report entitled, “Factors influencing the Bond Strength of Adhesive Anchors” [3]. From their conclusions, the two substantial concerns were the temperature and condition of the drilled hole. Subjecting adhesive anchors to an elevated temperature of 43.3°C (110° F) can substantially influence bond strength along with increased product variation. Also, the condition of the drilled hole during installation can have a substantial influence on bond strength. Products installed into holes that were damp, wet, or not cleaned out generally showed reductions in bond strength with increased variation.

1.4 Scope

A total of 90 tests were performed according to the ICBO-AC58. The testing quantities and specifications established for this project are shown in Tables 1-1 and 1-2.

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Table 1-1: Testing Quantities

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<th>Rebar Size</th>
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<tr>
<td>Drill Diameter</td>
<td>22.2mm (7/8&quot;)</td>
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<tr>
<td>Rebar Material</td>
<td>Grade A706</td>
</tr>
<tr>
<td>Coating Thickness</td>
<td>0.178-0.305 mm (7-12 mils)</td>
</tr>
<tr>
<td>Deformation Pattern</td>
<td>S (diagonal)</td>
</tr>
<tr>
<td>Concrete Dimensions</td>
<td>813mm (32&quot;) dia, 279mm (11&quot;) and 356mm (14&quot;) depth</td>
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</table>

Table 1-2: Testing Specifications

2. SUMMARY OF RESULTS

The epoxy-coated rebar tested with all three epoxy adhesive brands in tension and seismic loading met or exceeded the requirements of ICBO-AC58, Section 5.3.7.2.4, “Conditions of Acceptance”.

The epoxy-coated rebar tested with the Covert Operations CIA-Gel 7000 epoxy adhesive in creep loading met or exceeded the requirements of the Caltrans Augmentation/Revisions to ICBO-AC58, Section 5.3.3.2, “Conditions of Acceptance”. However, the Simpson Strong –Tie SET22 and Red Head Epcon Ceramic 6 epoxy adhesives did not meet the requirements for creep loading.
3. PRODUCT DESCRIPTIONS

3.1 Simpson Strong-Tie SET22

Simpson Strong-Tie SET22 epoxy is a two-component, low odor, 1:1 ratio, 100% solids epoxy-based adhesive for use as a high strength, non-shrink anchor grouting material. Resin and hardener are dispensed and mixed simultaneously through the mixing nozzle. SET22 meets the ASTM C-881 specification for Type I, II, IV and V, Grade 3, Class B and C.

Surfaces to receive epoxy must be clean. The base material temperature must be 4.44°C (40°F) or above at the time of installation. For best results, material should be 21.1°C - 26.7°C (70° - 80°F) at the time of application. The shelf life of an unopened side-by-side cartridge is two years from the date of manufacture. The batch number and expiration date is found on each cartridge. For best results cartridges should be stored between 7.22°C (45°F) and 32.2°C (90°F). The recommended cure times for different base material temperatures are shown in Table 3-1.

<table>
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<th>Base Material Temperature</th>
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<td>°F</td>
<td>°C</td>
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<tr>
<td>40</td>
<td>4</td>
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<td>65</td>
<td>18</td>
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<td>85</td>
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<td>90</td>
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Table 3-1: Simpson SET22 Cure Times

SET22 samples were randomly chosen via purchase from White Cap Industries in Rancho Cordova, CA.

3.2 Red Head Epcon Ceramic 6

Red Head Epcon Ceramic 6 (or C6) is a two-component, 100% solids, non-sag paste adhesive formulated for use in concrete, stone, and hollow masonry. Epoxy components are dispensed through a static mixing nozzle that thoroughly mixes the material. It meets NSF Standard 61 for use in conjunction with drinking water systems, and meets ASTM C881-90, Type IV Grade 3, Class A, B, and C with the exception of gel time.

Surfaces to receive epoxy must be clean. At temperatures between -17.8°C -10°C (0°F - 50°F), C6 should be heated to room temperature or up to 65.6°C (150°F) maximum to improve product flow and assure proper curing. The minimum shelf life for C6 is 3 years. Two codes, a four-letter batch code and five-number cartridge code, are printed on a single sticker affixed to each epoxy cartridge. Expiration dates were not found on the cartridges, but are available on the boxes. The expiration dates for each cartridge were obtained by calling the manufacturer. The recommended cure times for different base temperatures are shown in Table 3-2.
C6 samples were randomly chosen via purchase from White Cap Industries in Rancho Cordova, CA and Rainbow Fasteners Inc. in Sacramento, CA.

### 3.3 Covert Operations CIA-Gel 7000

Covert Operations CIA-Gel 7000 epoxy is a 100% solids, two-component, non-sag structural adhesive designed to be used on a wide range of applications. It is a low odor, low toxicity, and non-shrink epoxy. CIA-Gel 7000 meets ASTM C881. Resin and hardener are simultaneously dispensed and mixed through a mixing nozzle.

Surfaces to receive epoxy must be clean. Application at a substrate temperature below 4.44°C (40°F) is not recommended. Exposure to temperature exceeding 43.3°C (110°F) for prolonged periods is not recommended. The shelf life for unopened containers is a minimum of one year. CIA-Gel 7000 is not sensitive to heat or UV light, but should be prevented from freezing. The epoxy should be stored in temperatures above 4.44°C (40°F). The lot number and expiration date are printed on a label affixed to each cartridge. The recommended cure times for different base temperatures are shown in Table 3-3.

<table>
<thead>
<tr>
<th>Base Material Temperature</th>
<th>Working Time</th>
<th>Full Cure Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>°F</td>
<td>°C</td>
<td>45 min.</td>
</tr>
<tr>
<td>40</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>50</td>
<td>10</td>
<td>20 min.</td>
</tr>
<tr>
<td>60</td>
<td>16</td>
<td>10 min.</td>
</tr>
<tr>
<td>70</td>
<td>20</td>
<td>7 min.</td>
</tr>
<tr>
<td>90</td>
<td>32</td>
<td>5 min.</td>
</tr>
<tr>
<td>120</td>
<td>49</td>
<td>4 min.</td>
</tr>
</tbody>
</table>

**Table 3-2: Red Head Epcon C6 Cure times**

CIA-Gel 7000 samples were randomly chosen via purchase from White Cap Industries in Rancho Cordova, CA.
4. TEST MATERIALS

4.1 Epoxy-Coated Rebar

The epoxy-coated rebar samples were specified to be M19 (#6), grade A706 rebar with an “S”, or diagonal, deformation pattern. The coating thickness was specified as 0.178-0.305 mm (7-12 mils) with a gray (rigid) coating. The rebar was from the same heat and the cut ends were coated. The epoxy-coated rebar was obtained from FBC Systems, Inc. in Vallejo, CA.

4.2 Concrete

All testing was performed in unreinforced and uncracked concrete. The Caltrans concrete mix design T0A6342A, which has a compressive strength of 31 ± 3.45 MPa (4500 ± 500 psi), was used instead of the 20.7 ± 3.45 MPa (3000 ± 500 psi) strength requirement of ICBO-AC58. This mix design was tested because it is more representative of the mix used in the construction of Caltrans structures, and it allowed the epoxy-coated rebar to be more accurately tested. Concrete was supplied by Teichert in Sacramento, CA.

The concrete structural samples were cylinders of 813 mm (32”) in diameter and either 279 mm (11”) or 356 mm (14”) in depth (depending on embedment depth). The test surface was rough, “screed” finished to replicate field applications.

Concrete compressive test cylinders were prepared and tested in accordance with CTM 521 and ASTM C39. The actual compressive strength of the concrete when tested ranged from 30.8 MPa (4470 psi) to 43.8 MPa (6350 psi). Additional concrete data is located in Appendix A.1.

5. TEST EQUIPMENT

5.1 Tension and Seismic Loading

Tension and seismic testing was conducted using equipment designed in compliance with ASTM E488. The equipment used for the tension and seismic loading of the epoxy-coated rebar was a custom made system designed in by Caltrans in conjunction with SATEC. The system includes a load frame, a Labtronic 8800 Digital Controller, and a hydraulic pump.

The load frame uses a 267 kN (60 kip), 254 mm (10”) stroke hydraulic actuator to apply tension force to the rebar samples. (See Figure 5-1) Attached in-line to the end of the actuator is a load cell, a linear alignment coupler, and a bolt holder. The linear alignment coupler is a ball-in-socket type coupler that allows small x-y movement of the bolt holder via rotation about a fixed point. It is used to prevent a moment from being applied to the rebar sample during testing. The bolt holder is a high-strength part that holds the rebar gripping device. The entire frame is supported by a ring that is 12.7 mm (½”) thick by 25.4 mm (1”) tall and has an internal diameter of 635 mm (25”). This ring allows the rebar sample to experience an unconstrained failure. Therefore, the rebar
sample can fail in a number of ways which best simulates actual failures in the field. The load frame was moved onto and off of the samples with a gantry crane due to its weight.

The Labtronic 8800 Digital Controller is a sophisticated device that allows a multitude of testing capabilities. The controller manages the hydraulics to perform the necessary tension and seismic loading conditions. The controller is connected to a laptop computer, which collects all of the pertinent test data. The controller is housed in a watertight cabinet and mounted to a cart along side the hydraulic pump. (See Figure 5-2)

The load measurements were obtained from the 267 kN (60 kip) load cell on the load frame. The displacement measurements were obtained by a pair of ±25.4 mm (±1”) stroke AC LVDT’s. The LVDT’s were attached to the rebar by a custom made bracket that holds them 381 mm (15”) away from the rebar in opposite directions. Using two LVDT’s in this configuration and taking their average helps to minimize errors that can occur from misaligned samples. The displacements were measured relative to the concrete test surface. The LVDT’s were calibrated with the Labtronic controller at the beginning of each test day. (See Figure 5-3)
5.2 Creep Loading

In order to perform the testing in a timely manner, a method of applying a creep load to five samples simultaneously was developed. For each sample this method uses a hydraulic actuator, a spherical washer set, a barlock rebar clamp, a pair of LVDT’s, an LVDT bracket, and a hydraulic actuator support frame. The barlock screws into the rebar to create a shoulder for the actuator to push against. The spherical washer is placed between the actuator piston and the barlock, and is used to minimize any moment in the system. The actuator support frame is made of two steel C-channels and two I-beams welded together, and holds the actuator above the concrete test surface. The I-beams support the actuator load and they sit on the concrete test surface allowing a clearance of about 229 mm (9”) around the rebar. This clearance creates an unconstrained condition on the rebar and allows any type of failure mode. The LVDT’s are mounted in the same manner as for the tension testing, however; they only allow 229 mm (9”) of clearance around the rebar and have a full stroke of ±12.7 mm (±0.5”). (See Figures 5-4 and 5-5)

An air-powered pump simultaneously pressurizes all five actuators. This pump is driven by a static compressed air supply, which converts air pressure to hydraulic pressure through a mechanical piston ratio. Once pressurized, the pump holds a constant pressure, which in turn applies a constant load on the rebar samples. (See Figure 5-6)
Figure 5-4: Creep Loading Setup

Figure 5-5: LVDT Bracket for Creep Testing

Figure 5-6: Air Powered Pump
5.3 Environmental Chamber

An environmental chamber was used to bring the samples to the appropriate temperatures for testing. The chamber that was used is a wooden shed that is fully insulated. It is equipped with an HVAC unit with enough capacity to bring the chamber to the necessary temperatures regardless of outside temperature. A programmable thermostat was used to maintain the necessary temperature tolerance.

5.4 Other Equipment

Testing could not be performed inside of the environmental chamber because it was too small. Therefore, a method of moving the heavy concrete test cylinders was necessary. A small steel cart was designed that would allow the cylinders to be moved in and out of the chamber one at a time as needed (see Figure 5-7).

The load frame was equipped with a bolt holder that is used to grip threaded rod outfitted with a nut and washer. Since there was not an easy method of attaching a nut and washer to the rebar, a gripping device was designed specially to grip the rebar and fit into the bolt holder. This rebar grip consists of three tapered conical jaws in a tapered cylindrical housing (see Figure 5-9). As the gripper is pulled up with a piece of rebar in the jaws, the jaws will grip into the rebar at a ratio of approximately 6:1 of the pulling load. This gives a firm grip on the rebar to minimize the possibility of rebar slippage during testing.

During the creep testing of the rebar, data must be collected at anywhere from minutely to daily during the span of testing. For this, a Campbell Scientific CR23X datalogger was used (see Figure 5-8). For the first 6 hours of testing, the datalogger was programmed to collect all data every three seconds. This gave more than enough data to accurately record the initial elastic deformation and the critical first six hours of rebar displacement. After the first six hours, the datalogger was programmed to collect all data on an hourly basis. This gave enough data to satisfy all requirements. The datalogger program is located in Appendix B.

To minimize the clutter of wiring from the 10 LVDT’s, a multiplexer with integrated power supply was designed and fabricated (see Figure 5-10). This LVDT multiplexer allowed the 10 LVDT’s to be plugged into it, gave the appropriate power to each LVDT, and output a clean set of 10 twisted wire pairs to be connected to the datalogger. This multiplexer greatly facilitated connecting and disconnecting the LVDT’s between tests.
More detailed information for most of the equipment described in this section may be found in Appendix C in the form of data sheets and/or drawings.
6. INSTALLATION INSTRUCTIONS

For each epoxy adhesive, the epoxy-coated rebar was installed into concrete cylinders measuring 813 mm (32") in diameter by 279 mm (11") deep for the 9d [171.5mm (6 ¾") embedded depth, and 813 mm (32") in diameter by 356 mm (14") deep for the 12d [228.6mm (9") embedded depth. Holes were drilled into the hardened concrete using a rotary hammer to depths of 171.5 mm (6 ¾") or 228.6 mm (9") depending on the test. The freshly drilled holes were blown out with compressed air, thoroughly brushed, and blown out again until no particles blew out. Tape was immediately put over each cleaned hole until the rebar was installed to prevent debris infiltration. The holes were drilled to a size of 22.2 mm (7/8") in diameter at less than 6° from vertical.

The concrete cylinders were brought to a temperature of 21.1°C ± 2.8°C (70°F ± 5°F) in an environmental chamber. The epoxy adhesive was dispensed into each hole from the bottom up, filling each hole approximately half way. The epoxy-coated rebar was then inserted into each adhesive filled hole with a twisting motion to help eliminate air pockets from forming. The epoxy adhesive was allowed to cure for 48 hours at 21.1°C ± 2.8°C (70°F ± 5°F) prior to testing.

7. TEST PROCEDURE

Testing was conducted in accordance with ICBO-AC58, ASTM E488-96, ASTM E1512-01, CTM 681, and Caltrans Augmentation/Revisions to ICBO-AC58, except for concrete compressive strength in which a higher strength than required was used.

7.1 Tension and Seismic Tests

Tension and seismic tests were first performed on the 12d embedment depth epoxy-coated rebar samples, and then the 9d. Ten samples were tested at a time; five samples for each tension and seismic loadings. One at a time, the cured samples were brought outside from an environmental chamber at 21.1°C ± 2.8°C (70°F ± 5°F) and quickly tested. The samples were unconstrained to allow any possible failure mode.

Five samples (controls) were tested in tension until failure and an average ultimate load was determined, T_{ref}. Loading criteria, N_s, N_i, and N_m, for the seismic tests were then calculated using the average ultimate load (see Figure 7-1). The remaining five samples were then tested in seismic loading at a frequency of 0.5 Hz and according to the calculated loading criteria. Immediately after the seismic loading was complete, the samples were pulled in tension until failure. An average ultimate tension load after seismic loading was calculated.
7.2 Creep Tests

High temperature creep tests were performed on samples with the 9d embedment depth only. Ten cured samples were brought up to 43.3 °C ± 1.65°C (110°F ± 3°F) in an environmental chamber in approximately 24 hours. Elevated temperature tension tests were first performed on five of the samples. One at a time, the heated samples were taken out of the heated environmental chamber and quickly tested. A maximum displacement at ultimate load was calculated from the five high temperature tests.

A sustained creep load of 40% of the average ultimate load, T_{ref}, was applied to the remaining five samples by the use of an air-powered hydraulic pump and five hydraulic actuators. Each sample was fitted with a hydraulic actuator, one set of spherical washers, a barlock clamping device, an actuator support fixture, and a bracket which held two LVDT’s 228.6mm (9”) away from the rebar in opposite directions. One of the five samples was also equipped with a load cell.

With the samples already up to temperature, a preload of approximately 4% of the sustained creep load was applied to the samples. The displacements were then zeroed, and the remaining sustained creep load was applied. The displacements were recorded every three seconds for the first six hours, and hourly until the end of the test cycle. Other data that was recorded hourly until the end of the test cycle includes: internal chamber temperature and humidity, tension force applied to the rebar, air pump pressure, sample concrete temperature, and outside temperature. The samples were left in the environmental chamber that was programmed to warm up to 43.3 °C ± 1.65°C (110°F ± 3°F) and maintain that temperature within ±1.65°C (±3°F) for at least 42 days. The sample concrete temperature was recorded by a thermocouple cast into two of the five samples 114 mm (4 ½”) down from the test surface.

After the 42-day test cycle, the samples were unloaded and the fixtures were removed. The rebar was then cut to a length of approximately 203 mm (8”) to both remove the marred section of rebar created by the barlocks, and to allow the sample to fit into the testing machine. One at a time, each sample was then taken out of the heated chamber and quickly tested in tension until failure.

Data and specific details for the above test procedure may be found in the Appendix, and are summarized in Section 8, Test Results.
8. TEST RESULTS

The testing revealed that epoxy-coated rebar bonded into hardened concrete generally outperforms uncoated rebar in tensile loading, however; it under performs uncoated rebar in creep loading. One interesting discovery was that failures occurred via the adhesive debonding from the epoxy coating on the rebar. For uncoated rebar, the adhesive rarely debonds from the rebar interface. The seismic testing revealed that the epoxy-coated rebar satisfied the ICBO-AC58 conditions of acceptance for each adhesive. A summary of all tests performed is displayed in Tables 8-1 through 8-3.

After performing the tests and having the concrete test cylinders compression tested, the concrete strength was found to be slightly higher than initially intended. The concrete strength was found to be in the range of 30.8 MPa (4470 psi) to 43.8 MPa (6350 psi). Even with the higher strength concrete, the epoxy-coated rebar still failed the creep tests for two adhesives.
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<th>Test Type</th>
<th>Sample #</th>
<th>Date</th>
<th>Time</th>
<th>Outside Temp</th>
<th>Max Load</th>
<th>Max Displacement</th>
<th>Method of Failure</th>
<th>Average Load</th>
<th>Average Disp</th>
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<td>63.8</td>
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<td>Rebar</td>
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Table 8-1: Summary of Results for SET22 Epoxy Testing
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<th>Max Displacement</th>
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<td>mm</td>
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<td>31670</td>
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<td>0.0711</td>
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<td>12/18/03</td>
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<td>33.7</td>
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<td>0.1292</td>
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<td>3</td>
<td>12/18/03</td>
<td>14:40</td>
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<td>5</td>
<td>12/18/03</td>
<td>15:13</td>
<td>61.2</td>
<td>34.0</td>
<td>30650</td>
<td>136393</td>
<td>0.1782</td>
<td>4.526</td>
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<td>50.6</td>
<td>28.1</td>
<td>31110</td>
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<td>0.2159</td>
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<td>Temperature Creep Tensile</td>
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<td>01/30/04</td>
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<td>30.1</td>
<td>27590</td>
<td>122776</td>
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<td>01/30/04</td>
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<td>123933</td>
<td>0.1125</td>
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<td>-</td>
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Table 8-2: Summary of Results for Red Head Epon C6 Epoxy Testing
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<tr>
<th>Test Type</th>
<th>Sample #</th>
<th>Date</th>
<th>Time</th>
<th>Outside Temp</th>
<th>Max Load</th>
<th>Max Displacement</th>
<th>Method of Failure</th>
<th>Average Load (N lbf)</th>
<th>Average Disp (mm in)</th>
</tr>
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<tbody>
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<td>CIA-Gel 7000 12d Tensile</td>
<td>1</td>
<td>02/04/04</td>
<td>9:13</td>
<td>50.0  27.8</td>
<td>41060</td>
<td>182717</td>
<td>Rebar</td>
<td>168148</td>
<td>12.066 (0.475)</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>02/04/04</td>
<td>9:36</td>
<td>50.6  28.1</td>
<td>38770</td>
<td>172527</td>
<td>Adhesive</td>
<td>(37786)</td>
<td>8.183</td>
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<td></td>
<td>3</td>
<td>02/04/04</td>
<td>9:57</td>
<td>47.6  26.4</td>
<td>32210</td>
<td>143335</td>
<td>Adhesive</td>
<td></td>
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<tr>
<td></td>
<td>4</td>
<td>02/04/04</td>
<td>10:25</td>
<td>49.6  27.6</td>
<td>38710</td>
<td>172260</td>
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<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>02/04/04</td>
<td>10:42</td>
<td>50.4  28.0</td>
<td>38180</td>
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<td>CIA-Gel 7000 12d Seismic</td>
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<td>52.6  29.2</td>
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<td>180047</td>
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<td>179415</td>
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<td></td>
<td>2</td>
<td>02/04/04</td>
<td>11:42</td>
<td>55.8  31.0</td>
<td>40040</td>
<td>178178</td>
<td>Adhesive</td>
<td>(40318)</td>
<td>11.780 (0.494)</td>
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<td></td>
<td>3</td>
<td>02/04/04</td>
<td>12:06</td>
<td>56.8  31.6</td>
<td>41610</td>
<td>185165</td>
<td>Rebar</td>
<td></td>
<td></td>
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<td>02/04/04</td>
<td>12:29</td>
<td>58.4  32.4</td>
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<td>02/04/04</td>
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<td>59.6  33.1</td>
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<td>54.0  30.0</td>
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<td>131097</td>
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<td>10:37</td>
<td>56.8  31.6</td>
<td>35280</td>
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<td>145248</td>
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<td>2.014 (0.0793)</td>
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<td>02/11/04</td>
<td>11:12</td>
<td>58.4  32.4</td>
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<td>(30082)</td>
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<td>12:30</td>
<td>68.0  37.8</td>
<td>28910</td>
<td>128650</td>
<td>Conc/Adhesive</td>
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<td>02/11/04</td>
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<td>61.0  33.9</td>
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<td>128160</td>
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<td>136437</td>
<td>1.719 (0.0677)</td>
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<td>(30660)</td>
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<td>56.2  31.2</td>
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<td>32510</td>
<td>144670</td>
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<td>04/05/04</td>
<td>10:55</td>
<td>69.8  38.8</td>
<td>34330</td>
<td>152769</td>
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<td>139401</td>
<td>2.025 (0.0797)</td>
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<td>04/06/04</td>
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<td>66.4  36.9</td>
<td>33050</td>
<td>147073</td>
<td>Adhesive</td>
<td>(31326)</td>
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<td>3</td>
<td>04/07/04</td>
<td>11:35</td>
<td>68.0  37.8</td>
<td>33200</td>
<td>147740</td>
<td>Adhesive</td>
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<td>4</td>
<td>04/08/04</td>
<td>11:50</td>
<td>62.6  34.8</td>
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<td>68.2  37.9</td>
<td>26270</td>
<td>116902</td>
<td>Conc/Adhesive</td>
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Table 8-3: Summary of Results for CIA-Gel 7000 7000 Epoxy Testing

8.1 Tension and Seismic Tests

For the CIA-Gel 7000 and Ceramic 6 adhesives, the average ultimate strength from tensile loading of the bonded epoxy-coated rebar was found to be slightly higher than the manufacturers specifications for uncoated rebar. However, the SET22 adhesive under performed the manufacturer specifications for uncoated rebar. This shows that epoxy-coated rebar bonded in hardened concrete generally performs comparable to uncoated rebar. Tables 8-4 and 8-5 summarize the tension and seismic test results and give the conditions of acceptance.
Table 8-4: Preliminary Test Results and Seismic Parameters

<table>
<thead>
<tr>
<th>Embedment</th>
<th>Epoxy Type</th>
<th>Avg. Load N (lb)</th>
<th>Preload N (lb)</th>
<th>Failure Mode</th>
<th>Ns 10 cycles</th>
<th>Ni 30 cycles</th>
<th>Nm 100 cycles</th>
</tr>
</thead>
<tbody>
<tr>
<td>228.6 mm (9&quot;) [12d]</td>
<td>SET22</td>
<td>178436</td>
<td>4450</td>
<td>2.49</td>
<td>2-epoxy 1-grip 2-rebar</td>
<td>89215 (20048)</td>
<td>66912 (15036)</td>
</tr>
<tr>
<td></td>
<td>Red Head</td>
<td>155323</td>
<td>4450</td>
<td>2.66</td>
<td>5-epoxy</td>
<td>77659 (17451)</td>
<td>58245 (13089)</td>
</tr>
<tr>
<td></td>
<td>CIA-GEL 7000</td>
<td>168148</td>
<td>4450</td>
<td>2.65</td>
<td>4-epoxy 1-rebar</td>
<td>84072 (18893)</td>
<td>63054 (14169)</td>
</tr>
<tr>
<td>171.5 mm (6-3/4&quot;) [9d]</td>
<td>SET22</td>
<td>149983</td>
<td>4450</td>
<td>2.86</td>
<td>3-epoxy 2-cnc/epy</td>
<td>74989 (16851)</td>
<td>56242 (12639)</td>
</tr>
<tr>
<td></td>
<td>Red Head</td>
<td>142178</td>
<td>4450</td>
<td>3.13</td>
<td>5-epoxy</td>
<td>71087 (15975)</td>
<td>53316 (11981)</td>
</tr>
<tr>
<td></td>
<td>CIA-GEL 7000</td>
<td>139890</td>
<td>4450</td>
<td>3.18</td>
<td>5-epoxy</td>
<td>69943 (15718)</td>
<td>52458 (11788)</td>
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</table>

Table 8-5: Seismic Test Conditions of Acceptance

<table>
<thead>
<tr>
<th>Embedment</th>
<th>Epoxy Type</th>
<th>Avg. Load N (lb)</th>
<th>Preload N (lb)</th>
<th>Failure Mode</th>
<th>Pass/ Fail</th>
<th>Ns 10 cycles</th>
<th>Ni 30 cycles</th>
<th>Nm 100 cycles</th>
</tr>
</thead>
<tbody>
<tr>
<td>228.6 mm (9&quot;) [12d]</td>
<td>SET22</td>
<td>182121</td>
<td>4450</td>
<td>2.44</td>
<td>Pass</td>
<td>0.684 ≤ 3.481 (0.026 ≤ 0.137)</td>
<td>0.734 ≤ 3.481 (0.029 ≤ 0.137)</td>
<td>0.504 ≤ 3.481 (0.020 ≤ 0.137)</td>
</tr>
<tr>
<td></td>
<td>Red Head</td>
<td>148924</td>
<td>4450</td>
<td>2.99</td>
<td>Pass</td>
<td>1.563 ≤ 2.383 (0.062 ≤ 0.0938)</td>
<td>1.459 ≤ 2.383 (0.057 ≤ 0.0938)</td>
<td>1.291 ≤ 2.383 (0.051 ≤ 0.0938)</td>
</tr>
<tr>
<td></td>
<td>CIA-GEL 7000</td>
<td>179415</td>
<td>4450</td>
<td>2.48</td>
<td>Pass</td>
<td>0.664 ≤ 6.033 (0.026 ≤ 0.238)</td>
<td>0.604 ≤ 6.033 (0.024 ≤ 0.238)</td>
<td>0.537 ≤ 6.033 (0.021 ≤ 0.238)</td>
</tr>
<tr>
<td>171.5 mm (6-3/4&quot;) [9d]</td>
<td>SET22</td>
<td>148354</td>
<td>4450</td>
<td>3.00</td>
<td>Pass</td>
<td>0.224 ≤ 1.327 (0.009 ≤ 0.0522)</td>
<td>0.177 ≤ 1.327 (0.007 ≤ 0.0522)</td>
<td>0.123 ≤ 1.327 (0.005 ≤ 0.0522)</td>
</tr>
<tr>
<td></td>
<td>Red Head</td>
<td>140967</td>
<td>4450</td>
<td>3.16</td>
<td>Pass</td>
<td>0.337 ≤ 1.493 (0.013 ≤ 0.0588)</td>
<td>0.286 ≤ 1.493 (0.011 ≤ 0.0588)</td>
<td>0.236 ≤ 1.493 (0.009 ≤ 0.0588)</td>
</tr>
<tr>
<td></td>
<td>CIA-GEL 7000</td>
<td>133665</td>
<td>4450</td>
<td>3.32</td>
<td>Pass</td>
<td>0.373 ≤ 1.897 (0.015 ≤ 0.0747)</td>
<td>0.326 ≤ 1.897 (0.013 ≤ 0.0747)</td>
<td>0.274 ≤ 1.897 (0.011 ≤ 0.0747)</td>
</tr>
</tbody>
</table>

8.1.1 Simpson SET22

This was the first epoxy tested and therefore, was the test with the most errors. The first two tension tests on the 12d embedment depth were performed without oversight. However, on the third test the rebar gripper slipped off of the rebar just before failure of the rebar due to the gripper being inadvertently placed over the lettering on the
rebar. The lettering created an area where the gripper could not fully engage the rebar, and therefore caused slippage. On tests 4 and 5, the LVDT bracket came loose from the rebar causing it to slip down the rebar just before failure, and thus creating inaccurate displacement data. This occurred because the LVDT bracket was unable to maintain a tight grip once the rebar began to neck. Figures A-6 through A-10 in the appendix show the load vs. displacement curves for the five 12d tension tests.

After the tension tests, the seismic tests for the 12d embedment depth were performed. For these tests, every failure was a rebar failure. This caused excessive necking in the rebar just before failure, which allowed the LVDT bracket to slip down on every test. This, again, created erroneous displacement data. The load vs. displacement plots for the 12d seismic tests can be seen in Figures A-11 through A-15.

The 9d embedment depth tests were performed next and done so without fault. Figures A-16 through A-25 show the results for the tension and seismic tests in graphical form. See Table 8-1 for all results from SET22 epoxy testing summarized in tabular form.

8.1.2 Red Head Epcon C6

For the testing of the Red Head Epoxy, the LVDT bracket was improved to accommodate for necking of the rebar. During its installation into the concrete, the epoxy adhesive began to harden before all ten 12d cylinders could be filled. This caused the need to use another epoxy cartridge to fill the last two samples. These two samples were numbers 1 and 3 of the tensile test group. During the tensile testing it was found that the two samples with the epoxy from the second cartridge had slightly higher strengths than the other three, however the values were within reasonable tolerances (see Table 8-2).

In addition to the premature hardening of the epoxy, sample #5 in the 12d seismic test group did not receive enough epoxy. After testing this sample, it was noticed that the strength was much lower than the other four samples, and therefore the data for this sample was neglected. Figures A-33 through A-42 show the results for the 12d tensile and seismic tests.

The 9d testing was performed without fault and the results can be found in Figures A-43 through A-52.

8.1.3 Covert Operations CIA-Gel 7000

All tensile and seismic tests for CIA-Gel 7000 were performed without errors and the results can be found in Figures A-60 through A-79. The results are also summarized in Table 8-3.

8.2 Creep Tests

8.2.1 Simpson SET22

During the elevated temperature creep tests for the SET22 epoxy, one of the hydraulic rams leaked out all of the hydraulic fluid from the pump on day 41 of testing.
This caused a complete loss of pressure, and therefore a complete loss of loading on the samples. Although the creep testing did not go for the minimum 42-day period, testing continued. The creep testing data and results are shown in Figures A-26 through A-30. In Figure A-29 some very large spikes can be seen in the temperature graph. These spikes are not actual temperature fluctuations, however they are due to electronic interference with the datalogging device and should therefore be ignored. The tension tests after creep were performed and the results can be found in Figure A-32.

The average displacement at ultimate load from the elevated temperature tensile tests was compared to the 1.52mm (0.06”) requirement from the Caltrans Augmentation to ICBO-AC58, and was found to be a higher value (6.31 mm, [0.248”]). Therefore, the 1.52mm (0.06”) displacement value is the requirement to be met. The average displacement at 600 days was found to be 1.50 mm (0.0591”), however this is the average of all five samples. One sample (sample #3) strayed from the other four, and those four samples all failed to meet the displacement limit, with an average of 1.59 mm (0.0626”). This leads to the conclusion that sample #3 should be neglected and that the epoxy-coated rebar bonded with SET22 did not meet the required displacement criteria.

Revision (2007): Due to the load fluctuations of 5.3 kN or about 10% of the creep load on day 27, it is recommended to use only the first 26 days of data were used for the logarithmic curve fit. The revised 600-day creep value is 1.02 mm.

**8.2.2 Red Head Epcon C6**

The displacement criteria for the Red Head epoxy testing was determined to be 1.52 mm (0.06”), because the average displacement at ultimate load of the elevated temperature tensile tests was found to be 3.34 mm (0.131”). The elevated temperature tensile tests results can be seen on Figure A-58.

During the elevated temperature creep testing with the Red Head epoxy, all five of the samples failed the Caltrans Augmentation to ICBO-AC58 displacement criteria (Section 5.3.3.2) before the 42-day creep cycle was over. Two of the samples displaced farther than the stroke of the LVDT’s, with one of them pulling completely out of the concrete. This event can be seen on Figure A-55. Without a doubt, the epoxy-coated rebar bonded with Red Head Epcon C6 did not meet the required displacement criteria. The average displacement at 600 days was found to be 2.75 mm (0.108”). The results for this creep testing can be found on Figures A-53 through A-57, and the results for the tensile testing after creep can be found on Figure A-59. As in the SET22 testing, the spikes on Figure A-56 are not actual temperature fluctuations, but are due to electronic interference with the datalogger.

**8.2.3 Covert Operations CIA-Gel 7000**

The CIA-Gel 7000 average displacement at ultimate load for the elevated temperature tensile tests was found to be 1.72 mm (0.0676”). Since this value is higher than that set by the Caltrans Augmentation to ICBO-AC58, the displacement limit was set as 1.52 mm (0.06”). The elevated temperature tensile test results can be seen on Figure A-85.

The average displacement at 600 days for the epoxy-coated rebar bonded with CIA-Gel 7000 was found to be 0.538 mm (0.0212”). This shows that the epoxy-coated rebar bonded with CIA-Gel 7000 did meet the displacement criteria. The creep testing results are shown in Figures A-80 through A-84. Once again, the temperature spikes
during the first 11 days in Figure A-83 are not actual temperature fluctuations, but are due to electronic interference with the datalogger. The small jump and rebound in displacement near day 37 was due to a jump in pressure from pump inaccuracies. The pressure jump occurred over a weekend and was compensated for as soon as it was discovered. The results for the elevated temperature tensile tests after creep are shown in Figure A-86.

9. CONCLUSION

The epoxy-coated rebar was found to meet the conditions of acceptance for seismic loading when bonded into hardened concrete using an epoxy adhesive. However, the epoxy-coated rebar did not meet the conditions of acceptance for creep loading when bonded into hardened concrete. The rebar bonded with CIA-Gel 7000 was found to meet the creep requirements, whereas the rebar bonded with SET22 and Red Head Epcon C6 did not meet the conditions of acceptance for creep loading. It was also noticed that, when compared to the manufacturer test data, the epoxy-coated rebar outperformed uncoated rebar in allowable tensile loads for two of the three epoxies tested. SET22 adhesive under performed the manufacturer test data.

Although the testing procedures and instrumentation were burdened with error, the testing revealed enough accurate data to be valuable. The displacement data on the 12d testing with the SET22 epoxy was accurate until the last few seconds of each test, where the LVDT brackets slipped creating inaccurate data. Even though the displacement data was not complete, the loading data was complete and accurate. Beneficially, the incomplete portions of data did not affect the calculation of the conditions of acceptance. The interference in the instrumentation that created undesirable spikes in the temperature data was not found to be detrimental to the testing. The temperature was often checked manually to ensure that it was within the allowable tolerances.

The target concrete compressive strength was $31 \pm 3.45 \text{ MPa (4500 \pm 500 psi)}$, however the actual strength ranged from 30.8 MPa (4470 psi) to 43.8 MPa (6350 psi). The concrete mix design used in this testing is representative of the mix used in the construction of Caltrans structures. Since this testing is designed to evaluate epoxy-coated rebar in actual use applications, the data obtained from the testing is in direct correlation.

Overall, this testing has proved to be valuable and has provided a better understanding of how epoxy-coated rebar reacts when bonded into hardened concrete with different epoxy adhesives.

10. RECOMMENDATION

It is recommended that a higher factor of safety be applied to epoxy-coated rebar than is to uncoated rebar when bonding it into hardened concrete. This can be done in the form of a deeper embedment depth or other method. The Reinforced Concrete Committee should determine whether a change in the general notes of the pre-qualified products list for cartridge epoxies / chemical adhesives is necessary to address the factor of safety modification. Also, the Reinforced Concrete Committee should review the
creep displacement acceptance criteria to determine if the value should be changed to accommodate epoxy-coated rebar, or if a separate set of specifications should be made for epoxy-coated rebar. The Red Head Epcon C6 epoxy is currently not on the Caltrans pre-qualified products list, and from the results in this testing, it is recommended that it stay off of the list.

11. IMPLEMENTATION

The Office of Structure Design will be responsible for the modification of the pre-qualified products list for cartridge epoxies / chemical adhesives and the bridge design aids for the use of epoxy-coated rebar bonded into hardened concrete.

12. REFERENCES


APPENDIX

Appendix A  General Test Data

A.1 Kelly Ball and Slump Test Results

<table>
<thead>
<tr>
<th>Epoxy</th>
<th>Time Date</th>
<th>Air Temp</th>
<th>Concrete Temp</th>
<th>Kelly Ball</th>
<th>Slump</th>
<th>Mix Design</th>
</tr>
</thead>
<tbody>
<tr>
<td>SET22</td>
<td>12:00 9/2/2003</td>
<td>26.9°C (80.4°F)</td>
<td>28.6°C (83.4°F)</td>
<td>54 mm (2-1/8&quot;)</td>
<td>63.5 mm (2-1/2&quot;)</td>
<td>T0A6342A</td>
</tr>
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<td>Ceramic 6</td>
<td>14:30 11/5/2003</td>
<td>17.8°C (64.0°F)</td>
<td>22.7°C (72.8°F)</td>
<td>50.8 mm (2&quot;)</td>
<td>63.5 mm (2-1/2&quot;)</td>
<td>T0A6342A</td>
</tr>
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<td>14:00 1/5/2004</td>
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<td>–</td>
<td>63.5 mm (2-1/2&quot;)</td>
<td>82.5 mm (3-1/4&quot;)</td>
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Table A-1: Concrete Pour Information

A.2 Epoxy Information

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<th>Expiration Date</th>
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<td>Jan-05</td>
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<tr>
<td>Ceramic 6</td>
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<td></td>
</tr>
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</tr>
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<td>12d Tests</td>
<td>EONR 79212</td>
<td>Sep-05</td>
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<td>(tensile test samples 1 &amp; 3)</td>
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<td></td>
</tr>
<tr>
<td>9d Tests</td>
<td>EONT 51816</td>
<td>Nov-05</td>
</tr>
<tr>
<td>9d Creep Tests</td>
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<tr>
<td>CIA-Gel 7000</td>
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Table A-2: Epoxy Adhesive Information
### A.3 Concrete Test Results

TL No.: 134606  
Contract No.: 65-680321  
Cast Date: 9/2/2003

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<th>Break Date</th>
<th>Concrete Lab Sample No.</th>
<th>Cylinder No.</th>
<th>Cylinder Age</th>
<th>Peak Load</th>
<th>Compressive Strength</th>
<th>Test Result (Average)</th>
</tr>
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<tr>
<td>9/29/03</td>
<td>CL031730</td>
<td>1/2</td>
<td>27 days</td>
<td>588 kN</td>
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<td>32.5 MPa (4710 psi)</td>
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<td>597 kN</td>
<td>32.7 MPa (4746 psi)</td>
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<td>10/1/03</td>
<td>CL031731</td>
<td>1/2</td>
<td>29 days</td>
<td>604 kN</td>
<td>33.1 MPa (4799 psi)</td>
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</tr>
<tr>
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<td></td>
<td>2/2</td>
<td></td>
<td>607 kN</td>
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<td></td>
</tr>
<tr>
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<td>36 days</td>
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<td>CL031733</td>
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*Table A-3: Simpson SET22 Concrete Compressive Strengths*
TL No.: 134607  
Contract No.: 65-680321  
Cast Date: 11/5/2003

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<th>Break Date</th>
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<th>Cylinder Age</th>
<th>Peak Load</th>
<th>Compressive Strength</th>
<th>Test Result (Average)</th>
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<td>12/3/03</td>
<td>CL032361</td>
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<td>34.3 MPa (4980 psi)</td>
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<td>612 kN (137500 lbf)</td>
<td>33.5 MPa (4863 psi)</td>
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<tr>
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<td>CL032360</td>
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<td>29 days</td>
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<td>34.4 MPa (4990 psi)</td>
<td>33.9 MPa (4920 psi)</td>
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<td>610 kN (137100 lbf)</td>
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<td>701 kN (157500 lbf)</td>
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Table A-4: Red Head C6 Concrete Compressive Strengths
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<th>Peak Load</th>
<th>Compressive Strength</th>
<th>Test Result (Average)</th>
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<td>CL040169</td>
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<td>28 days</td>
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*Table A-3: Covert Operations CIA-GEL 7000 Concrete Compressive Strengths*
## A.4 Failure Modes

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<tr>
<td></td>
<td>3</td>
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<td>Significant concrete breakage</td>
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<td></td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>E1/S2C</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>E1/S3C</td>
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*Table A-6: Testing Failure Modes for Epoxy-Coated Rebar Bonded with SET22 Adhesive*
<table>
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<th>Test</th>
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<th>Adhesive- Rebar Interface</th>
<th>Rebar</th>
<th>Other</th>
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<td>5</td>
<td>E2/S5T/12d</td>
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</tr>
<tr>
<td>Red Head 12d Seismic</td>
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<td>E2/S4T/9d</td>
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<td>5</td>
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<td></td>
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<td>X</td>
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</tr>
<tr>
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<td>2</td>
<td>E2/S2S/9d</td>
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<td></td>
<td>X</td>
<td></td>
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<tr>
<td></td>
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<td>E2/S3S/9d</td>
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<td></td>
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<tr>
<td></td>
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<td>E2/S4S/9d</td>
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<td>X</td>
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<td></td>
</tr>
<tr>
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<td>E2/S5S/9d</td>
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<td>X</td>
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</tr>
<tr>
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<td>E2/S1HT</td>
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<td></td>
<td>X</td>
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<td>Adhesive removed at bottom</td>
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<tr>
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<td></td>
<td>X</td>
<td></td>
<td>Adhesive removed at bottom</td>
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<tr>
<td></td>
<td>3</td>
<td>E2/S3HT</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td>Adhesive removed at bottom</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>E2/S4HT</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td>Adhesive removed at bottom</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>E2/S5HT</td>
<td></td>
<td></td>
<td>X</td>
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<td></td>
<td>X</td>
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<tr>
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<td>3</td>
<td>E2/S3C</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>E2/S4C</td>
<td></td>
<td></td>
<td>X</td>
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</tr>
<tr>
<td></td>
<td>5</td>
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Table A-7: Testing Failure Modes for Epoxy-Coated Rebar Bonded with Ceramic 6 Adhesive
<table>
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<th>Rebar</th>
<th>Other</th>
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<td></td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>CG/S2T/12d</td>
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<td>3</td>
<td>CG/S3T/12d</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>CG/S4T/12d</td>
<td></td>
<td>X</td>
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<tr>
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<td>5</td>
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<td>X</td>
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<td>X</td>
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<tr>
<td></td>
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<td>X</td>
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<tr>
<td></td>
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<td>CG/S5S/12d</td>
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<tr>
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<td>3</td>
<td>CG/S3T/9d</td>
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<td>CG/S5S/9d</td>
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</table>

Table A-8: Testing Failure Modes for Epoxy-Coated Rebar Bonded with CIA-Gel 7000 Adhesive
A.5 Sample Failure Mode Photos

Figure A-1: Typical Concrete–Concrete/Adhesive Interface Failure

Figure A-2: Typical Concrete/Adhesive Interface Failure
Figure A-3: Typical Concrete/Adhesive Interface–Adhesive/Rebar Interface Failure

Figure A-4: Typical Adhesive/Rebar Interface Failure
Figure A-5: Typical Rebar Failure

Figure A-6: Red Head C6 Creep Failure
A.6 SET22 Test Data:

Figure A-6

Figure A-7
Figure A-8

Figure A-9

Figure A-10
Figure A-11

Figure A-12

Figure A-13
Figure A-14

Figure A-15

Figure A-16
Figure A-17

Figure A-18

Figure A-19
Figure A-20

Figure A-21

Figure A-22
Figure A-26

Figure A-27: SET22 Creep Displacement 600-Day Logarithmic Regression Analysis
Figure A-28

Simpson 42-Day Creep Displacements

Figure A-29

Simpson Chamber and Concrete Temperatures

Figure A-30

Simpson Creep Load
Figure A-31: Displacements at Maximum Load for SET22 Elevated Temperature Tensile Tests

Figure A-32: SET22 Tensile Tests After 42-Day Creep Cycle
A.7 Red Head Epcon C6 Test Data:

Figure A-33

Figure A-34
Figure A-35

Figure A-36

Figure A-37
Figure A-38

Figure A-39

Figure A-40
Figure A-41

Figure A-42

Figure A-43
Figure A-47

Figure A-48

Figure A-49
Red Head Creep Displacements Over First 6 Hours

![Graph showing creep displacements over time for different samples.](image1)

Figure A-53

Red Head Elevated Temperature Creep Logarithmic Regression Analysis

![Graph showing logarithmic regression analysis for creep displacement.](image2)

Figure A-54: Red Head Creep Displacement 600-Day Logarithmic Regression Analysis

\[
y = 0.5577 \ln(x) + 0.1025 \\
R^2 = 0.8168
\]

\[
y = 0.301 \ln(x) + 0.1979 \\
R^2 = 0.8608
\]

\[
y = 0.3222 \ln(x) + 0.4048 \\
R^2 = 0.88
\]
Figure A-58: Displacements at Maximum Load for Red Head Elevated Temperature Tensile Tests

Figure A-59: Red Head Tensile Tests After 42-Day Creep Cycle
A.8 CIA-Gel 7000 Test Data:

![Graph of CIA GEL 12d Tensile Test #1](image)

Figure A-60

![Graph of CIA GEL 12d Tensile Test #2](image)

Figure A-61
Figure A-62

Figure A-63

Figure A-64
Figure A-65

Figure A-66

Figure A-67
Figure A-68

Figure A-69

Figure A-70
Figure A-77

Figure A-78

Figure A-79
CIA-GEL Creep Displacements Over First 6 Hours

Figure A-80

CIA-GEL Elevated Temperature Creep Logarithmic Regression Analysis

Figure A-81: CIA-GEL 7000 Creep Displacement 600-Day Logarithmic Regression Analysis
Figure A-82

Figure A-83

Figure A-84
Figure A-85: Displacements at Maximum Load for CIA-GEL 7000 Elevated Temperature Tensile Tests

Figure A-86: CIA-GEL 7000 Tensile Tests After 42-Day Creep Cycle
Appendix B  Data Logger Programs

B.1  Initial Creep Program (First 8 hours)

;{CR23X-TD}
;Epoxy Bonded Dowel Project
;
; This program collects data from thermocouples, temp/humidity
; probe, load cell, & pump digital gauge. Two tables have been
; set-up. Table 1 collects every hour, while Table 2 collects
; every 3 seconds for 8 hours.
;
; **This version is for 2 concrete thermocouple.**

; ******************************************************* TABLE 1 ***********************
;
; Collects data every hour and stores into final storage
;
*Table 1 Program
  01: 3600   Execution Interval (seconds)

; --------------------------------------------------------
; TEMPERATURE SECTION
; --------------------------------------------------------
;
; Reference temperature
;
1:  Panel Temperature (P17)
  1: 1   Loc [ PANEL_TEMP_C   ]

; Convert reference temp from C to F
;
2:  Z=X*F (P37)
  1: 1   X Loc [ PANEL_TEMP_C   ]
  2: 1.8   F
  3: 2   Z Loc [ PANEL_TEMP_F   ]

3:  Z=X+F (P34)
  1: 2   X Loc [ PANEL_TEMP_F   ]
  2: 32   F
  3: 2   Z Loc [ PANEL_TEMP_F   ]

;  CONCRETE 1
; Thermocouple 1 temp in F
;
4:  Thermocouple Temp (DIFF) (P14)
  1: 1   Reps
  2: 21   10 mV, 60 Hz Reject, Slow Range
  3: 1   DIFF Channel
  4: 1   Type T (Copper-Constantan)
  5: 1   Ref Temp (Deg. C) Loc [ PANEL_TEMP_C   ]
  6: 9   Loc [ C1_TEMP_F     ]
  7: 1.8   Mult
  8: 32   Offset
; CONCRETE 2
; Thermocouple 2 temp in F
;
5: Thermocouple Temp (DIFF) (P14)
  1: 1 Reps
  2: 21 10 mV, 60 Hz Reject, Slow Range
  3: 2 DIFF Channel
  4: 1 Type T (Copper-Constantan)
  5: 1 Ref Temp (Deg. C) Loc [ PANEL_TEMP_C ]
  6: 10 Loc [ C2_TEMP_F ]
  7: 1.8 Mult
  8: 32 Offset

; OUTSIDE
; Thermocouple 3 temp in F
;
6: Thermocouple Temp (DIFF) (P14)
  1: 1 Reps
  2: 21 10 mV, 60 Hz Reject, Slow Range
  3: 3 DIFF Channel
  4: 1 Type T (Copper-Constantan)
  5: 1 Ref Temp (Deg. C) Loc [ PANEL_TEMP_C ]
  6: 11 Loc [ OUTSIDE_TEMP_F ]
  7: 1.8 Mult
  8: 32 Offset

; ENCLOSURE
; Thermocouple 4 temp in F
;
7: Thermocouple Temp (DIFF) (P14)
  1: 1 Reps
  2: 21 10 mV, 60 Hz Reject, Slow Range
  3: 4 DIFF Channel
  4: 1 Type T (Copper-Constantan)
  5: 1 Ref Temp (Deg. C) Loc [ PANEL_TEMP_C ]
  6: 12 Loc [ BOX_TEMP_F ]
  7: 1.8 Mult
  8: 32 Offset

;-------------------------------
; HMP45C TEMPERATURE AND RELATIVE HUMIDITY PROBE SECTION
;-------------------------------
;
8: Do (P86)
  1: 41 Set Port 1 High

; Delay for probe stabilization
;
9: Delay w/Opt Excitation (P22)
  1: 1 Ex Channel
  2: 0 Delay W/Ex (0.01 sec units)
  3: 15 Delay After Ex (0.01 sec units)
  4: 0 mV Excitation

; Temp from probe
; 10: Volt (Diff) (P2)
  1: 1   Reps
  2: 24  1000 mV, 60 Hz Reject, Slow Range
  3: 7   DIFF Channel
  4: 3   Loc [ PROBE_TEMP_C ]
  5: .1  Mult
  6: -40 Offset

; Relative humidity from probe
;
11: Volt (Diff) (P2)
  1: 1   Reps
  2: 24  1000 mV, 60 Hz Reject, Slow Range
  3: 8   DIFF Channel
  4: 5   Loc [ REL_HUMIDITY ]
  5: .1  Mult
  6: 0.0 Offset

; Probe off
;
12: Do (P86)
  1: 51  Set Port 1 Low

; ------------
; Convert probe temp from C to F
;
13: Z=X*F (P37)
  1: 3   X Loc [ PROBE_TEMP_C ]
  2: 1.8 F
  3: 4   Z Loc [ PROBE_TEMP_F ]

14: Z=X+F (P34)
  1: 4   X Loc [ PROBE_TEMP_F ]
  2: 32  F
  3: 4   Z Loc [ PROBE_TEMP_F ]

;-----------------------------
; LVDT SECTION (MUX)
;-----------------------------
; Multiplexer on - power
;
15: Do (P86)
  1: 43  Set Port 3 High

; Begin LVDT measurement loop (10 measurements)
;
16: Beginning of Loop (P87)
  1: 0   Delay
  2: 10  Loop Count

; Clock pulse - switch between ports LVDT's
;
17: Do (P86)
  1: 74  Pulse Port 4
; Delay between pulses for LVDT stabilization
;
18: Delay w/Opt Excitation (P22)
  1: 2 Ex Channel
  2: 0 Delay W/Ex (0.01 sec units)
  3: 1 Delay After Ex (0.01 sec units)
  4: 0 mV Excitation

; LVDT displacement voltage reading
; w/ mV to V conversion
;
; NOTE: F4 is used to add "--" (location incrementor)
in step 4.
;
19: Volt (Diff) (P2)
  1: 1 Reps
  2: 45 5000 mV, 60 Hz Reject, Fast Range
  3: 10 DIFF Channel
  4: 24 -- Loc [ LVDT_1_V ]
  5: .001 Mult
  6: 0.0 Offset

; End loop
;
20: End (P95)

; Multiplexer off
;
21: Do (P86)
  1: 53 Set Port 3 Low

-------------
; LVDT Factory Calibration (V/in)
;
; LVDT #1
;
22: Z=F x 10^n (P30)
  1: 9.932 F
  2: 0 n, Exponent of 10
  3: 14 Z Loc [ CALIBRATION_1 ]

; LVDT #2
;
23: Z=F x 10^n (P30)
  1: 9.959 F
  2: 00 n, Exponent of 10
  3: 15 Z Loc [ CALIBRATION_2 ]

; LVDT #3
;
24: Z=F x 10^n (P30)
  1: 9.926 F
  2: 00 n, Exponent of 10
  3: 16 Z Loc [ CALIBRATION_3 ]

; LVDT #4
;
25: Z=F x 10^n (P30)
1: 9.914  F
2: 00   n, Exponent of 10
3: 17   Z Loc [ CALIBRATION_4 ]

; LVDT #5
;
26: Z=F x 10^n (P30)
1: 9.875  F
2: 00   n, Exponent of 10
3: 18   Z Loc [ CALIBRATION_5 ]

; LVDT #6
;
27: Z=F x 10^n (P30)
1: 9.938  F
2: 00   n, Exponent of 10
3: 19   Z Loc [ CALIBRATION_6 ]

; LVDT #7
;
28: Z=F x 10^n (P30)
1: 9.885  F
2: 00   n, Exponent of 10
3: 20   Z Loc [ CALIBRATION_7 ]

; LVDT #8
;
29: Z=F x 10^n (P30)
1: 9.980  F
2: 00   n, Exponent of 10
3: 21   Z Loc [ CALIBRATION_8 ]

; LVDT #9
;
30: Z=F x 10^n (P30)
1: 9.918  F
2: 00   n, Exponent of 10
3: 22   Z Loc [ CALIBRATION_9 ]

; LVDT #10
;
31: Z=F x 10^n (P30)
1: 9.926  F
2: 00   n, Exponent of 10
3: 23   Z Loc [ CALIBRATION_10 ]

----------
LVDT Reading (V) / Calibration Factor (V/in)
= Linear Displacement (in)

; LVDT #1
32: Z=X/Y (P38)
1: 24 X Loc [ LVDT_1_V ]
2: 14 Y Loc [ CALIBRATION_1 ]
3: 34 Z Loc [ LVDT_1_IN ]

; LVDT #2
;
33: Z=X/Y (P38)
1: 25 X Loc [ LVDT_2_V ]
2: 15 Y Loc [ CALIBRATION_2 ]
3: 35 Z Loc [ LVDT_2_IN ]

; LVDT #3
;
34: Z=X/Y (P38)
1: 26 X Loc [ LVDT_3_V ]
2: 16 Y Loc [ CALIBRATION_3 ]
3: 36 Z Loc [ LVDT_3_IN ]

; LVDT #4
;
35: Z=X/Y (P38)
1: 27 X Loc [ LVDT_4_V ]
2: 17 Y Loc [ CALIBRATION_4 ]
3: 37 Z Loc [ LVDT_4_IN ]

; LVDT #5
;
36: Z=X/Y (P38)
1: 28 X Loc [ LVDT_5_V ]
2: 18 Y Loc [ CALIBRATION_5 ]
3: 38 Z Loc [ LVDT_5_IN ]

; LVDT #6
;
37: Z=X/Y (P38)
1: 29 X Loc [ LVDT_6_V ]
2: 19 Y Loc [ CALIBRATION_6 ]
3: 39 Z Loc [ LVDT_6_IN ]

; LVDT #7
;
38: Z=X/Y (P38)
1: 30 X Loc [ LVDT_7_V ]
2: 20 Y Loc [ CALIBRATION_7 ]
3: 40 Z Loc [ LVDT_7_IN ]

; LVDT #8
;
39: Z=X/Y (P38)
1: 31 X Loc [ LVDT_8_V ]
2: 21 Y Loc [ CALIBRATION_8 ]
3: 41 Z Loc [ LVDT_8_IN ]

; LVDT #9
;
40: Z=X/Y (P38)
1: 32 X Loc [ LVDT_9_V ]
2: 22 Y Loc [ CALIBRATION_9 ]
3: 42 Z Loc [ LVDT_9_IN ]

; LVDT #10
;
41: Z=X/Y (P38)
1: 33 X Loc [ LVDT_10_V ]
2: 23 Y Loc [ CALIBRATION_10 ]
3: 43 Z Loc [ LVDT_10_IN ]

;--------
; Average reading
;
; LVDT 1 & 2 = Sample 1
42: Z=X+Y (P33)
1: 34 X Loc [ LVDT_1_IN ]
2: 35 Y Loc [ LVDT_2_IN ]
3: 44 Z Loc [ SMP_1_AVG_IN ]

43: Z=X*F (P37)
1: 44 X Loc [ SMP_1_AVG_IN ]
2: .5 F
3: 44 Z Loc [ SMP_1_AVG_IN ]

; LVDT 3 & 4 = Sample 2
44: Z=X+Y (P33)
1: 36 X Loc [ LVDT_3_IN ]
2: 37 Y Loc [ LVDT_4_IN ]
3: 45 Z Loc [ SMP_2_AVG_IN ]

45: Z=X*F (P37)
1: 45 X Loc [ SMP_2_AVG_IN ]
2: .5 F
3: 45 Z Loc [ SMP_2_AVG_IN ]

; LVDT 5 & 6 = Sample 3
46: Z=X+Y (P33)
1: 38 X Loc [ LVDT_5_IN ]
2: 39 Y Loc [ LVDT_6_IN ]
3: 46 Z Loc [ SMP_3_AVG_IN ]

47: Z=X*F (P37)
1: 46 X Loc [ SMP_3_AVG_IN ]
2: .5 F
3: 46 Z Loc [ SMP_3_AVG_IN ]

; LVDT 7 & 8 = Sample 4
48: Z=X+Y (P33)
1: 40 X Loc [ LVDT_7_IN ]
2: 41 Y Loc [ LVDT_8_IN ]
3: 47 Z Loc [ SMP_4_AVG_IN ]

49: Z=X*F (P37)
1: 47 X Loc [ SMP_4_AVG_IN ]
2: 5 F
3: 47 Z Loc [ SMP_4_AVG_IN ]

; LVDT 9 & 10 = Sample 5
50: Z=X+Y (P33)
1: 42 X Loc [ LVDT_9_IN ]
2: 43 Y Loc [ LVDT_10_IN ]
3: 48 Z Loc [ SMP_5_AVG_IN ]

51: Z=X*F (P37)
1: 48 X Loc [ SMP_5_AVG_IN ]
2: 5 F
3: 48 Z Loc [ SMP_5_AVG_IN ]

; ----------------------------------------
; LOAD CELL SECTION
; ----------------------------------------
; Load cell reading
;
52: Full Bridge (P6)
1: 1 Reps
2: 11 10 mV, Fast Range
3: 12 DIFF Channel
4: 1 Excite all reps w/Exchan 1
5: 5000 mV Excitation
6: 6 Loc [ LOAD_CELL_1_LB ]
7: -26444 Mult
8: -153.49 Offset

; ----------------------------------------
; PRESSURE SECTION (PUMP & RAMS)
; ----------------------------------------
; Pressure output
; (3000 psi / 2 V) * (1 V / 1000 mV) = 1.5 psi/mV
;
53: Volt (Diff) (P2)
1: 1 Reps
2: 15 5000 mV, Fast Range
3: 6 DIFF Channel
4: 7 Loc [ PRESSURE_PSIG ]
5: 1.5 Mult
6: 0.0 Offset

; -----------
; Convert pressure into force using ram's effective area
; = 7.22 in^2
;
54: Z=X*F (P37)
1: 7 X Loc [ PRESSURE_PSIG ]
2: 7.22 F
3: 8 Z Loc [ RAM_FORCE1_LB ]

; ----------------------------------------
; BATTERY MONITOR SECTION
Monitor battery voltage

55: Batt Voltage (P10)
1: 13 Loc [ BAT_VOLTAGE_V ]

--DATA COLLECTION SECTION--

Collect data and put into table format

56: Data Table (P84)^27244
1: 0 Seconds into Interval
2: 0.0 ______
3: 0.0 (0 = auto allocate, -x = redirect to inloc x)
4: EpoxyRebarData1 Table Name

; High resolution enabled (5 character)

57: Resolution (P78)
1: 1 High Resolution

; Store average into table

58: Average (P71)^25775
1: 13 Reps
2: 1 Loc [ PANEL_TEMP_C ]

59: Average (P71)^1908
1: 15 Reps
2: 34 Loc [ LVDT_1_IN ]

Collects data every 3 seconds and stores into limited storage.
8 hours of data collected, but will continue to display results w/o storing.

Table 2 Program
01: 3 Execution Interval (seconds)

--TEMPERATURE SECTION--

Reference temperature

1: Panel Temperature (P17)
1: 1 Loc [ PANEL_TEMP_C ]

; Convert reference temp from C to F

2: Z=X*F (P37)
1: 1 X Loc [ PANEL_TEMP_C ]
2: 1.8 F
3: 2 Z Loc [ PANEL_TEMP_F ]
<p>| | | | | | | | | | | | |</p>
<table>
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</thead>
</table>

; CONCRETE 1
; Thermocouple 1 temp in F
;
4: Thermocouple Temp (DIFF) (P14)
<p>| | | | | | | | | | | | |</p>
<table>
<thead>
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</thead>
<tbody>
<tr>
<td>1:</td>
<td>Reps</td>
<td>2:</td>
<td>10 mV, 60 Hz Reject, Slow Range</td>
<td>3:</td>
<td>DIFF Channel</td>
<td>4:</td>
<td>Type T (Copper-Constantan)</td>
<td>5:</td>
<td>Ref Temp (Deg. C) Loc [ PANEL_TEMP_C ]</td>
<td>6:</td>
<td>Loc [ C1_TEMP_F ]</td>
</tr>
</tbody>
</table>

; CONCRETE 2
; Thermocouple 2 temp in F
;
5: Thermocouple Temp (DIFF) (P14)
<p>| | | | | | | | | | | | |</p>
<table>
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</tr>
</thead>
<tbody>
<tr>
<td>1:</td>
<td>Reps</td>
<td>2:</td>
<td>10 mV, 60 Hz Reject, Slow Range</td>
<td>3:</td>
<td>DIFF Channel</td>
<td>4:</td>
<td>Type T (Copper-Constantan)</td>
<td>5:</td>
<td>Ref Temp (Deg. C) Loc [ PANEL_TEMP_C ]</td>
<td>6:</td>
<td>Loc [ C2_TEMP_F ]</td>
</tr>
</tbody>
</table>

; OUTSIDE
; Thermocouple 3 temp in F
;
6: Thermocouple Temp (DIFF) (P14)
<p>| | | | | | | | | | | | |</p>
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</tr>
</thead>
<tbody>
<tr>
<td>1:</td>
<td>Reps</td>
<td>2:</td>
<td>10 mV, 60 Hz Reject, Slow Range</td>
<td>3:</td>
<td>DIFF Channel</td>
<td>4:</td>
<td>Type T (Copper-Constantan)</td>
<td>5:</td>
<td>Ref Temp (Deg. C) Loc [ PANEL_TEMP_C ]</td>
<td>6:</td>
<td>Loc [ OUTSIDE_TEMP_F ]</td>
</tr>
</tbody>
</table>

; ENCLOSURE
; Thermocouple 4 temp in F
;
7: Thermocouple Temp (DIFF) (P14)
<p>| | | | | | | | | | | | |</p>
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</tr>
</thead>
<tbody>
<tr>
<td>1:</td>
<td>Reps</td>
<td>2:</td>
<td>10 mV, 60 Hz Reject, Slow Range</td>
<td>3:</td>
<td>DIFF Channel</td>
<td>4:</td>
<td>Type T (Copper-Constantan)</td>
<td>5:</td>
<td>Ref Temp (Deg. C) Loc [ PANEL_TEMP_C ]</td>
<td>6:</td>
<td>Loc [ BOX_TEMP_F ]</td>
</tr>
</tbody>
</table>
8: 32 Offset

; HMP45C TEMPERATURE AND RELATIVE HUMIDITY PROBE SECTION

; Temp/humidity probe on

8: Do (P86)
1: 41 Set Port 1 High

; Delay for probe stabilization

9: Delay w/Opt Excitation (P22)
1: 1 Ex Channel
2: 0 Delay W/Ex (0.01 sec units)
3: 15 Delay After Ex (0.01 sec units)
4: 0 mV Excitation

; Temp from probe

10: Volt (Diff) (P2)
1: 1 Reps
2: 24 1000 mV, 60 Hz Reject, Slow Range
3: 7 DIFF Channel
4: 3 Loc [ PROBE_TEMP_C ]
5: .1 Mult
6: -.4 Offset

; Relative humidity from probe

11: Volt (Diff) (P2)
1: 1 Reps
2: 24 1000 mV, 60 Hz Reject, Slow Range
3: 8 DIFF Channel
4: 5 Loc [ REL_HUMIDITY ]
5: .1 Mult
6: 0.0 Offset

; Probe off

12: Do (P86)
1: 51 Set Port 1 Low

; Convert probe temp from C to F

13: Z=X*F (P37)
1: 3 X Loc [ PROBE_TEMP_C ]
2: 1.8 F
3: 4 Z Loc [ PROBE_TEMP_F ]

14: Z=X+F (P34)
1: 4 X Loc [ PROBE_TEMP_F ]
2: 32 F
3: 4 Z Loc [ PROBE_TEMP_F ]
;--------------------------------------------------------------------------
; LVDT SECTION (MUX)
;--------------------------------------------------------------------------
; Multiplexer on - power
;
15: Do (P86)
  1: 43  Set Port 3 High

; Begin LVDT measurement loop (10 measurements)
;
16: Beginning of Loop (P87)
  1: 0  Delay
  2: 10  Loop Count

; Clock pulse - switch between ports LVDT's
;
17: Do (P86)
  1: 74  Pulse Port 4

; Delay between pulses for LVDT stabilization
;
18: Delay w/Opt Excitation (P22)
  1: 2  Ex Channel
  2: 0  Delay W/Ex (0.01 sec units)
  3: 1  Delay After Ex (0.01 sec units)
  4: 0  mV Excitation

; LVDT displacement voltage reading
; w/ mV to V conversion
;
; NOTE: F4 is used to add "--" (location incrementor)
; in step 4.
;
19: Volt (Diff) (P2)
  1: 1  Reps
  2: 45  5000 mV, 60 Hz Reject, Fast Range
  3: 10  DIFF Channel
  4: 24  -- Loc [ LVDT_1_V ]
  5: .001  Mult
  6: 0.0  Offset

; End loop
;
20: End (P95)

; Multiplexer off
;
21: Do (P86)
  1: 53  Set Port 3 Low

;----------------------
; LVDT Factory Calibration (V/in)
;
; LVDT #1
;
22: \( Z = F \times 10^n \) (P30)
1: 9.932 F
2: 0 n, Exponent of 10
3: 14 Z Loc [ CALIBRATION_1 ]

; LVDT #2
;
23: \( Z = F \times 10^n \) (P30)
1: 9.959 F
2: 00 n, Exponent of 10
3: 15 Z Loc [ CALIBRATION_2 ]

; LVDT #3
;
24: \( Z = F \times 10^n \) (P30)
1: 9.926 F
2: 00 n, Exponent of 10
3: 16 Z Loc [ CALIBRATION_3 ]

; LVDT #4
;
25: \( Z = F \times 10^n \) (P30)
1: 9.914 F
2: 00 n, Exponent of 10
3: 17 Z Loc [ CALIBRATION_4 ]

; LVDT #5
;
26: \( Z = F \times 10^n \) (P30)
1: 9.875 F
2: 00 n, Exponent of 10
3: 18 Z Loc [ CALIBRATION_5 ]

; LVDT #6
;
27: \( Z = F \times 10^n \) (P30)
1: 9.938 F
2: 00 n, Exponent of 10
3: 19 Z Loc [ CALIBRATION_6 ]

; LVDT #7
;
28: \( Z = F \times 10^n \) (P30)
1: 9.885 F
2: 00 n, Exponent of 10
3: 20 Z Loc [ CALIBRATION_7 ]

; LVDT #8
;
29: \( Z = F \times 10^n \) (P30)
1: 9.980 F
2: 00 n, Exponent of 10
3: 21 Z Loc [ CALIBRATION_8 ]

; LVDT #9
;
30: \( Z=F \times 10^n \) (P30)
1: 9.918 \( F \)
2: 00 \( n, \) Exponent of 10
3: 22 Z Loc [ CALIBRATION_9 ]

; LVDT #10
;
31: \( Z=F \times 10^n \) (P30)
1: 9.926 \( F \)
2: 00 \( n, \) Exponent of 10
3: 23 Z Loc [ CALIBRATION_10 ]

; -------------
; LVDT Reading (V) / Calibration Factor (V/in)
; = Linear Displacement (in)
;
; LVDT #1
;
32: \( Z=X/Y \) (P38)
1: 24 X Loc [ LVDT_1_V ]
2: 14 Y Loc [ CALIBRATION_1 ]
3: 34 Z Loc [ LVDT_1_IN ]

; LVDT #2
;
33: \( Z=X/Y \) (P38)
1: 25 X Loc [ LVDT_2_V ]
2: 15 Y Loc [ CALIBRATION_2 ]
3: 35 Z Loc [ LVDT_2_IN ]

; LVDT #3
;
34: \( Z=X/Y \) (P38)
1: 26 X Loc [ LVDT_3_V ]
2: 16 Y Loc [ CALIBRATION_3 ]
3: 36 Z Loc [ LVDT_3_IN ]

; LVDT #4
;
35: \( Z=X/Y \) (P38)
1: 27 X Loc [ LVDT_4_V ]
2: 17 Y Loc [ CALIBRATION_4 ]
3: 37 Z Loc [ LVDT_4_IN ]

; LVDT #5
;
36: \( Z=X/Y \) (P38)
1: 28 X Loc [ LVDT_5_V ]
2: 18 Y Loc [ CALIBRATION_5 ]
3: 38 Z Loc [ LVDT_5_IN ]

; LVDT #6
;
37: \( Z=X/Y \) (P38)
1: 29 X Loc [ LVDT_6_V ]

75
2: 19 Y Loc [ CALIBRATION_6 ]
3: 39 Z Loc [ LVDT_6_IN ]

; LVDT #7
;
38: Z=X/Y (P38)
1: 30 X Loc [ LVDT_7_V ]
2: 20 Y Loc [ CALIBRATION_7 ]
3: 40 Z Loc [ LVDT_7_IN ]

; LVDT #8
;
39: Z=X/Y (P38)
1: 31 X Loc [ LVDT_8_V ]
2: 21 Y Loc [ CALIBRATION_8 ]
3: 41 Z Loc [ LVDT_8_IN ]

; LVDT #9
;
40: Z=X/Y (P38)
1: 32 X Loc [ LVDT_9_V ]
2: 22 Y Loc [ CALIBRATION_9 ]
3: 42 Z Loc [ LVDT_9_IN ]

; LVDT #10
;
41: Z=X/Y (P38)
1: 33 X Loc [ LVDT_10_V ]
2: 23 Y Loc [ CALIBRATION_10 ]
3: 43 Z Loc [ LVDT_10_IN ]

; Average reading
;
; LVDT 1 & 2 = Sample 1
42: Z=X+Y (P33)
1: 34 X Loc [ LVDT_1_IN ]
2: 35 Y Loc [ LVDT_2_IN ]
3: 44 Z Loc [ SMP_1_AVG_IN ]

43: Z=X*F (P37)
1: 44 X Loc [ SMP_1_AVG_IN ]
2: .5 F
3: 44 Z Loc [ SMP_1_AVG_IN ]

; LVDT 3 & 4 = Sample 2
44: Z=X+Y (P33)
1: 36 X Loc [ LVDT_3_IN ]
2: 37 Y Loc [ LVDT_4_IN ]
3: 45 Z Loc [ SMP_2_AVG_IN ]

45: Z=X*F (P37)
1: 45 X Loc [ SMP_2_AVG_IN ]
2: .5 F
3: 45 Z Loc [ SMP_2_AVG_IN ]
; LVDT 5 & 6 = Sample 3
46: Z=X+Y (P33)
   1: 38 X Loc [ LVDT_5_IN ]
   2: 39 Y Loc [ LVDT_6_IN ]
   3: 46 Z Loc [ SMP_3_AVG_IN ]

47: Z=X*F (P37)
   1: 46 X Loc [ SMP_3_AVG_IN ]
   2: .5 F
   3: 46 Z Loc [ SMP_3_AVG_IN ]

; LVDT 7 & 8 = Sample 4
48: Z=X+Y (P33)
   1: 40 X Loc [ LVDT_7_IN ]
   2: 41 Y Loc [ LVDT_8_IN ]
   3: 47 Z Loc [ SMP_4_AVG_IN ]

49: Z=X*F (P37)
   1: 47 X Loc [ SMP_4_AVG_IN ]
   2: .5 F
   3: 47 Z Loc [ SMP_4_AVG_IN ]

; LVDT 9 & 10 = Sample 5
50: Z=X+Y (P33)
   1: 42 X Loc [ LVDT_9_IN ]
   2: 43 Y Loc [ LVDT_10_IN ]
   3: 48 Z Loc [ SMP_5_AVG_IN ]

51: Z=X*F (P37)
   1: 48 X Loc [ SMP_5_AVG_IN ]
   2: .5 F
   3: 48 Z Loc [ SMP_5_AVG_IN ]

; ------------------------------------------
; CELL SECTION
; ------------------------------------------

52: Full Bridge (P6)
   1: 1 Reps
   2: 11 10 mV, Fast Range
   3: 12 DIFF Channel
   4: 1 Excite all reps w/Exchan 1
   5: 5000 mV Excitation
   6: 6 Loc [ LOAD_CELL_1_LB ]
   7: -26444 Mult
   8: -153.49 Offset

; ------------------------------------------
; PRESSURE SECTION (PUMP & RAMS)
; ------------------------------------------
; Pressure output
; When digital indicator is set to 0 - 3000 psi,
; the output is 1500 PSI/V
; (3000 psi / 2 V) * (1 V / 1000 mV) = 1.5 psi/mV
; 53: Volt (Diff) (P2)
  1: 1 Reps
  2: 15 5000 mV, Fast Range
  3: 6 DIFF Channel
  4: 7 Loc [ PRESSURE_PSIG ]
  5: 1.5 Mult
  6: 0.0 Offset

; Convert pressure into force using ram's effective area
; = 7.22 in^2
;
; 54: Z=X*F (P37)
  1: 7 X Loc [ PRESSURE_PSIG ]
  2: 7.22 F
  3: 8 Z Loc [ RAM_FORCE1_LB ]

; BATTERY MONITOR SECTION
; Monitor battery voltage
;
; 55: Batt Voltage (P10)
  1: 13 Loc [ BAT_VOLTAGE_V ]

; DATA COLLECTION SECTION
; Collect data and put into table format.
; Only 9600 records (8 hours) will be stored to conserve
; memory space.
;
; 56: If (X<>F) (P89)
  1: 49 X Loc [ COUNTER ]
  2: 4 <
  3: 9600 F
  4: 30 Then Do

; High resolution enabled (5 character)
;
; 57: Data Table (P84)^27244
  1: 0 Seconds into Interval
  2: 0.0 _____
  3: 0 (0 = auto allocate, -x = redirect to inloc x)
  4: EpoxyRebarData2 Table Name

; Store InLoc 1-13
;
; 58: Resolution (P78)
  1: 1 High Resolution

; 59: Average (P71)^25775
  1: 13 Reps
  2: 1 Loc [ PANEL_TEMP_C ]
; Store LVDT displacement
;
60: Average (P71)^25355
   1:  15   Reps
   2:  34   Loc [ LVDT_1_IN ]

; Increment counter by 1
;
61: Z=Z+1 (P32)
   1:  49   Z Loc [ COUNTER ]

62: End (P95)

*Table 3 Subroutines

End Program
B.2 Creep Program After Initial 8 Hours

; (CR23X-TD)
; Epoxy Bonded Dowel Project
;
; This program collects data from thermocouples, temp/humidity
; probe, load cell, & pump digital gauge. Two tables have been
; set-up. Table 1 collects and stores data every hour, while
; Table 2 collects every 3 seconds without storing data.
;
; **This version is for 2 concrete thermocouples.**

******************** TABLE 1 *******************************

; Collects data every hour and stores into final storage
;
*Table 1 Program
01: 3600 Execution Interval (seconds)

***************************************************** TEMPERATURE SECTION *****************************************************

; Reference temperature
;
1: Panel Temperature (P17)
1: 1 Loc [ PANEL_TEMP_C ]

; Convert reference temp from C to F
;
2: Z=X*F (P37)
1: 1 X Loc [ PANEL_TEMP_C ]
2: 1.8 F
3: 2 Z Loc [ PANEL_TEMP_F ]

3: Z=X+F (P34)
1: 2 X Loc [ PANEL_TEMP_F ]
2: 32 F
3: 2 Z Loc [ PANEL_TEMP_F ]

; CONCRETE 1
; Thermocouple 1 temp in F
;
4: Thermocouple Temp (DIFF) (P14)
1: 1 Reps
2: 21 10 mV, 60 Hz Reject, Slow Range
3: 1 DIFF Channel
4: 1 Type T (Copper-Constantan)
5: 1 Ref Temp (Deg. C) Loc [ PANEL_TEMP_C ]
6: 9 Loc [ C1_TEMP_F ]
7: 1.8 Mult
8: 32 Offset

; CONCRETE 2
; Thermocouple 2 temp in F
;
5: Thermocouple Temp (DIFF) (P14)
  1: 1 Reps
  2: 21 10 mV, 60 Hz Reject, Slow Range
  3: 2 DIFF Channel
  4: 1 Type T (Copper-Constantan)
  5: 1 Ref Temp (Deg. C) Loc [ PANEL_TEMP_C ]
  6: 10 Loc [ C2_TEMP_F ]
  7: 1.8 Mult
  8: 32 Offset

; OUTSIDE
; Thermocouple 3 temp in F
;
6: Thermocouple Temp (DIFF) (P14)
  1: 1 Reps
  2: 21 10 mV, 60 Hz Reject, Slow Range
  3: 3 DIFF Channel
  4: 1 Type T (Copper-Constantan)
  5: 1 Ref Temp (Deg. C) Loc [ PANEL_TEMP_C ]
  6: 11 Loc [ OUTSIDE_TEMP_F ]
  7: 1.8 Mult
  8: 32 Offset

; ENCLOSURE
; Thermocouple 4 temp in F
;
7: Thermocouple Temp (DIFF) (P14)
  1: 1 Reps
  2: 21 10 mV, 60 Hz Reject, Slow Range
  3: 4 DIFF Channel
  4: 1 Type T (Copper-Constantan)
  5: 1 Ref Temp (Deg. C) Loc [ PANEL_TEMP_C ]
  6: 12 Loc [ BOX_TEMP_F ]
  7: 1.8 Mult
  8: 32 Offset

;---------------------------
; HMP45C TEMPERATURE AND RELATIVE HUMIDITY PROBE SECTION
;---------------------------
; Temp/humidity probe on
;
8: Do (P86)
  1: 41 Set Port 1 High

; Delay for probe stabilization
;
9: Delay w/Opt Excitation (P22)
  1: 1 Ex Channel
  2: 0 Delay W/Ex (0.01 sec units)
  3: 15 Delay After Ex (0.01 sec units)
  4: 0 mV Excitation

; Temp from probe
;
10: Volt (Diff) (P2)
  1: 1 Reps
2: 24 1000 mV, 60 Hz Reject, Slow Range
3: 7 DIFF Channel
4: 3 Loc [ PROBE_TEMP_C ]
5: 1 Mult
6: -40 Offset

; Relative humidity from probe
;
11: Volt (Diff) (P2)
  1: 1 Reps
  2: 24 1000 mV, 60 Hz Reject, Slow Range
  3: 8 DIFF Channel
  4: 5 Loc [ REL_HUMIDITY ]
  5: 1 Mult
  6: 0.0 Offset

; Probe off
;
12: Do (P86)
  1: 51 Set Port 1 Low

;---------------------
; Convert probe temp from C to F
;
13: Z=X*F (P37)
  1: 3 X Loc [ PROBE_TEMP_C ]
  2: 1.8 F
  3: 4 Z Loc [ PROBE_TEMP_F ]

14: Z=X+F (P34)
  1: 4 X Loc [ PROBE_TEMP_F ]
  2: 32 F
  3: 4 Z Loc [ PROBE_TEMP_F ]

;---------------------
; LVDT SECTION (MUX)
;---------------------
; Multiplexer on - power
;
15: Do (P86)
  1: 43 Set Port 3 High

; Begin LVDT measurement loop (10 measurements)
;
16: Beginning of Loop (P87)
  1: 0 Delay
  2: 10 Loop Count

; Clock pulse - switch between ports LVDT's
;
17: Do (P86)
  1: 74 Pulse Port 4

; Delay between pulses for LVDT stabilization
;
18: Delay w/Opt Excitation (P22)
1: 2  Ex Channel
2: 0  Delay W/Ex (0.01 sec units)
3: 1  Delay After Ex (0.01 sec units)
4: 0  mV Excitation

; LVDT displacement voltage reading
; w/ mV to V conversion
;
; NOTE: F4 is used to add "--" (location incrementor)
; in step 4.
;
19: Volt (Diff) (P2)
  1: 1  Reps
  2: 45  5000 mV, 60 Hz Reject, Fast Range
  3: 10  DIFF Channel
  4: 24  -- Loc [ LVDT_1_V ]
  5: .001  Mult
  6: 0.0  Offset

; End loop
;
20: End (P95)
;
; Multiplexer off
;
21: Do (P86)
  1: 53  Set Port 3 Low

;-----------------
; LVDT Factory Calibration (V/in)
;
; LVDT #1
;
22: Z=F x 10^n (P30)
  1: 9.932  F
  2: 0  n, Exponent of 10
  3: 14  Z Loc [ CALIBRATION_1 ]

; LVDT #2
;
23: Z=F x 10^n (P30)
  1: 9.959  F
  2: 15  n, Exponent of 10
  3: 15  Z Loc [ CALIBRATION_2 ]

; LVDT #3
;
24: Z=F x 10^n (P30)
  1: 9.926  F
  2: 00  n, Exponent of 10
  3: 16  Z Loc [ CALIBRATION_3 ]

; LVDT #4
;
25: Z=F x 10^n (P30)
1: 9.914  F
2: 00    n, Exponent of 10
3: 17    Z Loc [ CALIBRATION_4 ]

; LVDT #5
;
26: Z=F x 10^n (P30)
1: 9.875  F
2: 00    n, Exponent of 10
3: 18    Z Loc [ CALIBRATION_5 ]

; LVDT #6
;
27: Z=F x 10^n (P30)
1: 9.938  F
2: 00    n, Exponent of 10
3: 19    Z Loc [ CALIBRATION_6 ]

; LVDT #7
;
28: Z=F x 10^n (P30)
1: 9.885  F
2: 00    n, Exponent of 10
3: 20    Z Loc [ CALIBRATION_7 ]

; LVDT #8
;
29: Z=F x 10^n (P30)
1: 9.980  F
2: 00    n, Exponent of 10
3: 21    Z Loc [ CALIBRATION_8 ]

; LVDT #9
;
30: Z=F x 10^n (P30)
1: 9.918  F
2: 00    n, Exponent of 10
3: 22    Z Loc [ CALIBRATION_9 ]

; LVDT #10
;
31: Z=F x 10^n (P30)
1: 9.926  F
2: 00    n, Exponent of 10
3: 23    Z Loc [ CALIBRATION_10 ]

;----------
; LVDT Reading (V) / Calibration Factor (V/in)
; = Linear Displacement (in)
;
; LVDT #1
;
32: Z=X/Y (P38)
1: 24    X Loc [ LVDT_1_V ]
2: 14    Y Loc [ CALIBRATION_1 ]

84
<table>
<thead>
<tr>
<th>Line</th>
<th>X Loc</th>
<th>Y Loc</th>
<th>Z Loc</th>
</tr>
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<td>LVDT_1_IN</td>
<td></td>
<td></td>
</tr>
<tr>
<td>33:</td>
<td>Z=X/Y (P38)</td>
<td>1: 25</td>
<td>2: 15</td>
</tr>
<tr>
<td></td>
<td>LVDT_2_V</td>
<td>LVDT_2_IN</td>
<td>LVDT_2_IN</td>
</tr>
<tr>
<td>34:</td>
<td>Z=X/Y (P38)</td>
<td>1: 26</td>
<td>2: 16</td>
</tr>
<tr>
<td></td>
<td>LVDT_3_V</td>
<td>LVDT_3_IN</td>
<td>LVDT_3_IN</td>
</tr>
<tr>
<td>35:</td>
<td>Z=X/Y (P38)</td>
<td>1: 27</td>
<td>2: 17</td>
</tr>
<tr>
<td></td>
<td>LVDT_4_V</td>
<td>CALIBRATION_3</td>
<td>CALIBRATION_3</td>
</tr>
<tr>
<td>36:</td>
<td>Z=X/Y (P38)</td>
<td>1: 28</td>
<td>2: 18</td>
</tr>
<tr>
<td></td>
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<td>CALIBRATION_5</td>
<td>CALIBRATION_5</td>
</tr>
<tr>
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<td>Z=X/Y (P38)</td>
<td>1: 29</td>
<td>2: 19</td>
</tr>
<tr>
<td></td>
<td>LVDT_6_V</td>
<td>CALIBRATION_6</td>
<td>CALIBRATION_6</td>
</tr>
<tr>
<td>38:</td>
<td>Z=X/Y (P38)</td>
<td>1: 30</td>
<td>2: 20</td>
</tr>
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<td>CALIBRATION_7</td>
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<td>Z=X/Y (P38)</td>
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<td>2: 21</td>
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<td>CALIBRATION_8</td>
<td>CALIBRATION_8</td>
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<td>Z=X/Y (P38)</td>
<td>1: 32</td>
<td>2: 22</td>
</tr>
<tr>
<td></td>
<td>LVDT_9_V</td>
<td>CALIBRATION_9</td>
<td></td>
</tr>
</tbody>
</table>
3: 42  Z Loc [ LVDT_9_IN ]

; LVDT #10
;
41:  Z=X/Y (P38)
1:  33  X Loc [ LVDT_10_V ]
2:  23  Y Loc [ CALIBRATION_10 ]
3:  43  Z Loc [ LVDT_10_IN ]

; ---------
; Average reading
;
; LVDT 1 & 2 = Sample 1
42:  Z=X+Y (P33)
1:  34  X Loc [ LVDT_1_IN ]
2:  35  Y Loc [ LVDT_2_IN ]
3:  44  Z Loc [ S1_AVG_IN ]

43:  Z=X*F (P37)
1:  44  X Loc [ S1_AVG_IN ]
2:  .5  F
3:  44  Z Loc [ S1_AVG_IN ]

; LVDT 3 & 4 = Sample 2
44:  Z=X+Y (P33)
1:  36  X Loc [ LVDT_3_IN ]
2:  37  Y Loc [ LVDT_4_IN ]
3:  45  Z Loc [ S2_AVG_IN ]

45:  Z=X*F (P37)
1:  45  X Loc [ S2_AVG_IN ]
2:  .5  F
3:  45  Z Loc [ S2_AVG_IN ]

; LVDT 5 & 6 = Sample 3
46:  Z=X+Y (P33)
1:  38  X Loc [ LVDT_5_IN ]
2:  39  Y Loc [ LVDT_6_IN ]
3:  46  Z Loc [ S3_AVG_IN ]

47:  Z=X*F (P37)
1:  46  X Loc [ S3_AVG_IN ]
2:  .5  F
3:  46  Z Loc [ S3_AVG_IN ]

; LVDT 7 & 8 = Sample 4
48:  Z=X+Y (P33)
1:  40  X Loc [ LVDT_7_IN ]
2:  41  Y Loc [ LVDT_8_IN ]
3:  47  Z Loc [ S4_AVG_IN ]

49:  Z=X*F (P37)
1:  47  X Loc [ S4_AVG_IN ]
2:  .5  F
3:  47  Z Loc [ S4_AVG_IN ]
; LVDT 9 & 10 = Sample 5
50: Z=X+Y (P33)
  1: 42  X Loc [ LVDT_9_IN ]
  2: 43  Y Loc [ LVDT_10_IN ]
  3: 48  Z Loc [ S5_AVG_IN ]

51: Z=X*F (P37)
  1: 48  X Loc [ S5_AVG_IN ]
  2: .5  F
  3: 48  Z Loc [ S5_AVG_IN ]

; ---------
; Total displacement

; Sample 1
52: Z=X+F (P34)
  1: 44  X Loc [ S1_AVG_IN ]
  2: -.026186 F
  3: 49  Z Loc [ S1_TOT_DISP ]

; Sample 2
53: Z=X+F (P34)
  1: 45  X Loc [ S2_AVG_IN ]
  2: -.011948 F
  3: 50  Z Loc [ S2_TOT_DISP ]

; Sample 3
54: Z=X+F (P34)
  1: 46  X Loc [ S3_AVG_IN ]
  2: -.022722 F
  3: 51  Z Loc [ S3_TOT_DISP ]

; Sample 4
55: Z=X+F (P34)
  1: 47  X Loc [ S4_AVG_IN ]
  2: -.025067 F
  3: 52  Z Loc [ S4_TOT_DISP ]

; Sample 5
56: Z=X+F (P34)
  1: 48  X Loc [ S5_AVG_IN ]
  2: -.12509  F
  3: 53  Z Loc [ S5_TOT_DISP ]

; ----------------------------------------
; LOAD CELL SECTION
; ----------------------------------------
; Load cell reading
;
57: Full Bridge (P6)
  1: 1  Reps
  2: 11 10 mV, Fast Range
  3: 12  DIFF Channel
  4: 1  Excite all reps w/Exchan 1
5: 5000 mV Excitation
6: 6 Loc [ LOAD_CELL_1_LB ]
7: -26444 Mult
8: -153.49 Offset

; PRESSURE SECTION (PUMP & RAMS)
; Pressures output
; (3000 psi / 2 V) * (1 V / 1000 mV) = 1.5 psi/mV

58: Volt (Diff) (P2)
1: 1 Reps
2: 15 5000 mV, Fast Range
3: 6 DIFF Channel
4: 7 Loc [ PRESSURE_PSIG ]
5: 1.5 Mult
6: 0.0 Offset

; Convert pressure into force using ram's effective area
; = 7.22 in^2

59: Z=X*F (P37)
1: 7 X Loc [ PRESSURE_PSIG ]
2: 7.22 F
3: 8 Z Loc [ RAM_FORCE1_LB ]

; BATTERY MONITOR SECTION
; Monitor battery voltage

60: Batt Voltage (P10)
1: 13 Loc [ BAT_VOLTAGE_V ]

; DATA COLLECTION SECTION
; Collect data and put into table format

61: Data Table (P84)^27244
1: 0 Seconds into Interval
2: 0.0 _____
3: 0.0 (0 = auto allocate, -x = redirect to inloc x)
4: EpoxyRebarData1 Table Name

; High resolution enabled (5 character)

62: Resolution (P78)
1: 1 High Resolution

; Store average into table

63: Average (P71)^25775
1: 13 Reps
2: 1 Loc [ PANEL_TEMP_C ]

64: Average (P71)²342
1: 20 Reps
2: 34 Loc [ LVDT_1_IN ]

: *********************** TABLE 2 ***********************

; Collects data every 3 seconds and stores into limited storage.
; 8 hours of data collected, but will continue to update w/o storing.

*Table 2 Program
01: 3 Execution Interval (seconds)

: -----------------------------------------------
: TEMPERATURE SECTION
: -----------------------------------------------

; Reference temperature

1: Panel Temperature (P17)
1: 1 Loc [ PANEL_TEMP_C ]

; Convert reference temp from C to F

2: Z=X+F (P37)
1: 1 X Loc [ PANEL_TEMP_C ]
2: 1.8 F
3: 2 Z Loc [ PANEL_TEMP_F ]

3: Z=X+F (P34)
1: 2 X Loc [ PANEL_TEMP_F ]
2: 32 F
3: 2 Z Loc [ PANEL_TEMP_F ]

: CONCRETE 1
: Thermocouple 1 temp in F

4: Thermocouple Temp (DIFF) (P14)
1: 1 Reps
2: 21 10 mV, 60 Hz Reject, Slow Range
3: 1 DIFF Channel
4: 1 Type T (Copper-Constantan)
5: 1 Ref Temp (Deg. C) Loc [ PANEL_TEMP_C ]
6: 9 Loc [ C1_TEMP_F ]
7: 1.8 Mult
8: 32 Offset

: CONCRETE 2
: Thermocouple 2 temp in F

5: Thermocouple Temp (DIFF) (P14)
1: 1 Reps
2: 21 10 mV, 60 Hz Reject, Slow Range
3: 2 DIFF Channel
4: 1 Type T (Copper-Constantan)
5: 1 Ref Temp (Deg. C) Loc [ PANEL_TEMP_C ]
6: 10 Loc [ C2_TEMP_F ]
7: 1.8 Mult
8: 32 Offset

; OUTSIDE
; Thermocouple 3 temp in F
;
6: Thermocouple Temp (DIFF) (P14)
1: 1 Reps
2: 21 10 mV, 60 Hz Reject, Slow Range
3: 3 DIFF Channel ;
4: 1 Type T (Copper-Constantan)
5: 1 Ref Temp (Deg. C) Loc [ PANEL_TEMP_C ]
6: 11 Loc [ OUTSIDE_TEMP_F ]
7: 1.8 Mult
8: 32 Offset

; ENCLOSURE
; Thermocouple 4 temp in F
;
7: Thermocouple Temp (DIFF) (P14)
1: 1 Reps
2: 21 10 mV, 60 Hz Reject, Slow Range
3: 3 DIFF Channel
4: 1 Type T (Copper-Constantan)
5: 1 Ref Temp (Deg. C) Loc [ PANEL_TEMP_C ]
6: 12 Loc [ BOX_TEMP_F ]
7: 1.8 Mult
8: 32 Offset

; HMP45C TEMPERATURE AND RELATIVE HUMIDITY PROBE SECTION
; Temp/humidity probe on
;
8: Do (P86)
1: 41 Set Port 1 High

; Delay for probe stabilization
;
9: Delay w/Opt Excitation (P22)
1: 1 Ex Channel
2: 0 Delay W/Ex (0.01 sec units)
3: 15 Delay After Ex (0.01 sec units)
4: 0 mV Excitation

; Temp from probe
;
10: Volt (Diff) (P2)
1: 1 Reps
2: 24 1000 mV, 60 Hz Reject, Slow Range
3: 7 DIFF Channel
4: 3 Loc [ PROBE_TEMP_C ]
5: .1 Mult
6: -40 Offset

; Relative humidity from probe

11: Volt (Diff) (P2)
1: 1 Reps
2: 24 1000 mV, 60 Hz Reject, Slow Range
3: 8 DIFF Channel
4: 5 Loc [ REL_HUMIDITY ]
5: .1 Mult
6: 0.0 Offset

; Probe off

12: Do (P86)
1: 51 Set Port 1 Low

;---------
; Convert probe temp from C to F

13: Z=X*F (P37)
1: 3 X Loc [ PROBE_TEMP_C ]
2: 1.8 F
3: 4 Z Loc [ PROBE_TEMP_F ]

14: Z=X+F (P34)
1: 4 X Loc [ PROBE_TEMP_F ]
2: 32 F
3: 4 Z Loc [ PROBE_TEMP_F ]

;--------------------------------------------------------
; LVDT SECTION (MUX)
;--------------------------------------------------------
; Multiplexer on - power

15: Do (P86)
1: 43 Set Port 3 High

; Begin LVDT measurement loop (10 measurements)

16: Beginning of Loop (P87)
1: 0 Delay
2: 10 Loop Count

; Clock pulse - switch between ports LVDT's

17: Do (P86)
1: 74 Pulse Port 4

; Delay between pulses for LVDT stabilization

18: Delay w/Opt Excitation (P22)
1: 2 Ex Channel
2: 0 Delay W/Ex (0.01 sec units)
3: 1 Delay After Ex (0.01 sec units)
4: 0 mV Excitation
; LVDT displacement voltage reading
; w/ mV to V conversion
;
; NOTE: F4 is used to add "--" (location incrementor)
; in step 4.
;
19: Volt (Diff) (P2)
   1: 1   Reps
   2: 45  5000 mV, 60 Hz Reject, Fast Range
   3: 10  DIFF Channel
   4: 24  -- Loc [ LVDT_1_V ]
   5: .001  Mult
   6: 0.0  Offset

; End loop
;
20: End (P95)

; Multiplexer off
;
21: Do (P86)
   1: 53   Set Port 3 Low

;----------------
; LVDT Factory Calibration (V/in)
;
; LVDT #1
;
22: Z=F x 10^n (P30)
   1: 9.932  F
   2: 0       n, Exponent of 10
   3: 14      Z Loc [ CALIBRATION_1 ]

; LVDT #2
;
23: Z=F x 10^n (P30)
   1: 9.959  F
   2: 00      n, Exponent of 10
   3: 15      Z Loc [ CALIBRATION_2 ]

; LVDT #3
;
24: Z=F x 10^n (P30)
   1: 9.926  F
   2: 00      n, Exponent of 10
   3: 16      Z Loc [ CALIBRATION_3 ]

; LVDT #4
;
25: Z=F x 10^n (P30)
   1: 9.914  F
   2: 00      n, Exponent of 10
   3: 17      Z Loc [ CALIBRATION_4 ]
26: \( Z = F \times 10^n \) (P30)
   1: \( 9.875 \) F
   2: 00 \( n \), Exponent of 10
   3: 18 \( Z \) Loc [ CALIBRATION_5 ]

27: \( Z = F \times 10^n \) (P30)
   1: \( 9.938 \) F
   2: 00 \( n \), Exponent of 10
   3: 19 \( Z \) Loc [ CALIBRATION_6 ]

28: \( Z = F \times 10^n \) (P30)
   1: \( 9.885 \) F
   2: 00 \( n \), Exponent of 10
   3: 20 \( Z \) Loc [ CALIBRATION_7 ]

29: \( Z = F \times 10^n \) (P30)
   1: \( 9.980 \) F
   2: 00 \( n \), Exponent of 10
   3: 21 \( Z \) Loc [ CALIBRATION_8 ]

30: \( Z = F \times 10^n \) (P30)
   1: \( 9.918 \) F
   2: 00 \( n \), Exponent of 10
   3: 22 \( Z \) Loc [ CALIBRATION_9 ]

31: \( Z = F \times 10^n \) (P30)
   1: \( 9.926 \) F
   2: 00 \( n \), Exponent of 10
   3: 23 \( Z \) Loc [ CALIBRATION_10 ]

-----------

LVDT Reading (V) / Calibration Factor (V/in)
\( = \) Linear Displacement (in)

32: \( Z = X/Y \) (P38)
   1: 24 \( X \) Loc [ LVDT_1_V ]
   2: 14 \( Y \) Loc [ CALIBRATION_1 ]
   3: 34 \( Z \) Loc [ LVDT_1_IN ]

LVDT #2
33: Z=X/Y (P38)
1: 25 X Loc [LVDT_2_V]
2: 15 Y Loc [CALIBRATION_2]
3: 35 Z Loc [LVDT_2_IN]

; LVDT #3

34: Z=X/Y (P38)
1: 26 X Loc [LVDT_3_V]
2: 16 Y Loc [CALIBRATION_3]
3: 36 Z Loc [LVDT_3_IN]

; LVDT #4

35: Z=X/Y (P38)
1: 27 X Loc [LVDT_4_V]
2: 17 Y Loc [CALIBRATION_4]
3: 37 Z Loc [LVDT_4_IN]

; LVDT #5

36: Z=X/Y (P38)
1: 28 X Loc [LVDT_5_V]
2: 18 Y Loc [CALIBRATION_5]
3: 38 Z Loc [LVDT_5_IN]

; LVDT #6

37: Z=X/Y (P38)
1: 29 X Loc [LVDT_6_V]
2: 19 Y Loc [CALIBRATION_6]
3: 39 Z Loc [LVDT_6_IN]

; LVDT #7

38: Z=X/Y (P38)
1: 30 X Loc [LVDT_7_V]
2: 20 Y Loc [CALIBRATION_7]
3: 40 Z Loc [LVDT_7_IN]

; LVDT #8

39: Z=X/Y (P38)
1: 31 X Loc [LVDT_8_V]
2: 21 Y Loc [CALIBRATION_8]
3: 41 Z Loc [LVDT_8_IN]

; LVDT #9

40: Z=X/Y (P38)
1: 32 X Loc [LVDT_9_V]
2: 22 Y Loc [CALIBRATION_9]
3: 42 Z Loc [LVDT_9_IN]

; LVDT #10

41: Z=X/Y (P38)
   1: 33 X Loc [ LVDT_10_IN ]
   2: 23 Y Loc [ CALIBRATION_10 ]
   3: 43 Z Loc [ LVDT_10_IN ]

;----------
; Average reading
;

; LVDT 1 & 2 = Sample 1
42: Z=X+Y (P33)
   1: 34 X Loc [ LVDT_1_IN ]
   2: 35 Y Loc [ LVDT_2_IN ]
   3: 44 Z Loc [ S1_AVG_IN ]

43: Z=X*F (P37)
   1: 44 X Loc [ S1_AVG_IN ]
   2: .5 F
   3: 44 Z Loc [ S1_AVG_IN ]

; LVDT 3 & 4 = Sample 2
44: Z=X+Y (P33)
   1: 36 X Loc [ LVDT_3_IN ]
   2: 37 Y Loc [ LVDT_4_IN ]
   3: 45 Z Loc [ S2_AVG_IN ]

45: Z=X*F (P37)
   1: 45 X Loc [ S2_AVG_IN ]
   2: .5 F
   3: 45 Z Loc [ S2_AVG_IN ]

; LVDT 5 & 6 = Sample 3
46: Z=X+Y (P33)
   1: 38 X Loc [ LVDT_5_IN ]
   2: 39 Y Loc [ LVDT_6_IN ]
   3: 46 Z Loc [ S3_AVG_IN ]

47: Z=X*F (P37)
   1: 46 X Loc [ S3_AVG_IN ]
   2: .5 F
   3: 46 Z Loc [ S3_AVG_IN ]

; LVDT 7 & 8 = Sample 4
48: Z=X+Y (P33)
   1: 40 X Loc [ LVDT_7_IN ]
   2: 41 Y Loc [ LVDT_8_IN ]
   3: 47 Z Loc [ S4_AVG_IN ]

49: Z=X*F (P37)
   1: 47 X Loc [ S4_AVG_IN ]
   2: .5 F
   3: 47 Z Loc [ S4_AVG_IN ]

; LVDT 9 & 10 = Sample 5
50: Z=X+Y (P33)
   1: 42 X Loc [ LVDT_9_IN ]
; Total displacement

; Sample 1

52: Z=X+F (P34)
1: 44  X Loc [ S1_AVG_IN    ]
2: -.026186 F
3: 49  Z Loc [ S1_TOT_DISP  ]

; Sample 2

53: Z=X+F (P34)
1: 45  X Loc [ S2_AVG_IN    ]
2: -.011948 F
3: 50  Z Loc [ S2_TOT_DISP  ]

; Sample 3

54: Z=X+F (P34)
1: 46  X Loc [ S3_AVG_IN    ]
2: -.022722 F
3: 51  Z Loc [ S3_TOT_DISP  ]

; Sample 4

55: Z=X+F (P34)
1: 47  X Loc [ S4_AVG_IN    ]
2: -.025067 F
3: 52  Z Loc [ S4_TOT_DISP  ]

; Sample 5

56: Z=X+F (P34)
1: 48  X Loc [ S5_AVG_IN    ]
2: -.12509  F
3: 53  Z Loc [ S5_TOT_DISP  ]

; ---------------------------------------------------------------------
; LOAD CELL SECTION
; ---------------------------------------------------------------------
; Load cell reading
;
57: Full Bridge (P6)
1: 1  Reps
2: 11 10 mV, Fast Range
3: 12 DIFF Channel
4: 1 Excite all reps w/Exchan 1
5: 5000 mV Excitation
6: 6 Loc [ LOAD_CELL_1_LB ]
7: -26444 Mult
8: -153.49 Offset
PRESSURE SECTION (PUMP & RAMS)

Pressure output
When digital indicator is set to 0 - 3000 psi,
the output is 1500 PSI/V
(3000 psi / 2 V) * (1 V / 1000 mV) = 1.5 psi/mV

58: Volt (Diff) (P2)
1: 1 Reps
2: 15 5000 mV, Fast Range
3: 6  DIFF Channel
4: 7  Loc [ PRESSURE_PSIG ]
5: 1.5 Mult
6: 0.0 Offset

Convert pressure into force using ram's effective area
= 7.22 in^2

59: Z=X*F (P37)
1: 7  X Loc [ PRESSURE_PSIG ]
2: 7.22 F
3: 8  Z Loc [ RAM_FORCE1_LB ]

BATTERY MONITOR SECTION

Monitor battery voltage

60: Batt Voltage (P10)
1: 13 Loc [ BAT_VOLTAGE_V ]

*Table 3 Subroutines

End Program
Appendix C   Equipment Details

C.1   Rebar Puller Equipment
Figure C-1: Rebar Puller
Figure C-2: Hydraulic Pump for Rebar Puller
C.2 Rebar Gripper Details

Figure C-4: Rebar Gripper – Collar Details
Figure C-5: Rebar Gripper – Jaw Details

THREADED USING 0.75-10 UNC PROFILE ENTIRE BORE

$\Phi 0.790$

$\Phi 1.996$

$0.1559$

$0.1459$

$16^\circ$

$120^\circ$

$\Phi 1.525$

$0.25$

$2.25$

$\Phi (1.364)$

SECTION A-A

SEE O-RING GROOVE DETAIL

FULL RADIUS

BREAK EDGE (2 PLACES)

O-RING GROOVE DETAIL

SCALE 2X

HEAT TREAT TO ROCKWELL 53-57 C SCALE

NOTE: USE 2-129 O-RING (70 DUOMETER)

REVISION HISTORY

REV | DESCRIPTION | DATE | APPROVED
A  | RELEASED | 1-6-03 |
C.3 LVDT Bracket
C.3.1 Pullout and Seismic Bracket

Figure C-6: LVDT Bracket for Pullout and Seismic Testing – Front View

Figure C-7: LVDT Bracket for Pullout and Seismic Testing – Top View
Figure C-8: LVDT Bracket for Pullout and Seismic Testing – Side View

Figure C-9: LVDT Bracket for Pullout and Seismic Testing – 3D View
C.3.2 Creep Bracket

Critical Dimensions - MUST be equal

Figure C-10: LVDT Bracket for Creep Testing – Front View

Figure C-11: LVDT Bracket for Creep Testing – Top View
Figure C-12: LVDT Bracket for Creep Testing – Side View

Figure C-13: LVDT Bracket for Creep Testing – 3D View
**C.4 Creep Load Frame**

All 10 fixtures should be interchangeable for ease of re-assembly after storage.

![Creep Load Frame Diagram]

Figure C-14: Creep Load Frame

**C.5 Concrete Mover Cart**

Double pinned pivoting handle to allow up-down & left-right pivoting.

![Concrete Mover Cart Diagram]

Figure C-15: Cart – 3D View
Figure C-16: Cart – Side View

Handle pivots freely up-down & left-right and can be removed.
C.6 LVDT Breakout Box and Power Supply

Figure C-17: LVDT Breakout Box Schematic

- 10 twisted/shielded wire pairs, 10 feet long, 24 AWG, bundled, color coded, bare wire termination
- Big Plug Connector
- 110 VAC Power
- +/- signal twisted wire pairs
- +/- power twisted wire pairs
- Power Supply
  - 24-40 VDC
  - or
  - ±12±20 VDC
- Vents on side if needed
- Patch Cables from LVDT’s to box with plug connectors