# Bond Strength Between Layers of Shotcrete

A Thesis

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# I. Introduction

Shotcrete is defined by the American Concrete Institute as a mortar or concrete which is pneumatically projected at high velocity onto a surface. Carlton Akeley, the inventor of sprayed concrete, or shotcrete, was looking for a method of producing concrete shapes that could not be formed using conventional means. This is still the basic philosophy behind the use of shotcrete for new construction. Shotcrete has created a wider range of shapes available to architects, and has also provided solutions to engineering problems.

A common application of shotcrete is in the construction of thin-shelled dome structures using air supported forms. Construction of these dome structures takes place in four phases. In phase one, a ring beam footing is poured with continuous reinforcing bars embedded in the ring beam. Vertical bars connect the dome to the footing. In phase two, an air form is attached and inflated. In phase three of construction, polyurethane foam is sprayed on the interior of the air form. The foam stiffens the form and allows reinforcing steel to be hung from the membrane. In the final phase of construction, after the reinforcing steel is hung, it is embedded with shotcrete.

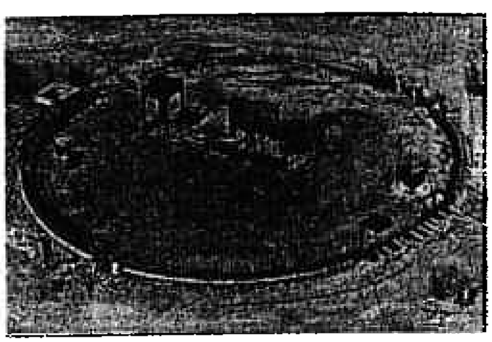


**Figure 1: Ring beam footing**

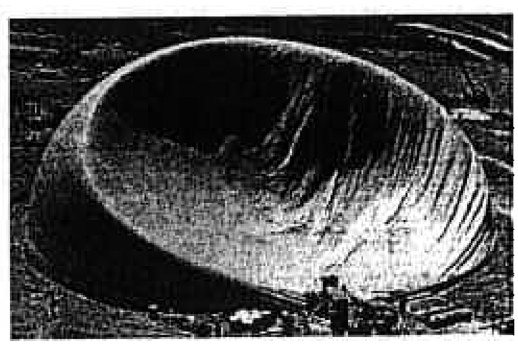


**Figure 2: Inflation of air form**

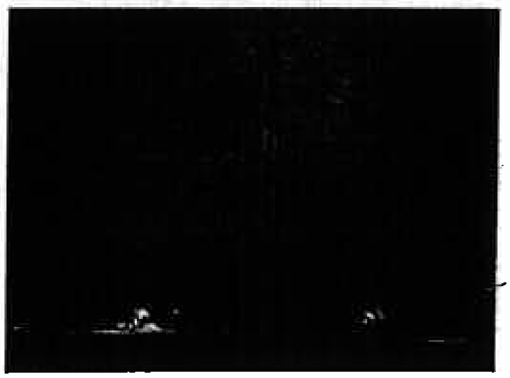


**Figure 3: Attachment of reinforcing steel after polyurethane foam is sprayed**

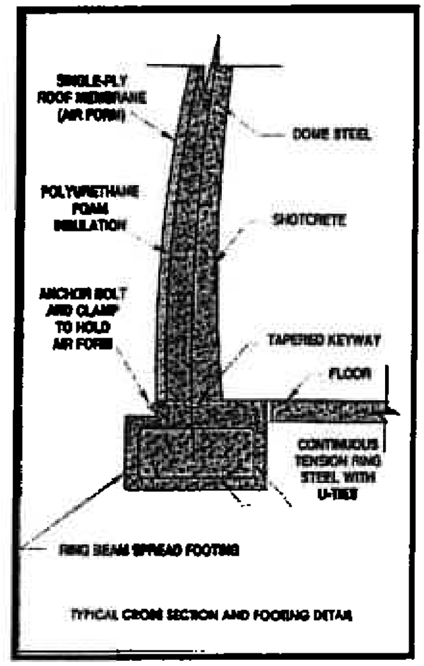



**Figure 4: Typical cross section and footing detail**

Shotcrete is applied in layers. One layer is sprayed and allowed to set; then the next layer is applied and so on until the desired thickness is achieved. Several questions are commonly asked about this construction process which, until now, have been left unanswered. Some of these questions include the following:

1. How good is the bond between layers of shotcrete?
2. Does delamination between layers take place?
3. What kind of surface preparation, if any, is required between layers?
4. Can a good bond still be achieved when several days pass before the next layer of shotcrete is applied?

The purpose of this investigation was to find answers to these questions and to prove that the construction procedure outlined above is a sound procedure. Cases of delamination between shotcrete layers have been reported but were most likely due to improper application techniques. One cause of delamination between layers is due to sand pockets that form as a result of rebound. Rebound is aggregate, cement , and water which does not adhere to the point of application but falls by gravity to a resting place. If enough rebound accumulates at one place, it becomes a loose, uncompacted mass which eventually hardens and appears quite like shotcrete. If rebound is covered with shotcrete, it forms a sand pocket which can lead to delamination in that region. Excessive rebound should be removed before application of additional shotcrete layers. Delamination can also be avoided by assuring that the nozzlemen are all properly trained and certified. If shotcrete is applied properly, by experienced individuals, delamination between layers should not be a problem.

In order to find answers to the above questions several shotcrete panels were prepared, each with different surface preparations between layers, and different time intervals between applications of shotcrete. Cores were taken and tested to determine how good the bond was between shotcrete layers. Three standard concrete panels were also made and tested in a similar fashion so that a comparison could be made between tests done on the shotcrete cores and the standard concrete cores.

## II. Test Procedure

Twelve 18" X 16" X 51/2" wood forms were used to make the shotcrete panels. These were divided into three "sets" (four panels per set). The first set had shotcrete layers sprayed within one day of each other, the second set had layers sprayed at one week intervals, and the third set had layers sprayed at two week intervals. The panels were all sprayed indoors and in a tent which would simulate the conditions during the construction of a dome structure. The four respective panels in each set were handled in the manner outlined below (see Figure 5).

Panel 1: Shotcrete layers were sandblasted immediately before the next layer was applied.

Panel 2: Shotcrete layers were sprayed with water about an hour before the next layer was applied. The water was allowed to soak in with no free water remaining when the next layer of shotcrete was applied.

Panel 3: Shotcrete layers were sandblasted **and** wet before the next application.

Panel 4: Nothing was done between applications of shotcrete.

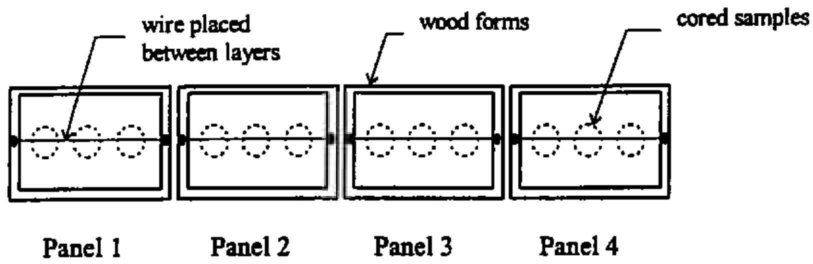



**Figure 5: Each "set" will appear as shown here.**

Set 1: Layers sprayed within one day of each other.
Set 2: Layers sprayed at one week intervals.
Set 3: Layers sprayed at two week intervals.

All panels in each set were sprayed simultaneously in a vertical position, and with five layers in each panel. In an attempt to distinguish where one layer ends and the next begins, a small wire was attached to the sides of the forms so that it ran through the middle of the form where the cores were to be taken (see Figure 5). This turned out to be ineffective though, as it was extremely difficult to locate the small wires after coring.

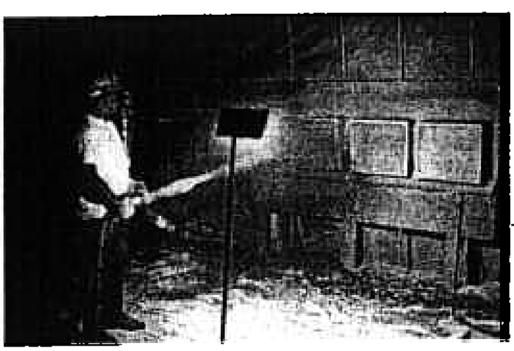


**Figure 6: Spraying the panels**

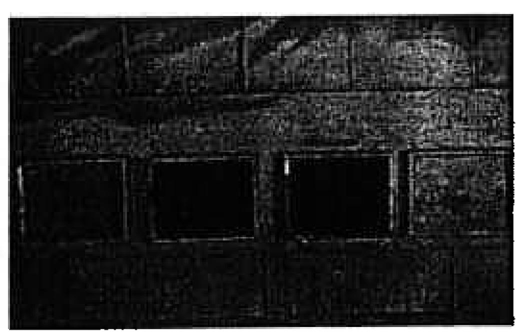


**Figure 7: Typical "set" of shotcrete panels**

**Figure 8: Mixer, pump, and tent**

The concrete mix design was such that the ratio of sand to cement was three to one by volume, and enough water was added to obtain a slump between three and five inches. This caused some variability in the concrete mix, but this is the typical procedure when constructing a dome structure.

In addition to the shotcrete specimens, three standard concrete; unlayered panels were made. These were also placed in the tent so as to be under the same curing conditions as the shotcrete panels. Results taken from tests done on the shotcrete specimens were then compared to results taken from similar tests done on the unlayered specimens. Several compression cylinders were also made and tested to get an idea of the compressive strength of the mix.

**Figure 9: Standard concrete panel**


**Figure 12: Tension test with cores breaking in middle**

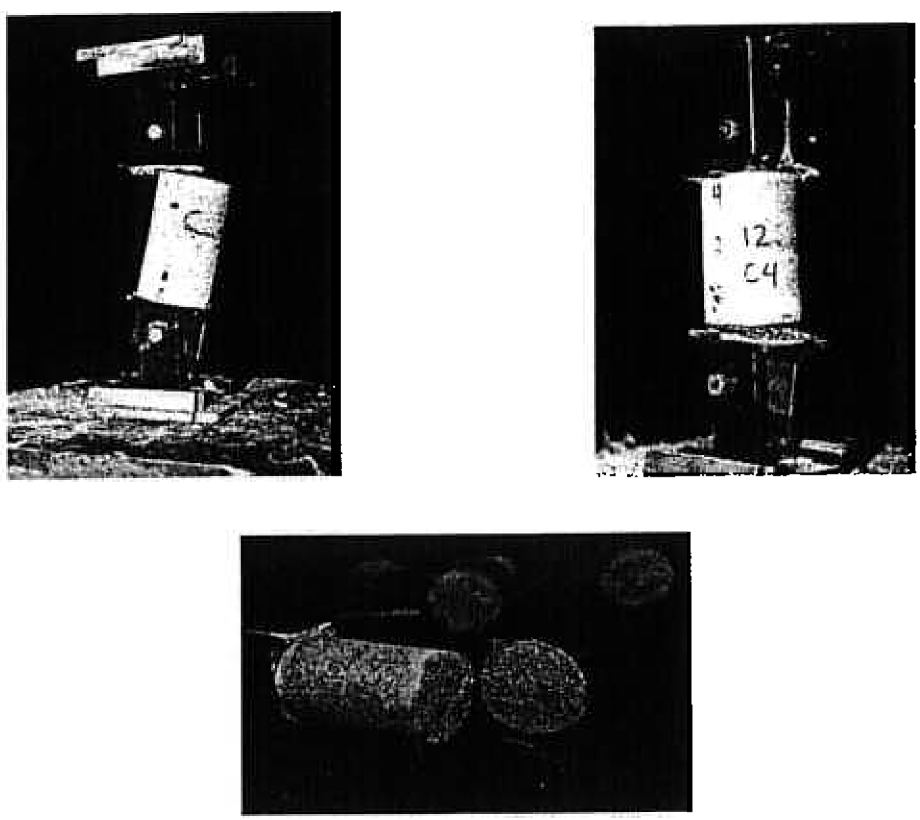
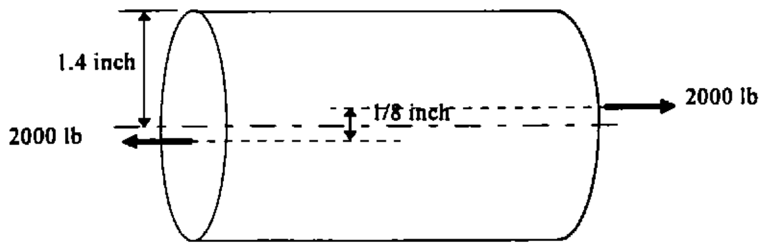



**Figure 13: Tension test with failure occurring on the end**

It was hoped that the specimens would fail at an interface between layers of shotcrete, but as the testing progressed, it was noted that the majority of the specimens failed near the ends. The epoxy rarely failed, but still the cores failed close to the ends where they were glued to the steel fixtures (see Figure 13). The reason why most of the specimens failed near the ends still is not known. One possible reason could be due to an abrupt change in stiffness of the material where the concrete was glued to the steel. Another reason why the specimens failed near the ends may have been the result of a small moment in the system. A moment could easily have been developed due to difficulty in gluing the fixtures such that the force acted exactly through the centroid of the specimens. A moment could have been the result of not welding the perpendicular pieces on the steel fixtures at exact right angles, or the holes may not have been drilled in the exact center of the plates even though great care was taken to prevent these problems. Figure 14 shows that if a 2000 pound force on the core is offset by an eighth of an inch, which was very possible, the increased stress at the extreme edge of the core caused by this moment is 113 psi. This is a significant increase, especially considering the fact that the average stress at failure was only about 360 psi. If the moment could be completely eliminated (which is probably impossible using this test procedure), and the cores were tested in pure tension, they probably would have fractured at much higher values. With so many possible sources of a moment, it was concluded that an effort must be made to reduce or eliminate the moment.




$$\frac{Mc}{I} = \frac{2000(\frac{1}{8})(1.4)}{3.1} = 113psi$$

**Figure 14: Increase in stress caused by a small moment**

Since several of the welds on the fixtures were not perfectly straight, an I-beam was cut up into several little "T's." The I-beam was cut such that the flange fit just over the diameter of the cores, and a hole was drilled in the center of the web. These new fixtures may have reduced the moment, but they did not solve the problem of the cores breaking on the ends.

A further attempt to reduce the moment was done by attaching cables to the fixtures and then pulling the cores apart. This did not seem to change the results. The cores still broke at about the same forces, and most of them on the ends.

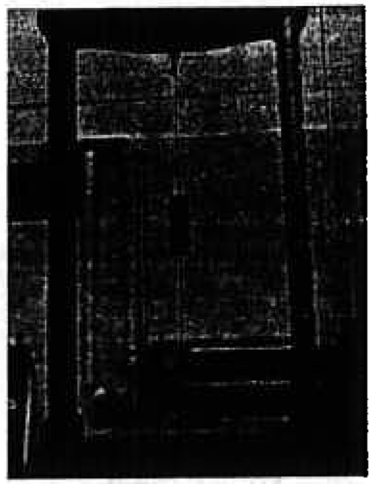


**Figure 15: Attempt to reduce moment by using cables**

Since the cores were all breaking at relatively high stresses, and due to difficulty in eliminating the problem of the cores breaking on the ends, a decision was made to break the remaining cores using the "T's" and as shown in Figures 12 and 13. At least three breaks were done on each core whether they broke on the ends or not.

# III. Results

Table 1: Shotcrete Panels

| | PANEL 1 | | PANEL 2 | | PANEL 3 | | PANEL 4 | |
|---|---|---|---|---|---|---|---|---|
| Surface Preparation: | Sandblasted | | Wet | | Sandblasted and Wet | | Nothing | |
| Max = | 443 | psi | 500 | psi | 432 | psi | 488 | psi |
| SET 1: Ave = | 365 | psi | 379 | psi | 361 | psi | 381 | psi |
| Sprayed at one Min = | 215 | psi | 295 | psi | 205 | psi | 290 | psi |
| day intervals St Dev = | 57.5 | | 52.5 | | 57.2 | | 54.2 | |
| Coef of Var = | 15.7 | | 13.9 | | 15.8 | | 14.2 | |
| | | | | | | | | |
| Max = | 442 | psi | 447 | psi | 439 | psi | 450 | psi |
| SET 2: Ave = | 373 | psi | 330 | psi | 350 | psi | 377 | psi |
| Sprayed at one Min = | 298 | psi | 253 | psi | 234 | psi | 296 | psi |
| week intervals St Dev = | 45.5 | | 61.3 | | 63.2 | | 49.4 | |
| Coef of Var = | 12.2 | | 18.6 | | 18.1 | | 13.1 | |
| | | | | | | | | |
| Max = | 359 | psi | 434 | psi | 477 | psi | 501 | psi |
| SET 3: Ave = | 311 | psi | 344 | psi | 369 | psi | 324 | psi |
| Sprayed at two Min = | 239 | psi | 264 | psi | 307 | psi | 232 | psi |
| week intervals St Dev = | 32.2 | | 58.3 | | 44.6 | | 67.6 | |
| Coef of Var = | 10.3 | | 16.9 | | 12.1 | | 20.9 | |

Table 2: Standard Concrete Panels

| | PANEL 1 | | PANEL 2 | | PANEL 3 | |
|---|---|---|---|---|---|---|
| Day Poured: | 11/11/96 | | 11/18/96 | | 11/25/96 | |
| Max = | 322 | psi | 411 | psi | 397 | psi |
| Ave = | 293 | psi | 354 | psi | 353 | psi |
| Min = | 223 | psi | 291 | psi | 275 | psi |
| St Dev = | 28.6 | | 38.8 | | 41.5 | |
| Coef of Var = | 9.8 | | 11.0 | | 11.8 | |

Table 3: Compression Cylinders

| | | | Expected range of tensile strength (0.07 to 0.11 times compressive strength) | | | |
|---|---|---|---|---|---|---|
| Max = | 7799 | psi | 546 | to | 858 | psi |
| Ave = | 6382 | psi | 447 | to | 702 | psi |
| Min = | 4633 | psi | 324 | to | 510 | psi |
| St Dev = | 1204.8 | | | | | |
| Coef of Var = | 18.9 | | | | | |

## IV. Discussion of Results

Using a generalized linear model procedure in SAS[1] version 6.11, a statistical analysis was done. The analysis tested for the significance of surface preparation and the time interval between applications of shotcrete. Since there were no "true" replications done in the experiment which would give an estimate of within cell variability, the interaction of surface preparation and the time interval between applications of shotcrete was used as the error term in the analysis. This test assumed no significant interaction between the two variables of different surface preparations and different time intervals between applications, and confirmed that neither variable was statistically significant. P-values less than 0.05 would have indicated significant interaction between the two variables. The P-value for surface preparation was 0.20, and the P-value for application time was 0.99 which confirmed that no significant interaction occurred.

A statistical analysis was also done to compare the results from the shotcrete panels with the results of the standard concrete panels. A one-way analysis of variance (ANOVA) was done. A P-value of 0.41 was obtained which indicated that there was no significant difference between the standard concrete and the shotcrete panels.

Due to the fact that the majority of the cores failed near their ends and not at the interface between layers, the exact bond strength between layers could not be determined. The average stress at failure for the cores was about 360 psi. The very lowest value obtained was 205 psi and the highest value was 501 psi. These values provide an indication that the bond strength between layers of shotcrete is quite good. According to Mindess and Young, the ratio of the direct tensile strength to the compressive strength ranges from about 0.07 to 0.11[2]. Table 3 shows the expected range of tensile strength for the specimens tested in this investigation. The values obtained during testing were on the lower end of this range, but as already mentioned, most of the values obtained during testing correspond to failure at the ends of the cores. Since failure rarely occurred between layers of shotcrete, it can be concluded that the bond strength between layers was higher than the values obtained during testing. Since the two variables of surface preparation and time interval between applications proved to be insignificant insofar as this test procedure is concerned, it can also be concluded that a good bond can be obtained no matter what surface preparation is used and even if there are two weeks between applications of shotcrete. The test results also showed that there was little difference between values obtained from the shotcrete panels and the standard concrete panels. The shotcrete cores performed just as well as the cores taken from the standard concrete panels. Figure 16 shows a core which had a large void in the middle. The panel from which this core was taken was sprayed at two week intervals with a wet surface preparation. Even with the big void in the middle the core still broke at 264 psi. which is quite good.

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[1] SAS is a common package used for analyzing statistical data.
[2] Mindess, Sidney, and Young, Francis J. Concrete. Prentice-Hall, Inc., New Jersey, 1981.

The cored specimens were 2.8 inches in diameter, and four cores were taken from each panel. The ends of each core were squared off and smoothed by use of a diamond saw.

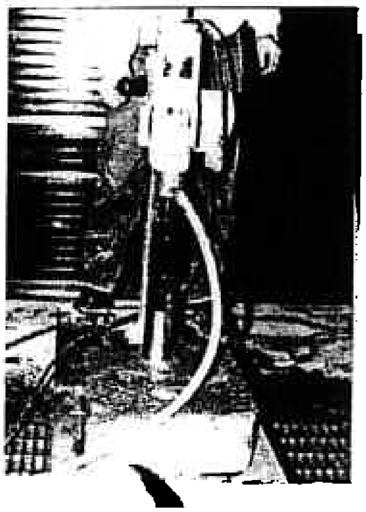

**Figure 10: Coring Machine**

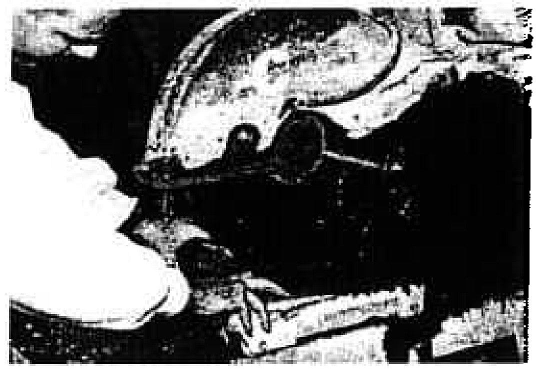

**Figure 11: Diamond Saw**

Several steel fixtures were made by first cutting several steel plates into squares that would just fit over the diameter of the cores. Next, steel plates, with holes drilled in their centers, were welded perpendicular to the above mentioned square plates.

These steel fixtures were then glued to each end of the cored specimens with a high strength epoxy (Sikadur 31 High Mod Gel). The specimens were then ready to be tested in tension as shown in Figures 12 and 13.

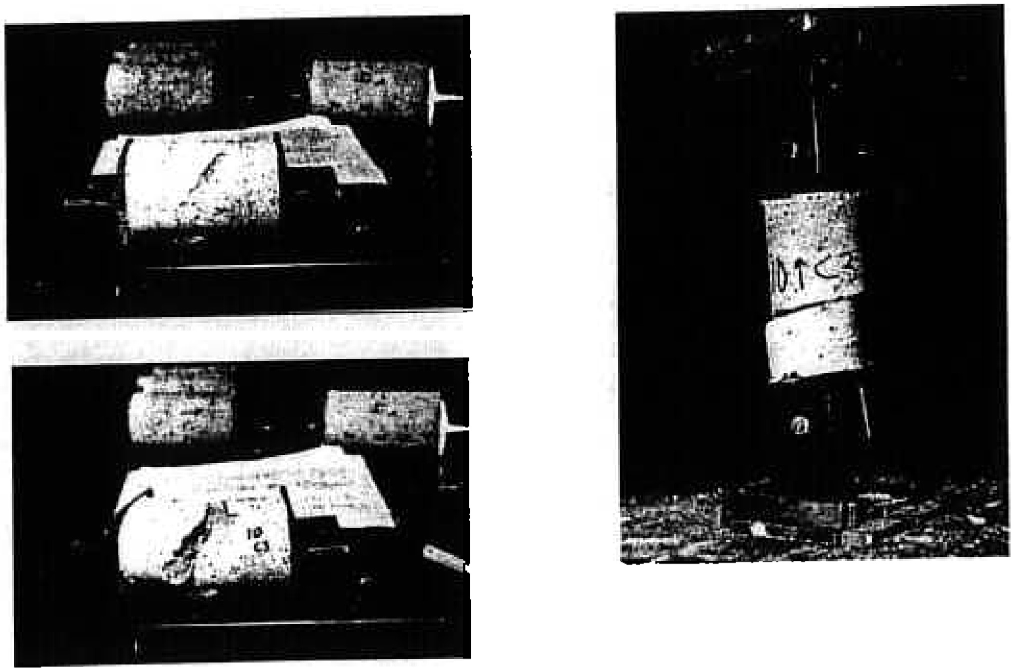

**Figure 16: Even with large void, still broke at 264 psi**

It should be noted that the low value of 205 psi occurred where a larger gage wire was placed. As discussed previously, wires were used in an attempt to distinguish where one layer ends and the next begins. A heavier wire was used between the first few layers of shotcrete before switching to a lighter gage wire. This bigger wire may have reduced the bond strength some as the core failed right where the wire was placed.

Low values were also obtained for the third set. In this set, the final layer appeared to have come either from a poor mix or was just not sprayed as well as the other layers. Fractures that occurred in this layer were noted to be lower than other values obtained from subsequent breaks of the same cores.

## V. Suggestions

As previously noted, this test procedure provided an indication that the bond strength between layers of shotcrete was higher than the values obtained during testing because most fractures occurred near one end and not between the shotcrete layers. This test procedure was adequate enough to show that the bond strength between layers of shotcrete is quite good, and that delamination between layers is not a problem. However, modifying this test procedure or utilizing a different test procedure may result in higher and more consistent results. It is difficult to obtain reliable results from a pure tension test done on concrete. As was discovered in this investigation, it was extremely difficult to eliminate any moment in the system and to test in pure tension. One suggestion is to develop a flexural test on the cores. The cores could be forced to fail at the interface between layers of shotcrete by placing them in two pipes as shown in Figure 17. The two pipes would come together at the desired failure location and a force would be applied at this point. Multiple breaks could be done on each core using this procedure.

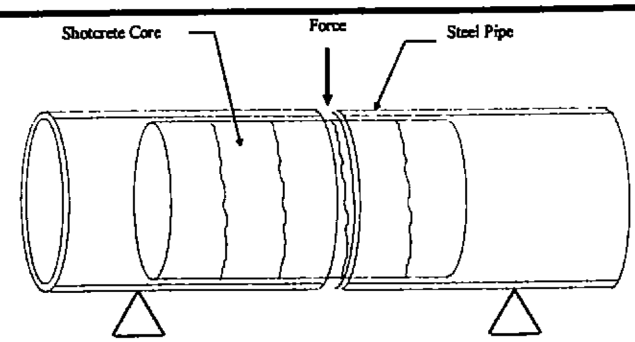


**Figure 17: Suggestion for flexural test of shotcrete specimen**

A second suggested test procecdure is shown in Figure 18. Point loads would be applied as shown until the core breaks. Using this test procedure, the cores could be forced to fail at the interface between layers and multiple breaks could be done on each core.

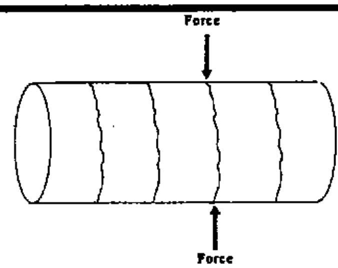


**Figure 18: Suggested point load test**

Another suggestion would be to develop a method of locating the interface between shotcrete layers. An attempt was made to do this in this investigation by placing a small wire between layers as shown in Figure 5. This was ineffective though because the wire was too hard to find. If it could be assumed that coloring in the mix would not affect its strength, this would be a good way to distinguish layers. Coloring the different layers in actual construction would not be practical.

A final suggestion for future testing would be to test how well shotcrete bonds to reinforcing steel. Comparisons could be made to how regular concrete bonds to reinforcing steel.

## VI. Conclusions

**1. The bond between layers of shotcrete was good and delamination between layers was not a problem.** It should be emphasized that in order to get a good bond between layers, excessive rebound should always be removed before applying shotcrete. It is also extremely important that the nozzleman be trained and certified. If proper application techniques are followed by experienced nozzlemen, delamination between layers should not be a problem.

**2. The bond between layers of shotcrete was higher than the values obtained in this test procedure.** Failure of the cores occurred on the ends and the bond between layers was rarely broken.

**3. The shotcrete cores performed just as well as the cores taken from the standard concrete.** Statistically, there was not a significant difference between the results obtained from the shotcrete cores and the results obtained from the standard concrete cores.

**4. The surface preparation type and the time interval between applications of shotcrete were both insignificant insofar as this test procedure was concerned.** Since the actual bond between shotcrete layers was not the cause of failure in the tension specimens, the affects of different surface preparations between layers and the different time intervals between applications could not be determined. However, it was determined that the bond strength between layers was greater than the values obtained in this test procedure. Whether the two variables of different surface preparations and different time intervals between applications of shotcrete have any effect at all on the bond strength of shotcrete is still not known, but it can be concluded that in order to obtain a bond strength comparable to the values obtained in this investigation, surface preparation between layers and the time interval between applications are of little importance. Since no surface preparation is required in order to get good bond strength between layers of shotcrete, time and money can be saved during the construction process. Also, if during construction problems arise and work must be delayed for several days, a good bond can still be achieved between layers which are sprayed up to two weeks apart.

# VII. Appendix

1
**SET 1, PANEL 1**
Sprayed at one day intervals
Surface Preparation: Sandblasted

**Core 1**

| Layer | Day Sprayed | Day Fractured | Cure Time (days) | Force (lb) | Stress (psi) | Notes |
|---|---|---|---|---|---|---|
| 1 | 10/28/96 | 2/4/97 | 99 | 2770 | 443 | bottom, cable |
| 5 | 11/1/96 | 1/22/97 | 82 | 1780 | 285 | top |
| 5 | 11/1/96 | 1/24/97 | 84 | 1920 | 307 | top |
| 5 | 11/1/96 | 1/25/97 | 82 | 1860 | 298 | top |
| 5 | 11/1/96 | 1/27/97 | 84 | 2070 | 331 | top |

**Core 2**

| Layer | Day Sprayed | Day Fractured | Cure Time (days) | Force (lb) | Stress (psi) | Notes |
|---|---|---|---|---|---|---|
| 1 | 10/28/96 | 1/21/97 | 85 | 2580 | 413 | bottom |
| 1 | 10/28/96 | 1/22/97 | 86 | 2510 | 402 | bottom |
| 1 | 10/28/96 | 1/24/97 | 88 | 2300 | 368 | bottom |
| 1 | 10/28/96 | 1/25/97 | 89 | 2360 | 378 | bottom |
| 1 | 10/28/96 | 1/27/97 | 91 | 2520 | 403 | bottom |
| 1 | 10/28/96 | 2/4/97 | 99 | 2620 | 419 | bottom, cable |
| 4 | 10/31/96 | 1/17/97 | 78 | 2170 | 347 | |
| 5 | 11/1/96 | 1/20/97 | 80 | 1840 | 295 | |

**Core 3**

| Layer | Day Sprayed | Day Fractured | Cure Time (days) | Force (lb) | Stress (psi) | Notes |
|---|---|---|---|---|---|---|
| 1 | 10/28/96 | 1/21/97 | 85 | 2050 | 328 | bottom |
| 1 | 10/28/96 | 1/22/97 | 86 | 2550 | 408 | bottom |
| 1 | 10/28/96 | 1/24/97 | 88 | 2320 | 371 | bottom |
| 1 | 10/28/96 | 1/25/97 | 89 | 2480 | 397 | bottom |
| 1 | 10/28/96 | 1/27/97 | 91 | 2310 | 370 | bottom |
| 2 | 10/29/96 | 2/4/97 | 98 | 2550 | 408 | bottom, part epoxy fail |
| 3 | 10/30/96 | 1/17/97 | 79 | 1340 | 215 | |
| 5 | 11/1/96 | 1/20/97 | 80 | 1620 | 259 | bet 4 & 5 |

**Core 4**

| Layer | Day Sprayed | Day Fractured | Cure Time (days) | Force (lb) | Stress (psi) | Notes |
|---|---|---|---|---|---|---|
| 1 | 10/28/96 | 1/17/97 | 81 | 2470 | 395 | bottom, fast load |
| 1 | 10/28/96 | 1/25/97 | 89 | 2470 | 395 | bottom |
| 1 | 10/28/96 | 1/27/97 | 91 | 2550 | 408 | bottom |
| 4 | 10/31/96 | 1/24/97 | 85 | 2550 | 408 | top |
| 4 | 10/31/96 | 2/4/97 | 96 | 2730 | 437 | top |
| 5 | 11/1/96 | 1/22/97 | 82 | 2340 | 375 | |

| | | |
|---|---|---|
| **Max =** | **443** | **psi** |
| **Ave =** | **365** | **psi** |
| **Min =** | **215** | **psi** |
| **St Dev =** | **57.5** | |
| **Coef of Var =** | **15.7** | |

2

**SET 1, PANEL 2**

Sprayed at one day intervals

Surface Preparation: Wet

**Core 1**

| Layer | Day Sprayed | Day Fractured | Cure Time (days) | Force (lb) | Stress (psi) | Notes |
|---|---|---|---|---|---|---|
| 2 | 10/29/96 | 1/21/97 | 84 | 2060 | 330 | bet 1 & 2 |
| 2 | 10/29/96 | 1/22/97 | 85 | 2730 | 437 | bottom |
| 4 | 10/31/96 | 1/24/97 | 85 | 3120 | 500 | top, part epoxy failure |
| 4 | 10/31/96 | 1/25/97 | 86 | 2920 | 468 | top, bond 3-4 not broken |

**Core 2**

| Layer | Day Sprayed | Day Fractured | Cure Time (days) | Force (lb) | Stress (psi) | Notes |
|---|---|---|---|---|---|---|
| 1 | 10/28/96 | 1/21/97 | 85 | 2580 | 413 | bottom |
| 1 | 10/28/96 | 1/22/97 | 86 | 2430 | 389 | bottom |
| 1 | 10/28/96 | 1/24/97 | 88 | 2360 | 378 | bottom |
| 1 | 10/28/96 | 1/25/97 | 89 | 2300 | 368 | bottom |
| 2 | 10/29/96 | 2/5/97 | 99 | 1840 | 295 | bet 1 & 2 |
| 4 | 10/31/96 | 1/27/97 | 88 | 2390 | 383 | top |
| 5 | 11/1/96 | 1/17/97 | 77 | 1940 | 311 | bet 4 & 5, wire |

**Core 3**

| Layer | Day Sprayed | Day Fractured | Cure Time (days) | Force (lb) | Stress (psi) | Notes |
|---|---|---|---|---|---|---|
| 1 | 10/28/96 | 1/21/97 | 85 | 2440 | 391 | bottom |
| 1 | 10/28/96 | 1/24/97 | 88 | 2470 | 395 | bottom |
| 1 | 10/28/96 | 1/25/97 | 89 | 2410 | 386 | bottom |
| 1 | 10/28/96 | 1/27/97 | 91 | 2530 | 405 | bottom |
| 2 | 10/29/96 | 2/5/97 | 99 | 2150 | 344 | bet 1 & 2 |
| 3 | 10/30/96 | 1/22/97 | 84 | 2470 | 395 | top |
| 4 | 10/31/96 | 1/17/97 | 78 | 2260 | 362 | bet 3 & 4 |
| 4 | 10/31/96 | 1/20/97 | 81 | 2380 | 381 | |
| 5 | 11/1/96 | 1/21/97 | 81 | 1970 | 315 | top |

**Core 4**

| Layer | Day Sprayed | Day Fractured | Cure Time (days) | Force (lb) | Stress (psi) | Notes |
|---|---|---|---|---|---|---|
| 1 | 10/28/96 | 1/21/97 | 85 | 2070 | 331 | bottom |
| 1 | 10/28/96 | 1/22/97 | 86 | 2760 | 442 | bottom |
| 1 | 10/28/96 | 1/24/97 | 88 | 2080 | 333 | bottom |
| 1 | 10/28/96 | 1/25/97 | 89 | 2670 | 427 | bottom |
| 2 | 10/29/96 | 1/27/97 | 90 | 2720 | 435 | bet 1 & 2, bottom |
| 2 | 10/29/96 | 2/5/97 | 99 | 2000 | 320 | bet 1 & 2, bottom |
| 5 | 11/1/96 | 1/17/97 | 77 | 1880 | 301 | bet 4 & 5 |

| | | |
|---|---|---|
| **Max =** | **500** | **psi** |
| **Ave =** | **379** | **psi** |
| **Min =** | **295** | **psi** |
| **St Dev =** | **52.5** | |
| **Coef of Var =** | **13.9** | |

3

**SET 1, PANEL 3**

Sprayed at one day intervals

Surface Preparation: Sandblasted and Wet

**Core 1**

| Layer | Day Sprayed | Day Fractured | Cure Time (days) | Force (lb) | Stress (psi) | Notes |
|---|---|---|---|---|---|---|
| 1 | 10/28/96 | 1/27/97 | 91 | 2490 | 399 | bottom |
| 1 | 10/28/96 | 2/5/97 | 100 | 2260 | 362 | bottom |
| 3 | 10/30/96 | 1/24/97 | 86 | 2440 | 391 | top |
| 3 | 10/30/96 | 1/25/97 | 87 | 2390 | 383 | top |
| 4 | 10/31/96 | 1/22/97 | 83 | 2030 | 325 | |

**Core 2**

| Layer | Day Sprayed | Day Fractured | Cure Time (days) | Force (lb) | Stress (psi) | Notes |
|---|---|---|---|---|---|---|
| 2 | 10/29/96 | 1/17/97 | 80 | 1280 | 205 | 1-2, big wire |
| 4 | 10/31/96 | 1/25/97 | 86 | 2180 | 349 | top |
| 4 | 10/31/96 | 1/27/97 | 88 | 2150 | 344 | top, eccentric load |
| 5 | 11/1/96 | 1/21/97 | 81 | 2250 | 360 | top, eccentric load |
| 5 | 11/1/96 | 1/22/97 | 82 | 2520 | 403 | top |
| 5 | 11/1/96 | 1/24/97 | 84 | 2030 | 325 | top, eccentric load |
| 5 | 11/1/96 | 2/5/97 | 96 | 2700 | 432 | top |

**Core 3**

| Layer | Day Sprayed | Day Fractured | Cure Time (days) | Force (lb) | Stress (psi) | Notes |
|---|---|---|---|---|---|---|
| 1 | 10/28/96 | 1/21/97 | 85 | 2610 | 418 | bottom |
| 1 | 10/28/96 | 1/22/97 | 86 | 2210 | 354 | bottom |
| 1 | 10/28/96 | 1/24/97 | 88 | 2170 | 347 | bottom |
| 1 | 10/28/96 | 1/25/97 | 89 | 2310 | 370 | bottom |
| 1 | 10/28/96 | 1/27/97 | 91 | 2700 | 432 | bottom |
| 2 | 10/29/96 | 2/5/97 | 99 | 2660 | 426 | bottom, bet 1 & 2 |
| 4 | 10/31/96 | 1/17/97 | 78 | 2015 | 323 | bet 3 & 4 |
| 5 | 11/1/96 | 1/20/97 | 80 | 2320 | 371 | |
| 5 | 11/1/96 | 1/21/97 | 81 | 1480 | 237 | top |

**Core 4**

| Layer | Day Sprayed | Day Fractured | Cure Time (days) | Force (lb) | Stress (psi) | Notes |
|---|---|---|---|---|---|---|
| 2 | 10/29/96 | 1/21/97 | 84 | 1860 | 298 | bet 1 & 2 |
| 4 | 10/31/96 | 1/22/97 | 83 | 2540 | 407 | bet 3 & 4 |
| 5 | 11/1/96 | 1/24/97 | 84 | 2560 | 410 | top |

| | | |
|---|---|---|
| **Max =** | **432** | **psi** |
| **Ave =** | **361** | **psi** |
| **Min =** | **205** | **psi** |
| **St Dev =** | **57.2** | |
| **Coef of Var =** | **15.8** | |

4

**SET 1, PANEL 4**

Sprayed at one day intervals

Surface Preparation: Nothing

**Core 1**

| Layer | Day Sprayed | Day Fractured | Cure Time (days) | Force (lb) | Stress (psi) | Notes |
|---|---|---|---|---|---|---|
| 1 | 10/28/96 | 1/24/97 | 88 | 2620 | 419 | bottom |
| 2 | 10/29/96 | 1/25/97 | 88 | 2500 | 400 | bottom |
| 2 | 10/29/96 | 1/27/97 | 90 | 2300 | 368 | bottom |
| 2 | 10/29/96 | 2/5/97 | 99 | 2680 | 429 | bottom |
| 5 | 11/1/96 | 1/22/97 | 82 | 2000 | 320 | |

**Core 2**

| Layer | Day Sprayed | Day Fractured | Cure Time (days) | Force (lb) | Stress (psi) | Notes |
|---|---|---|---|---|---|---|
| 1 | 10/28/96 | 1/20/97 | 84 | 2720 | 435 | bond 1-2 not broken |
| 2 | 10/29/96 | 1/17/97 | 80 | 2400 | 384 | |
| 3 | 10/30/96 | 1/22/97 | 84 | 2340 | 375 | top |
| 4 | 10/31/96 | 1/24/97 | 85 | 2200 | 352 | layer 4 |
| 5 | 11/1/96 | 1/21/97 | 81 | 2610 | 418 | |

**Core 3**

| Layer | Day Sprayed | Day Fractured | Cure Time (days) | Force (lb) | Stress (psi) | Notes |
|---|---|---|---|---|---|---|
| 1 | 10/28/96 | 1/17/97 | 81 | 1860 | 298 | bottom |
| 4 | 10/31/96 | 1/22/97 | 83 | 2880 | 461 | top |
| 4 | 10/31/96 | 1/25/97 | 86 | 2720 | 435 | top |
| 4 | 10/31/96 | 1/27/97 | 88 | 3050 | 488 | top |
| 4 | 10/31/96 | 2/5/97 | 97 | 2640 | 423 | top, part epoxy fail |
| 5 | 11/1/96 | 1/22/97 | 82 | 2020 | 323 | bet 4 & 5 |

**Core 4**

| Layer | Day Sprayed | Day Fractured | Cure Time (days) | Force (lb) | Stress (psi) | Notes |
|---|---|---|---|---|---|---|
| 1 | 10/28/96 | 1/17/97 | 81 | 2400 | 384 | bottom |
| 1 | 10/28/96 | 1/22/97 | 86 | 2200 | 352 | bottom |
| 1 | 10/28/96 | 1/24/97 | 88 | 2350 | 376 | bottom |
| 5 | 11/1/96 | 1/25/97 | 85 | 2070 | 331 | top |
| 5 | 11/1/96 | 1/27/97 | 87 | 1810 | 290 | top |
| 5 | 11/1/96 | 2/5/97 | 96 | 1990 | 319 | top, bet 4 & 5 |

| | | |
|---|---|---|
| **Max =** | **488** | **psi** |
| **Ave =** | **381** | **psi** |
| **Min =** | **290** | **psi** |
| **St Dev =** | **54.2** | |
| **Coef of Var =** | **14.2** | |

5

**SET 2, PANEL 1**

Sprayed at one week intervals

Surface Preparation: Sandblasted

**Core 2**

| Layer | Day Sprayed | Day Fractured | Cure Time (days) | Force (lb) | Stress (psi) | Notes |
|---|---|---|---|---|---|---|
| 1 | 10/28/96 | 1/17/97 | 81 | 1910 | 306 | |
| 3 | 11/11/96 | 1/24/97 | 74 | 2520 | 403 | top |
| 3 | 11/11/96 | 1/25/97 | 75 | 2560 | 410 | top |
| 3 | 11/11/96 | 1/27/97 | 77 | 2680 | 429 | top |
| 3 | 11/11/96 | 2/5/97 | 86 | 2440 | 391 | top |
| 4 | 11/18/96 | 1/22/97 | 65 | 2210 | 354 | bet 3 & 4 |
| 4 | 11/18/96 | 1/24/97 | 67 | 2500 | 400 | bottom, bond 4-5 not broken |

**Core 3**

| Layer | Day Sprayed | Day Fractured | Cure Time (days) | Force (lb) | Stress (psi) | Notes |
|---|---|---|---|---|---|---|
| 2 | 11/4/96 | 1/20/97 | 77 | 2360 | 378 | 1-2, fast load |
| 3 | 11/11/96 | 1/17/97 | 67 | 2020 | 323 | bet 2 & 3 |
| 3 | 11/11/96 | 1/20/97 | 70 | 2160 | 346 | |
| 4 | 11/18/96 | 1/22/97 | 65 | 2760 | 442 | bet 3 & 4 |
| 5 | 11/25/96 | 1/24/97 | 60 | 2390 | 383 | top |

**Core 4**

| Layer | Day Sprayed | Day Fractured | Cure Time (days) | Force (lb) | Stress (psi) | Notes |
|---|---|---|---|---|---|---|
| 1 | 10/28/96 | 1/20/97 | 84 | 2580 | 413 | |
| 3 | 11/11/96 | 1/17/97 | 67 | 1860 | 298 | |
| 5 | 11/25/96 | 1/20/97 | 56 | 2030 | 325 | bet 4 & 5 |

| | | |
|---|---|---|
| **Max =** | **442** | **psi** |
| **Ave =** | **373** | **psi** |
| **Min =** | **298** | **psi** |
| **St Dev =** | **45.5** | |
| **Coef of Var =** | **12.2** | |

6

**SET 2, PANEL 2**

Sprayed at one week intervals

Surface Preparation: Wet

**Core 1**

| Layer | Day Sprayed | Day Fractured | Cure Time (days) | Force (lb) | Stress (psi) | Notes |
|---|---|---|---|---|---|---|
| 3 | 11/11/96 | 1/21/97 | 71 | 1830 | 293 | |
| 3 | 11/11/96 | 1/22/97 | 72 | 2790 | 447 | |
| 5 | 11/25/96 | 1/22/97 | 58 | 2210 | 354 | top |

**Core 2**

| Layer | Day Sprayed | Day Fractured | Cure Time (days) | Force (lb) | Stress (psi) | Notes |
|---|---|---|---|---|---|---|
| 1 | 10/28/96 | 1/20/97 | 84 | 1840 | 295 | |
| 3 | 11/11/96 | 1/17/97 | 67 | 1580 | 253 | |
| 4 | 11/18/96 | 1/21/97 | 64 | 2210 | 354 | top |
| 5 | 11/25/96 | 1/20/97 | 56 | 2070 | 331 | |

**Core 3**

| Layer | Day Sprayed | Day Fractured | Cure Time (days) | Force (lb) | Stress (psi) | Notes |
|---|---|---|---|---|---|---|
| 1 | 10/28/96 | 1/20/97 | 84 | 2110 | 338 | |
| 3 | 11/11/96 | 1/17/97 | 67 | 1760 | 282 | |
| 5 | 11/25/96 | 1/20/97 | 56 | 2730 | 437 | |

**Core 4**

| Layer | Day Sprayed | Day Fractured | Cure Time (days) | Force (lb) | Stress (psi) | Notes |
|---|---|---|---|---|---|---|
| 2 | 11/4/96 | 1/22/97 | 79 | 1830 | 293 | 1-2, bottom |
| 3 | 11/11/96 | 1/20/97 | 70 | 1860 | 298 | |
| 4 | 11/18/96 | 1/17/97 | 60 | 1580 | 253 | 3-4, fast load |
| 5 | 11/25/96 | 1/20/97 | 56 | 2420 | 387 | |

| | | |
|---|---|---|
| **Max =** | **447** | **psi** |
| **Ave =** | **330** | **psi** |
| **Min =** | **253** | **psi** |
| **St Dev =** | **61.3** | |
| **Coef of Var =** | **18.6** | |

7

**SET 2, PANEL 3**

Sprayed at one week intervals

Surface Preparation: Sandblasted and Wet

**Core 1**

| Layer | Day Sprayed | Day Fractured | Cure Time (days) | Force (lb) | Stress (psi) | Notes |
|---|---|---|---|---|---|---|
| 1 | 10/28/96 | 1/25/97 | 89 | 2370 | 379 | bottom |
| 1 | 10/28/96 | 1/27/97 | 91 | 2260 | 362 | bottom |
| 2 | 11/4/96 | 2/5/97 | 93 | 2650 | 424 | bottom, bet 1 & 2 |

**Core 2**

| Layer | Day Sprayed | Day Fractured | Cure Time (days) | Force (lb) | Stress (psi) | Notes |
|---|---|---|---|---|---|---|
| 1 | 10/28/96 | 2/5/97 | 100 | 2740 | 439 | bottom |
| 3 | 11/11/96 | 1/27/97 | 77 | 1490 | 239 | 2-3, bond 1-2 not broken |
| 4 | 11/18/96 | 1/25/97 | 68 | 1460 | 234 | layer 4, 4-5 not broken |

**Core 3**

| Layer | Day Sprayed | Day Fractured | Cure Time (days) | Force (lb) | Stress (psi) | Notes |
|---|---|---|---|---|---|---|
| 1 | 10/28/96 | 2/5/97 | 100 | 2060 | 330 | bottom, fast load |
| 1 | 10/28/96 | 1/27/97 | 91 | 2170 | 347 | bottom |
| 3 | 11/11/96 | 1/25/97 | 75 | 1710 | 274 | |
| 5 | 11/25/96 | 1/27/97 | 63 | 2330 | 373 | top |
| 5 | 11/25/96 | 2/5/97 | 72 | 2350 | 376 | top |

**Core 4**

| Layer | Day Sprayed | Day Fractured | Cure Time (days) | Force (lb) | Stress (psi) | Notes |
|---|---|---|---|---|---|---|
| 1 | 10/28/96 | 1/25/97 | 89 | 2220 | 355 | bottom |
| 1 | 10/28/96 | 1/27/97 | 91 | 2170 | 347 | bottom |
| 2 | 11/4/96 | 2/5/97 | 93 | 2590 | 415 | bottom, bet 1 & 2 |

| | | |
|---|---|---|
| **Max =** | **439** | **psi** |
| **Ave =** | **350** | **psi** |
| **Min =** | **234** | **psi** |
| **St Dev =** | **63.2** | |
| **Coef of Var =** | **18.1** | |

8

**SET 2, PANEL 4**

Sprayed at one week intervals

Surface Preparation: Nothing

**Core 1**

| Layer | Day Sprayed | Day Fractured | Cure Time (days) | Force (lb) | Stress (psi) | Notes |
|---|---|---|---|---|---|---|
| 1 | 10/28/96 | 2/6/97 | 101 | 2510 | 402 | bottom |
| 2 | 11/4/96 | 2/7/97 | 95 | 1850 | 296 | bottom, 1-2, wire |
| 4 | 11/18/96 | 2/5/97 | 79 | 2530 | 405 | |
| 4 | 11/18/96 | 2/6/97 | 80 | 2010 | 322 | bottom |

**Core 2**

| Layer | Day Sprayed | Day Fractured | Cure Time (days) | Force (lb) | Stress (psi) | Notes |
|---|---|---|---|---|---|---|
| 2 | 11/4/96 | 2/7/97 | 95 | 2500 | 400 | bet 1 & 2 |
| 3 | 11/11/96 | 2/6/97 | 87 | 2110 | 338 | top |
| 4 | 11/18/96 | 2/5/97 | 79 | 2700 | 432 | |
| 4 | 11/18/96 | 2/6/97 | 80 | 1920 | 307 | bottom |

**Core 3**

| Layer | Day Sprayed | Day Fractured | Cure Time (days) | Force (lb) | Stress (psi) | Notes |
|---|---|---|---|---|---|---|
| 1 | 10/28/96 | 2/7/97 | 102 | 2810 | 450 | bottom |
| 1 | 10/28/96 | 2/8/97 | 103 | 2470 | 395 | bottom |
| 1 | 10/28/96 | 2/10/97 | 105 | 2540 | 407 | bottom |

**Core 4**

| Layer | Day Sprayed | Day Fractured | Cure Time (days) | Force (lb) | Stress (psi) | Notes |
|---|---|---|---|---|---|---|
| 5 | 11/25/96 | 2/8/97 | 75 | 2550 | 408 | top |
| 5 | 11/25/96 | 2/10/97 | 77 | 2020 | 323 | top |
| 5 | 11/25/96 | 2/12/97 | 79 | 2470 | 395 | top |

| | | |
|---|---|---|
| **Max =** | **450** | **psi** |
| **Ave =** | **377** | **psi** |
| **Min =** | **296** | **psi** |
| **St Dev =** | **49.4** | |
| **Coef of Var =** | **13.1** | |

9

**SET 3, PANEL 1**

Sprayed at two week intervals

Surface Preparation: Sandblasted

**Core 1**

| Layer | Day Sprayed | Day Fractured | Cure Time (days) | Force (lb) | Stress (psi) | Notes |
|---|---|---|---|---|---|---|
| 1 | 10/28/96 | 2/12/97 | 107 | 2120 | 339 | bottom |
| 5 | 12/23/96 | 2/7/97 | 46 | 2010 | 322 | top |
| 5 | 12/23/96 | 2/8/97 | 47 | 1490 | 239 | top |
| 5 | 12/23/96 | 2/10/97 | 49 | 1840 | 295 | top |

**Core 2**

| Layer | Day Sprayed | Day Fractured | Cure Time (days) | Force (lb) | Stress (psi) | Notes |
|---|---|---|---|---|---|---|
| 1 | 10/28/96 | 2/8/97 | 103 | 1990 | 319 | bottom |
| 1 | 10/28/96 | 2/10/97 | 105 | 1870 | 299 | bottom |
| 1 | 10/28/96 | 2/12/97 | 107 | 1720 | 275 | bottom |
| 5 | 12/23/96 | 2/7/97 | 46 | 1820 | 291 | bet 4 & 5 |

**Core 3**

| Layer | Day Sprayed | Day Fractured | Cure Time (days) | Force (lb) | Stress (psi) | Notes |
|---|---|---|---|---|---|---|
| 1 | 10/28/96 | 2/7/97 | 102 | 1920 | 307 | bottom |
| 1 | 10/28/96 | 2/8/97 | 103 | 2100 | 336 | bottom |
| 1 | 10/28/96 | 2/10/97 | 105 | 1980 | 317 | bottom |
| 5 | 12/23/96 | 2/12/97 | 51 | 2100 | 336 | top |

**Core 4**

| Layer | Day Sprayed | Day Fractured | Cure Time (days) | Force (lb) | Stress (psi) | Notes |
|---|---|---|---|---|---|---|
| 1 | 10/28/96 | 2/8/97 | 103 | 2240 | 359 | bottom |
| 1 | 10/28/96 | 2/10/97 | 105 | 2150 | 344 | bottom |
| 1 | 10/28/96 | 2/12/97 | 107 | 2100 | 336 | bottom |
| 5 | 12/23/96 | 2/7/97 | 46 | 1670 | 267 | top |

| | | |
|---|---|---|
| **Max =** | **359** | **psi** |
| **Ave =** | **311** | **psi** |
| **Min =** | **239** | **psi** |
| **St Dev =** | **32.2** | |
| **Coef of Var =** | **10.3** | |

10

**SET 3, PANEL 2**

Sprayed at two week intervals

Surface Preparation: Wet

**Core 1**

| Layer | Day Sprayed | Day Fractured | Cure Time (days) | Force (lb) | Stress (psi) | Notes |
|---|---|---|---|---|---|---|
| 1 | 10/28/96 | 2/10/97 | 105 | 2230 | 357 | bottom |
| 1 | 10/28/96 | 2/12/97 | 107 | 2230 | 357 | bottom |
| 5 | 12/23/96 | 2/7/97 | 46 | 1760 | 282 | top |
| 5 | 12/23/96 | 2/8/97 | 47 | 2020 | 323 | top |

**Core 2**

| Layer | Day Sprayed | Day Fractured | Cure Time (days) | Force (lb) | Stress (psi) | Notes |
|---|---|---|---|---|---|---|
| 1 | 10/28/96 | 2/10/97 | 105 | 2530 | 405 | bottom |
| 4 | 12/9/96 | 2/8/97 | 61 | 2570 | 411 | top |
| 4 | 12/9/96 | 2/12/97 | 65 | 2710 | 434 | top |
| 5 | 12/23/96 | 2/7/97 | 46 | 1960 | 314 | top |

**Core 3**

| Layer | Day Sprayed | Day Fractured | Cure Time (days) | Force (lb) | Stress (psi) | Notes |
|---|---|---|---|---|---|---|
| 1 | 10/28/96 | 2/8/97 | 103 | 2060 | 330 | bottom |
| 3 | 11/25/96 | 2/7/97 | 74 | 1650 | 264 | big void |
| 5 | 12/23/96 | 2/8/97 | 47 | 1900 | 304 | top |
| 5 | 12/23/96 | 2/10/97 | 49 | 1680 | 269 | top |

**Core 4**

| Layer | Day Sprayed | Day Fractured | Cure Time (days) | Force (lb) | Stress (psi) | Notes |
|---|---|---|---|---|---|---|
| 1 | 10/28/96 | 2/8/97 | 103 | 2340 | 375 | bottom |
| 1 | 10/28/96 | 2/10/97 | 105 | 2330 | 373 | bottom |
| 3 | 11/25/96 | 2/12/97 | 79 | 2700 | 432 | bet 2 & 3 |
| 5 | 12/23/96 | 2/7/97 | 46 | 1680 | 269 | top |

| | | |
|---|---|---|
| **Max =** | **434** | **psi** |
| **Ave =** | **344** | **psi** |
| **Min =** | **264** | **psi** |
| **St Dev =** | **58.3** | |
| **Coef of Var =** | **16.9** | |

11
**SET 3, PANEL 3**
Sprayed at two week intervals
Surface Preparation: Sandblasted and Wet

**Core 1**

| Layer | Day Sprayed | Day Fractured | Cure Time (days) | Force (lb) | Stress (psi) | Notes |
|---|---|---|---|---|---|---|
| 1 | 10/28/96 | 2/8/97 | 103 | 2160 | 346 | bottom |
| 1 | 10/28/96 | 2/10/97 | 105 | 2220 | 355 | bottom |
| 1 | 10/28/96 | 2/12/97 | 107 | 2980 | 477 | bottom |
| 5 | 12/23/96 | 2/7/97 | 46 | 1920 | 307 | top |

**Core 2**

| Layer | Day Sprayed | Day Fractured | Cure Time (days) | Force (lb) | Stress (psi) | Notes |
|---|---|---|---|---|---|---|
| 1 | 10/28/96 | 2/7/97 | 102 | 1960 | 314 | bottom |
| 1 | 10/28/96 | 2/10/97 | 105 | 2370 | 379 | bottom |
| 2 | 11/11/96 | 2/12/97 | 93 | 2550 | 408 | middle |
| 5 | 12/23/96 | 2/8/97 | 47 | 2130 | 341 | top |

**Core 3**

| Layer | Day Sprayed | Day Fractured | Cure Time (days) | Force (lb) | Stress (psi) | Notes |
|---|---|---|---|---|---|---|
| 1 | 10/28/96 | 2/10/97 | 105 | 2450 | 392 | bottom |
| 1 | 10/28/96 | 2/12/97 | 107 | 2500 | 400 | bottom |
| 4 | 12/9/96 | 2/8/97 | 61 | 2390 | 383 | top |
| 5 | 12/23/96 | 2/7/97 | 46 | 2210 | 354 | top |

**Core 4**

| Layer | Day Sprayed | Day Fractured | Cure Time (days) | Force (lb) | Stress (psi) | Notes |
|---|---|---|---|---|---|---|
| 1 | 10/28/96 | 2/10/97 | 105 | 2450 | 392 | bottom |
| 1 | 10/28/96 | 2/12/97 | 107 | 2350 | 376 | bottom, big void, see photo |
| 5 | 12/23/96 | 2/8/97 | 47 | 1930 | 309 | top |

| | | |
|---|---|---|
| **Max =** | **477** | **psi** |
| **Ave =** | **369** | **psi** |
| **Min =** | **307** | **psi** |
| **St Dev =** | **44.6** | |
| **Coef of Var =** | **12.1** | |

12

**SET 3, PANEL 4**

Sprayed at two week intervals

Surface Preparation: Nothing

**Core 1**

| Layer | Day Sprayed | Day Fractured | Cure Time (days) | Force (lb) | Stress (psi) | Notes |
|---|---|---|---|---|---|---|
| 1 | 10/28/96 | 2/8/97 | 103 | 2210 | 354 | bottom |
| 1 | 10/28/96 | 2/12/97 | 107 | 2120 | 339 | bottom |
| 1 | 10/28/96 | 2/14/97 | 109 | 2420 | 387 | bottom |
| 4 | 12/9/96 | 2/10/97 | 63 | 1450 | 232 | middle |

**Core 2**

| Layer | Day Sprayed | Day Fractured | Cure Time (days) | Force (lb) | Stress (psi) | Notes |
|---|---|---|---|---|---|---|
| 1 | 10/28/96 | 2/10/97 | 105 | 2000 | 320 | bottom |
| 1 | 10/28/96 | 2/12/97 | 107 | 1830 | 293 | bottom |
| 3 | 11/25/96 | 2/14/97 | 81 | 2320 | 371 | middle |
| 5 | 12/23/96 | 2/8/97 | 47 | 1490 | 239 | top, big void, not sprayed well |

**Core 3**

| Layer | Day Sprayed | Day Fractured | Cure Time (days) | Force (lb) | Stress (psi) | Notes |
|---|---|---|---|---|---|---|
| 1 | 10/28/96 | 2/10/97 | 105 | 1630 | 261 | bottom |
| 1 | 10/28/96 | 2/12/97 | 107 | 1680 | 269 | bottom |
| 2 | 11/11/96 | 2/14/97 | 95 | 1960 | 314 | bet 1 & 2 |
| 5 | 12/23/96 | 2/8/97 | 47 | 1670 | 267 | top, big void, not sprayed well |

**Core 4**

| Layer | Day Sprayed | Day Fractured | Cure Time (days) | Force (lb) | Stress (psi) | Notes |
|---|---|---|---|---|---|---|
| 1 | 10/28/96 | 2/10/97 | 105 | 2210 | 354 | bottom |
| 1 | 10/28/96 | 2/12/97 | 107 | 2280 | 365 | bottom |
| 1 | 10/28/96 | 2/14/97 | 109 | 3130 | 501 | bottom |
| 5 | 12/23/96 | 2/8/97 | 47 | 1930 | 309 | top |

| | | |
|---|---|---|
| **Max =** | **501** | **psi** |
| **Ave =** | **324** | **psi** |
| **Min =** | **232** | **psi** |
| **St Dev =** | **67.6** | |
| **Coef of Var =** | **20.9** | |

**Standard Concrete Panels 11/11/96**

| | Day Poured | Day Fractured | Cure Time (days) | Force (lb) | Stress (psi) | Notes |
|---|---|---|---|---|---|---|
| core 1 | 11/11/96 | 1/22/97 | 72 | 1890 | 303 | bottom |
| core 1 | 11/11/96 | 1/24/97 | 74 | 1640 | 263 | bottom |
| core 1 | 11/11/96 | 1/25/97 | 75 | 1880 | 301 | bottom |
| core 2 | 11/11/96 | 1/22/97 | 72 | 1940 | 311 | middle |
| core 2 | 11/11/96 | 1/24/97 | 74 | 2010 | 322 | bottom |
| core 2 | 11/11/96 | 1/25/97 | 75 | 2010 | 322 | bottom |
| core 3 | 11/11/96 | 1/24/97 | 74 | 1840 | 295 | top |
| core 3 | 11/11/96 | 1/25/97 | 75 | 1880 | 301 | top |
| core 3 | 11/11/96 | 1/27/97 | 77 | 1390 | 223 | top |
| core 4 | 11/11/96 | 1/24/97 | 74 | 1920 | 307 | middle |
| core 4 | 11/11/96 | 1/25/97 | 75 | 1670 | 267 | bottom |
| core 4 | 11/11/96 | 1/27/97 | 77 | 1860 | 298 | bottom |

| | | |
|---|---|---|
| **Max =** | **322** | **psi** |
| **Ave =** | **293** | **psi** |
| **Min =** | **223** | **psi** |
| **St Dev =** | **28.6** | |
| **Coef of Var =** | **9.8** | |

**Standard Concrete Panels 11/18/96**

| | Day Poured | Day Fractured | Cure Time (days) | Force (lb) | Stress (psi) | Notes |
|---|---|---|---|---|---|---|
| core 1 | 11/18/96 | 1/27/97 | 70 | 2420 | 387 | bottom |
| core 1 | 11/18/96 | 2/3/97 | 77 | 2420 | 387 | bottom |
| core 1 | 11/18/96 | 2/6/97 | 80 | 2430 | 389 | bottom |
| core 2 | 11/18/96 | 1/27/97 | 70 | 2020 | 323 | top |
| core 2 | 11/18/96 | 2/3/97 | 77 | 2060 | 330 | top |
| core 2 | 11/18/96 | 2/6/97 | 80 | 2570 | 411 | top |
| core 3 | 11/18/96 | 2/3/97 | 77 | 1819 | 291 | top, cable |
| core 3 | 11/18/96 | 2/6/97 | 80 | 2010 | 322 | top |
| core 3 | 11/18/96 | 2/7/97 | 81 | 1900 | 304 | top |
| core 4 | 11/18/96 | 2/3/97 | 77 | 2350 | 376 | top, cable |
| core 4 | 11/18/96 | 2/6/97 | 80 | 2190 | 351 | top |
| core 4 | 11/18/96 | 2/7/97 | 81 | 2320 | 371 | top |

| | | |
|---|---|---|
| **Max =** | **411** | **psi** |
| **Ave =** | **354** | **psi** |
| **Min =** | **291** | **psi** |
| **St Dev =** | **38.8** | |

**Standard Concrete Panels 11/25/96**

| | Day Poured | Day Fractured | Cure Time (days) | Force (lb) | Stress (psi) | Notes |
|---|---|---|---|---|---|---|
| core 1 | 11/25/96 | 2/7/97 | 74 | 2360 | 378 | top |
| core 1 | 11/25/96 | 2/8/97 | 75 | 2280 | 365 | top |
| core 1 | 11/25/96 | 2/10/97 | 77 | 1840 | 295 | top |
| core 2 | 11/25/96 | 2/7/97 | 74 | 2410 | 386 | top |
| core 2 | 11/25/96 | 2/8/97 | 75 | 2270 | 363 | top |
| core 2 | 11/25/96 | 2/10/97 | 77 | 1720 | 275 | top |
| core 3 | 11/25/96 | 2/7/97 | 74 | 2400 | 384 | top |
| core 3 | 11/25/96 | 2/8/97 | 75 | 2240 | 359 | top |
| core 3 | 11/25/96 | 2/10/97 | 77 | 2210 | 354 | top |
| core 4 | 11/25/96 | 2/7/97 | 74 | 2400 | 384 | top |
| core 4 | 11/25/96 | 2/8/97 | 75 | 2480 | 397 | top |
| core 4 | 11/25/96 | 2/10/97 | 77 | 1830 | 293 | top |

| | | |
|---|---|---|
| **Max =** | **397** | **psi** |
| **Ave =** | **353** | **psi** |
| **Min =** | **275** | **psi** |
| **St Dev =** | **41.5** | |
| **Coef of Var =** | **11.8** | |

**Compression Cylinders**

| Day Poured | Day Fractured | Cure Time (days) | Slump (in) | Unit Weight (pcf) | Force (lb) | Stress (psi) | Notes |
|---|---|---|---|---|---|---|---|
| 10/29/96 | 1/20/97 | 83 | 3 1/2 | 131 | 142500 | 5040 | |
| 10/30/96 | 1/20/97 | 82 | 3 3/4 | 135 | 220500 | 7799 | |
| 10/31/96 | 1/20/97 | 81 | 4 1/2 | 133 | 177000 | 6260 | |
| 11/1/96 | 1/20/97 | 80 | 4 1/2 | 133 | 131000 | 4633 | looked like a poor mix |
| 11/4/96 | 1/20/97 | 77 | 4 | 134 | 155500 | 5500 | |
| 11/18/96 | 2/17/97 | 91 | 4 | 137 | 205500 | 7268 | |
| 11/25/96 | 2/17/97 | 84 | 4 1/2 | 136 | 212500 | 7516 | |
| 12/10/96 | 2/17/97 | 69 | 4 1/2 | 139 | 199000 | 7038 | |

| | | |
|---|---|---|
| **Max =** | **7799** | **psi** |
| **Ave =** | **6382** | **psi** |
| **Min =** | **4633** | **psi** |
| **St Dev =** | **1204.8** | |
| **Coef of Var =** | **18.9** | |