CONCRETE PIPE INFORMATION CONCRETE PIPE

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# EFFECTS OF CRACKS IN REINFORCED CONCRETE CULVERT PIPE

*Based on the report Diamond Bar Culvert, A Study of Corrosion of the Steel Reinforcement Relative to Crack Widths in Reinforced Concrete Pipe.*

*Prepared by The Technical Committee of The California Precast Concrete Pipe Association, February, 1976.*

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*It is well known that reinforced concrete pipe is designed and can continue to sustain a load and function as a conduit after exhibiting visible cracking. As with other reinforced concrete structures, the reinforcement is not effectively utilized until the concrete does crack. The question is always raised, however, "To what degree can cracking be tolerated in an installed reinforced concrete pipe before repairs are required?" A corollary, or perhaps a part of the same question, is, "Will a crack width greater than 0.01-inch result in corrosion of the reinforcement and perhaps reduce the life expectancy of the pipe?"*

*This article answers these questions, as applied to the Diamond Bar Culvert installed beneath an 80 foot high fill in mid-1962 at Diamond Bar, Los Angeles County, California. While the findings pertain to this particular culvert, they are indicative of what should be justifiably expected in similar environments. Additional investigations such as that for the Brazos River Authority, report similar conclusions of the minimal effect of cracking on the functional integrity of reinforced concrete pipe and the susceptibility of the reinforcement to corrosion.*

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## GENERAL

Over the years, there have been numerous discussions as to the degree of interior cracking that can be tolerated in relation to the integrity and life expectancy of reinforced concrete pipe. At present, some agencies may reject pipe which has developed a crack larger than 0.01 inches in width, one foot in length, during or after backfilling. Due to limited documentation and information on this problem, the Los Angeles County Flood Control District (LACFCD) requested the concrete pipe industry to study the relationship of the 0.01-inch crack width to corrosion induced failure. This investigation was sponsored by the California Precast Concrete Pipe Association.

## CULVERT SELECTION

The Diamond Bar Culvert, an existing flood control culvert shown in *Figure 1*, Plan View, was selected as it had the desired characteristics for the investigation. The inside diameter of the pipe is 78 inches at the entrance reducing to 63 inches approximately 160 feet downstream with a total culvert length of 680 feet. The 78-inch pipe is a 1,750 D-load with single deformed elliptical reinforcing and the 63-inch pipe is a

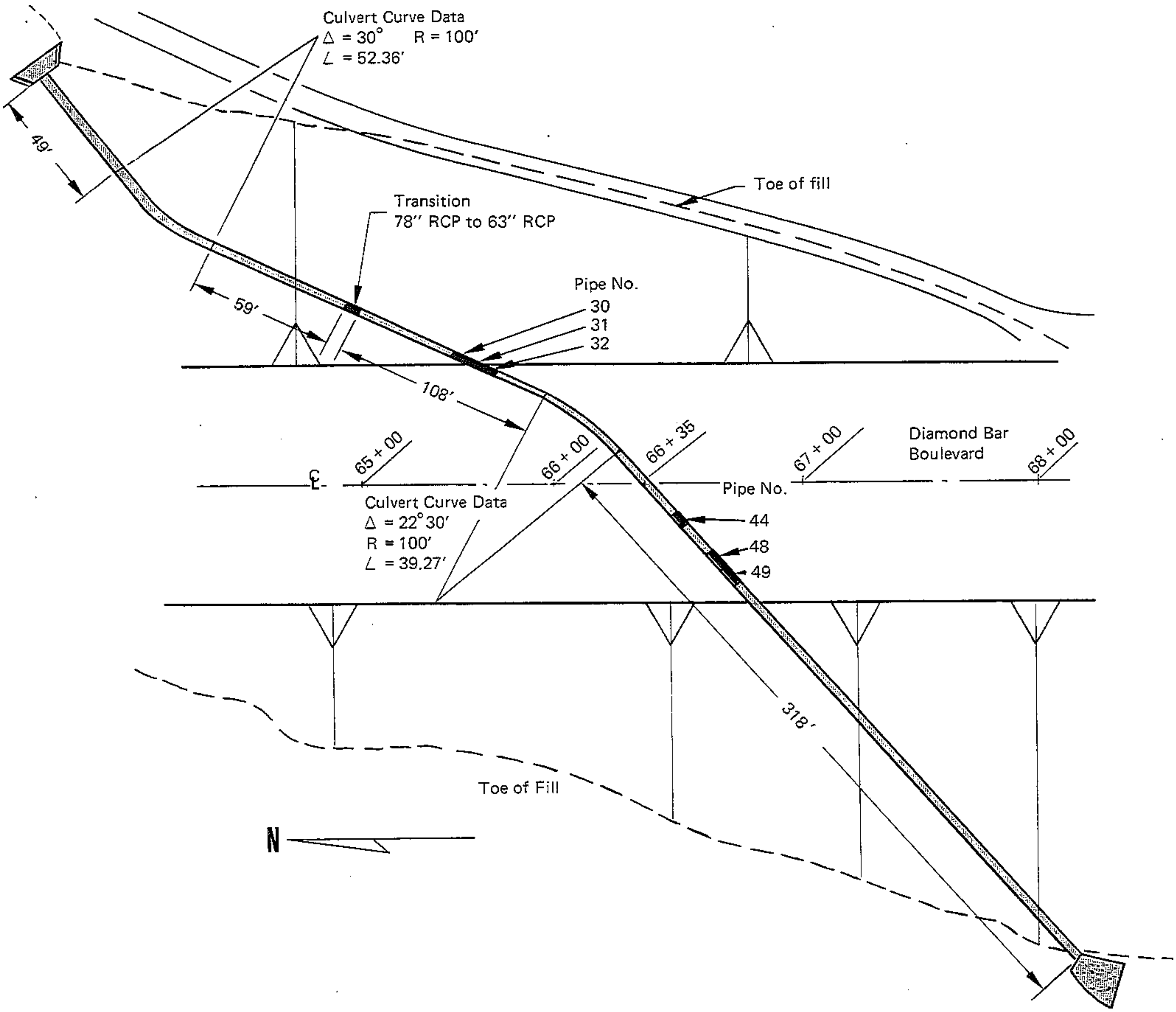


**FIGURE 1: DIAMOND BAR BOULEVARD — CULVERT PIPE PLAN VIEW.**

2,000 D-load, also with single deformed elliptical reinforcing. In this instance, "D-load" is the maximum three-edge bearing load supported by a concrete pipe before a crack occurs having a width of 0.01-inch measured at close intervals, throughout a length of at least 1-foot expressed in pounds per linear foot of inside diameter or horizontal span. The pipe was installed in 1962 using the induced trench installation referred to as Method "B" backfill by the State of California Department of Transportation. The function of this construction technique is to reduce the vertical load on the buried conduit by placing a layer of compressible material over the conduit. The limiting height of covers specified by the State of California were not exceeded.

## PRIOR INVESTIGATION

The Los Angeles County Road Department surveyed the pipe in 1962-64 and found that all pipe except the first 10 and the last 18 lengths exhibited hairline or larger cracks and had cracks continuous from the spigot end to the bell. The cracks were located at either the pipe crown, invert or both. Six pipe lengths numbered 30, 31, 32, 44, 48 and 49, as shown in *Figure 2*, Profile of Culvert, were selected for evaluation. Vertical and horizontal diameter measurements

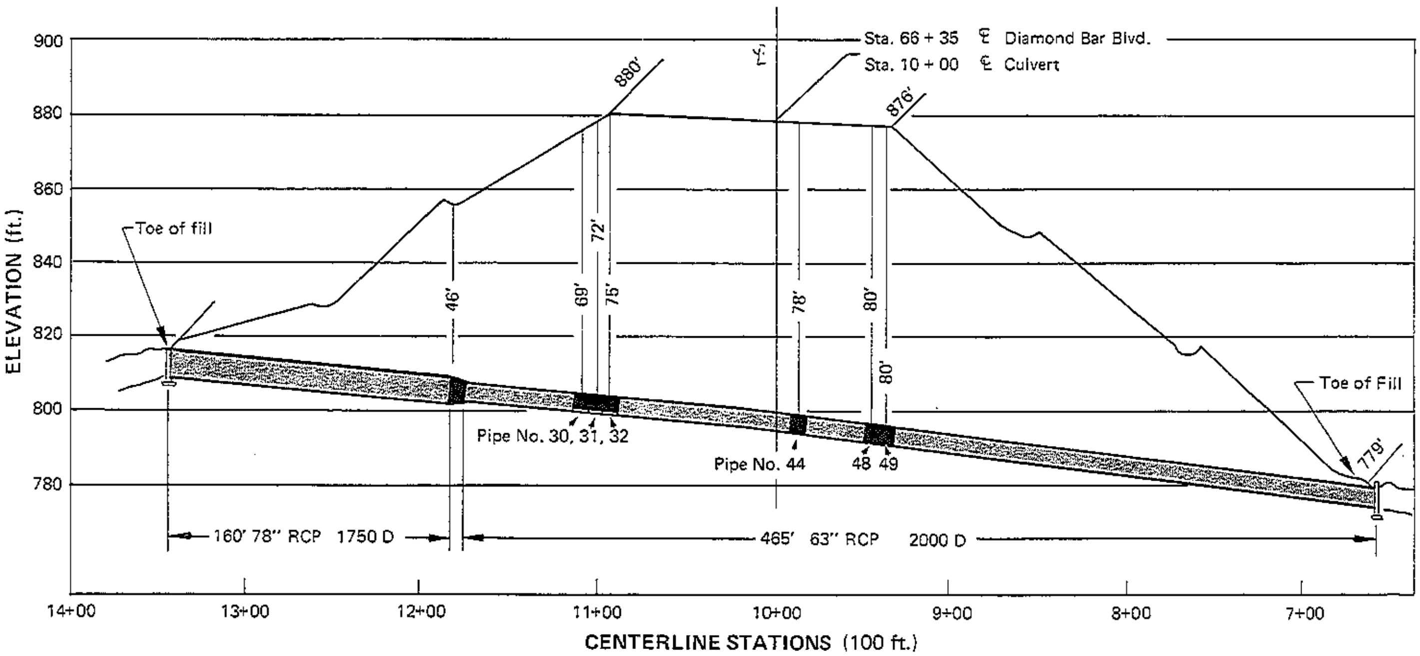


**FIGURE 2: DIAMOND BAR BOULEVARD — CULVERT PIPE PROFILE VIEW.**

were taken. The initial measurements taken in November, 1962 disclosed that pipe 31 had the maximum increase in horizontal diameter, two inches, and the maximum decrease in vertical diameter, one inch. During the following fifteen month period additional measurements indicated the subsequent maximum additional increase in horizontal diameter was 0.102 inch and the maximum additional decrease in vertical diameter was 0.200 inch.

Although the pipe design and manufacture were in accordance with the project specifications, the loads on the pipe after installation were found to be unsymmetrical and not as anticipated. This resulted in deflections causing vertical to horizontal diameter differences of over three inches which produced "slabbing," and flexural cracking. "Slabbing" can be defined as radial tension failure of the concrete and can be visualized as the tendency of the curved reinforcing to straighten out under load. Some of the cracks were repaired during the period 1962-63 with epoxy pressure grouting.

## INVESTIGATION OBJECTIVES

With approval in July, 1974, from the Los Angeles County Road Commissioner, the California Precast Concrete Pipe Association established a test program to relate cracks larger than 0.01 inch to potential corrosion induced failure and to accomplish the following specific objectives:

1. Determine the degree of cracking currently existing in the culvert.
2. Evaluate the extent of corrosion of the reinforcing steel, if any, in crack areas.
3. Determine if there was evidence of autogenous healing in the cracked areas.
4. Report the results and conclusions drawn from the investigation.

## TEST PROGRAM

A preliminary examination of the culvert aided in establishing locations for coring and measurement of pipe deflection and crack width. A total of sixteen coring locations were selected. Nine of the cores were taken at or near the invert, five at or near the springline and two at or near the crown. Three of the springline cores were taken in uncracked areas to provide reinforcing steel control samples. Deflection measurements were taken in the same six lengths of pipe and near the points previously established by the Road Department. Crack widths, where existing, were measured at core locations. Cracks were also examined visually for autogenous healing. Determination of the extent of corrosion was made on the reinforcing steel removed from the cores. Samples of the soil and groundwater from inside the culvert were tested.

## CORING

Cores were cut to obtain reinforcing steel samples. *Table I* lists each core and location, crack width, amount of concrete cover, measured wall thickness and brief comments on the condition of the pipe interior and the extent of corrosion of the reinforcing. In all cases, the uncracked areas of the concrete were found to be sound.

**TABLE I: CORE DESCRIPTIONS.**

| Pipe No. | Core No. | Location | Crack Width (In.) | Concrete Cover (In.) | Wall Thickness | Comments |
|---|---|---|---|---|---|---|
| 22 | 1 | Springline | .060 | 1-1/4 | 6-5/8 | Circumferential crack extended into steel. No corrosion. |
| | 2 | Invert | .160 | 1 | 6-1/2 | Epoxy grout to depth of 2-1/2". Concrete slabbed. Light corrosion. |
| 23 | 3 | Invert | .200 | 1-1/8 | 6-5/8 | Epoxy grout to depth of 2-1/2" extending 6" into vertical crack. Concrete slabbed. Light corrosion. |
| 29 | 4 | Invert | .110 | 1-1/8 | 6-5/8 | Epoxy grout to depth of 4". Concrete slabbed. Light corrosion. |
| | 5 | Springline | None | 1-1/4 | 6 | No cracks. No corrosion. |
| 30 | 6 | Invert | .140 | 3/4 | 6-3/8 | Epoxy grout to depth of 2-7/8". Concrete slabbed. Moderate corrosion to deformations. |
| 34 | 7 | Invert | Crack covered w/ epoxy | 1-3/4 | 6-1/2 | Epoxy did not penetrate below surface. Concrete slabbed. Moderate corrosion to deformations. |
| 34 | 8 | Springline | None | 1-1/4 | 6-1/4 | No cracks. No corrosion. |
| 48 | 9 | Crown | .030 | 1-5/16 | 6-1/4 | Crack extends into rebar. No corrosion. |
| 56 | 10 | Invert | .100 | 1-1/4 | 6 | Crack extends into rebar. No slabbing. No corrosion. |
| 65 | 11 | Crown | .025 | 2-3/8 | 6-1/2 | Crack feathers out at rebar. No corrosion. |
| 21 | 12 | Invert | .090 | 1-1/8 | 7-3/8 | No epoxy repairs. Slabbing of concrete under rebar. Moderate corrosion. |
| | 13 | Crown | .020 | 3-3/4 | 7-1/2 | Crack extends to rebar. No corrosion. |
| | 14 | Springline | None | 1-3/8 | 7-1/2 | No corrosion. |
| | 15 | Invert-30". downstream | .060 | 1-1/8 | 7-1/2 | Slabbing under rebar. |
| | 16 | Invert-13". downstream | .015 | 1-1/8 | 7-3/8 | No slabbing. No corrosion. |

## DEFLECTION MEASUREMENTS

Deflection measurements were taken in October 1974, near the points previously established by the Road Department in 1963. The results are listed in *Table II*. Since the reference points were not the same, a comparison between the two would be questionable.

However, the results did indicate that there had been very little movement in the pipe, both horizontally and vertically, over the eleven year period. It was concluded that maximum distress had already taken place and no future major movement could be anticipated.

## CRACK WIDTH

Crack widths measured in 1974 are tabulated in *Table I*. The most significant point to consider about the crack widths at the core locations is that at the invert, the cracks were more than 0.060 inches wide except at two locations. These areas were the most severely cracked and were purposely selected for coring so the reinforcing steel in these areas could be examined and evaluated. As expected, there appears to be some correlation between the amount of deflection and the width of the crack. As the difference between the horizontal and vertical diameters increase, the crack width increases. No attempt was made to correlate deflection to crack widths in the sidewalls or crown because most of the cracks in these areas were covered by epoxy repairs.

## CORROSION

The cores were broken apart and the steel reinforcing removed for examination and determination of weight loss as a result of corrosion. In all cases, the deformations were well defined and the height of deformations, even in the area most affected by corrosion, exceeded the ASTM Specification A 615 minimum requirement by 75 percent. Reduction in area of the bar cross section was minimal, approximately 5 percent in the area most affected by corrosion.

*Table III* shows the results of the five most corroded samples tested for weight loss. The most severe total weight loss from a sample was 1.372 percent. Corrosion activity was more apparent in areas where slabbing of the concrete had occurred. No significant corrosion had occurred where only flexural cracks existed, and the surrounding concrete was sound even though the depth of the cracks extended to the reinforcing.

## AUTOGENOUS HEALING

Examination of the cracks disclosed no evidence of autogenous healing. Autogenous healing is a process where small cracks are healed by the exposure of the concrete to moisture, forming calcium carbonate crystals that accumulate along the crack edges, inter-twining and building until the crack is filled. Since the culvert is installed on an intermittent stream, there may be insufficient moisture present to promote autogenous healing.

### TABLE II: DIAMETER MEASUREMENTS.

| Pipe No. | Los Angeles County Road Development[1] | | | California Precast Concrete Pipe Association[2] | | | Change |
|---|---|---|---|---|---|---|---|
| | 11/26/62 | | | 10/4/74 | | | |
| | Hor. | Vert. | Diff. | Hor. | Vert. | Diff. | |
| 30 | 63-3/4 | 62 | 1.750 | 63.809 | 52.106 | 1.703 | — .047 |
| 31 | 64 | 61 | 3.000 | 64.250 | 61.005 | 3.245 | + .245 |
| 32 | 63-3/4 | 61-1/2 | 2.250 | 64.015 | 61.360 | 2.655 | + .405 |
| 44 | 63-3/8 | 62-1/2 | .875 | 63.426 | 62.595 | .831 | — .044 |
| 48 | 63-1/4 | 62-3/4 | .500 | 63.398 | 62.884 | .514 | + .014 |
| 49 | 63-1/4 | 62-5/8 | .625 | 63.428 | 62.736 | .685 | + .040 |

NOTES: 1. Measurements made to nearest 1/8 inch.
2. Measurements made to nearest .001 inch.

### TABLE III: WEIGHT LOSS FROM CORROSION OF STEEL REINFORCING.

| Pipe No. | Core No. | Length (In.) | Weight in Gms. | | Weight Loss Gms. | % Weight Loss |
|---|---|---|---|---|---|---|
| | | | Before | After * | | |
| 21 | 12 | 3.738 | 87.3 | 86.5 | 0.8 | .848 |
| | 14 | 3.666 | Control | 88.5 | None | |
| | 15 | 3.745 | 94.3 | 93.0 | 1.3 | 1.372 |
| 22 | 2 | 3.742 | 92.5 | 91.9 | 0.6 | .635 |
| 30 | 6 | 3.362 | 82.9 | 82.2 | 0.7 | .824 |
| 34 | 7 | 3.348 | 78.7 | 78.1 | 0.6 | .710 |
| | 8 | 3.750 | Control | 88.9 | None | |
| 56 | 10 | 3.449 | 83.4 | 83.4 | None | |

* After removal of corrosion products.

NOTES: 1. Control samples taken from areas free of cracks.
2. Slabbing occurred on Core No. 12, 15, 2, 6 and 7.

## SOIL AND WATER SAMPLES

Samples of the soil and the groundwater inside the culvert were tested for pH, hardness, resistivity, iron, chlorides, sulfates, and hydrogen sulfide. The results, as presented in Tables IV and V, indicate the soil and water from inside the culvert is midly corrosive.

**TABLE IV: RESULTS OF PHYSICAL AND CHEMICAL TESTS MADE ON DEPOSITS FROM PIPE NO. 1 IN DIAMOND BAR CULVERT.**

| | |
|---|---|
| Color | Red-Brown |
| pH | 6.8 |
| Iron, mg/ℓ | 371,000 |
| Chloride, mg/ℓ | 500 |
| Sulfate, mg/ℓ | 400 |
| Hydrogen Sulfide | None |
| Magnetic Properties | None |

**TABLE V: RESULTS OF ELECTROCHEMICAL TESTS MADE ON SOIL AND WATER SAMPLES FROM INSIDE OF DIAMOND BAR CULVERT.**

| | Pipe #1 Soil | Pipe #5 Water | Pipe #31 Water | Pipe #84 Soil |
|---|---|---|---|---|
| pH | 7.38 | 7.58 | 8.0 | 8.15 |
| Hardness, mg/ℓ $CaCO_3$ | – | 102 | 136 | – |
| Resistivity, ohm-cm | 2100 | 655 | 642 | 4600 |
| Iron, mg/ℓ | 14000 | – | – | 9800 |
| Chloride, mg/ℓ | <10 | 113 | 137 | <10 |
| Sulfate, mg/ℓ | <40 | 275 | 340 | <40 |
| Hydrogen Sulfide | None | None | None | None |

## CONCLUSIONS AND RECOMMENDATIONS

The Conclusions and Recommendations of the Diamond Bar Culvert Report are:

"1. The presence of .01" wide cracks in Reinforced Concrete Pipe in the installed condition does not constitute failure of the pipe. In fact, cracks substantially larger than .01 inch did not significantly affect the structural integrity of the pipe.

2. Corrosion of the steel reinforcing was not observed at crack widths up to .10 inch where slabbing of the pipe wall had not occurred.

3. Structural integrity of this culvert is not affected by cracks to .10 inch where slabbing failure has not occurred. Even in those areas where cracks as wide as the maximum observed crack of .20 inch have occurred, the structural integrity of the culvert has been maintained.

4. Concrete encasement of this culvert with crack width up to .20 inch, as shown in Table I, has not been necessary to maintain structural integrity.

5. Based on the observed lack of corrosion in those areas where slabbing failure did not occur, the life expectancy of the pipe with cracks to .10-inch was not affected.

6. In those areas where slabbing failure has occurred and epoxy grouting was not performed, observed corrosion rate of the reinforcing steel would lead to a life expectancy of several hundred years. This projection is based on a linear projection of observed corrosion, a ratio of ultimate to working stress of the reinforcing steel of 2.0, and essentially unchanged environmental conditions.

7. Further investigations of this nature should be made to study crack/corrosion/serviceability relationships."