Exhibit A

Research Proposal

Reinforced Concrete Pipe Cracks - Acceptance Criteria

In response to FDOT RFRP #-08/09-005

Submitted to

Patti Brannon
Florida Department of Transportation
Research Center
605 Suwannee Street, MS 30
Tallahassee FL 32399-0450

Submitted by: Alberto A. Sagüés, Principal Investigator.
Department of Civil and Environmental Engineering,
University of South Florida, Tampa, FL 33620,
(813) 974 5819, sagues@eng.usf.edu

Proposed Contract Period: 21 months (18 mo execution + 3 Mo for Final Report preparation, review and revision).

Total Contract amount: $80,000

Proposal Date: February 9, 2009
(Revised 4/6/09)

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Reinforced Concrete Pipe Cracks -Acceptance Criteria

Understanding of the problem

Reinforced concrete pipe (RCP) is widely used by FDOT in installations requiring service over a period of many decades, so only extremely slow deterioration with time can be accepted. Concrete cracks are often revealed by inspection shortly after placement. A decision must be made then on the part of FDOT as to whether the cracks are of little consequence to future performance and accept the pipe, of if repairs or even pipe replacement is needed. FDOT is in need of in-place crack acceptance criteria.

In-place RCP cracks can degrade pipe performance by decreasing structural strength and dimensional stability, permitting leaks and marginally increasing hydraulic resistance, and by allowing premature corrosion of steel reinforcement [1-3]. The latter is of particular concern for long time performance as it can induce concrete spalls, with potentially severe increase in hydraulic resistance and obstructions as well as loss of load bearing wall thickness. Later stages of reinforcement corrosion would result in additional loss of the strength provided by the reinforcement.

Under certain circumstances concrete cracks can become filled with calcite and similar carbonate deposits from concrete leachates interacting with atmospheric or waterborne CO_2, thus recovering part of the initial strength and resistance to penetration of aggressive substances. That phenomenon, known as autogenous healing (AH), [4] has been often cited by pipe manufacturers [5] as a process that eventually seals the cracks and prevents the adverse effects indicated above. However, the occurrence of that process cannot be assured [4], as it depends on the precise water composition [4,6] and flow conditions prevalent at each pipe location. In particular, low pH values retard or prevent healing [6]. Moreover, for a given environment healing is less likely the wider the crack is [6].

Recent FDOT experience has brought this issue to the forefront. Remote camera inspections in two projects revealed extensive cracking [7,8] [A]with apparent widths typically exceeding 0.1 inch in 10% of the instances. Direct inspection of selected locations in one site confirmed the presence of cracks that were long (e.g. in excess of 50 in.), wide (many with largest width exceeding 0.05 in., and one instance reaching 0.3 in.) and deep (at least 0.3 in. measured with a straight insertion gage, likely much longer due to tortuosity; in one instance the straight gage reached a 2.8 in. depth). The depth observations support the expectation that cracks reach down to the reinforcing steel. Site survey data listed environmental pH values as low as ~4.5, which would be highly averse to autogenous healing [6].

From a durability standpoint, the wider cracks encountered in those cases are of concern due to corrosion of the reinforcing steel wire. At the bottom of such cracks bare steel is likely to be directly exposed to water which, if renewed regularly by flow, would

[A] The following restates some prior comments by the author to FDOT in [7,8].

eventually have a pH close to that of the environment. Under neutral and mildly acidic conditions and with natural aeration the steel surface is active, and corrodes where exposed. Galvanic coupling with nearby cathodic steel embedded in the concrete could dramatically aggravate local corrosion of the steel [9], leading to quick section loss and mechanical failure if under tension. The site survey data also showed some locations of elevated chloride content which could further promote corrosion.

Even without aggravating galvanic coupling significant de-rating of performance could take place, given that long term service life requirements (e.g. 100 years) are common in these applications. For example, it might be conservatively assumed that the exposed steel corroded as if it were buried in a typical, not highly aggressive soil environment (with no severe adverse galvanic action). In that case corrosion rate may be expected to be in the order of that used for AASHTO durability estimations, i.e.12 μm/year [10]. A typical reinforcing wire ~¼ inch (~2,500 μm) in diameter and roughly uniform corrosion around the perimeter may be considered. There, a penetration to ~1/3 of the radius (corresponding to ~1/2 cross section loss and hence risking fracture if the loads on the pipe are near design capacity) would be reached after only about 40 years of service. If aggravating galvanic coupling were to be present as well, the de-rating would be proportionately more severe [9], conceivably resulting in some failures after service times in the order of one decade or so. Increased severity from, for example, elevated chloride content could further decrease durability. It is noted also that if corroded wires would fail, the initial cracks could open further leading to more exposed steel, further corrosion and potential concrete spalling.

FDOT at present has acceptance criteria for pipe cracks observed before placement (Section 941, Item 941-1.4), effectively rejecting RP that shows cracks having width above 0.01 in. and extending for a length of 12 in. or more which is as specified in ASTM Standard Specification C 76. However, no FDOT specifications address at present the acceptable crack width once the pipe is in place, where static and dynamic stresses during and after placement caused the wide cracks noted earlier. Because of the interplay between aggravating (such as promoting corrosion related damage) and mitigating (AH) factors, it is not clear at present what may be considered to be an acceptable crack width and under which environmental composition circumstances.

This proposal addresses resolution of the above by presenting a research approach to achieve the objectives of FDOT RFRP 08-09-005, restated here as achieving the following:

(1) Determine what are the influential parameters responsible for crack healing in in-place RCP.

(2) Determine what may constitute a maximum crack width amenable to autogenous healing and sufficient to mitigate reinforcement corrosion

(3) Formulate a draft FDOT specification of guideline detailing pipe crack acceptance criteria during construction.

A scope of work toward achieving those objectives is presented next.

Proposed Research Approach

Pursuant to the requests in the RFRP document, the research sequence will be organized in tasks addressing the following:

Task 1 - Literature / Experience review.

This task will start by compiling any current guidelines for allowable in-place pipe crack acceptance criteria (if any) that may be already stated in other U.S. State DOTs and Federal agencies, as well as relevant foreign specifications. Additionally, a thorough review of the technical literature in scientific journals, conference proceedings and research reports will be conducted to reveal relevant information. The review will address all the issues indicated in the section "Understanding of the Problem" above. The findings from any prior FDOT investigations and technical opinions and experience from FDOT personnel pertaining to this issue will be elicited as well. The literature from pipe manufacturer trade associations will be consulted as appropriate.

State, Federal and foreign agencies will be contacted to learn of any relevant research projects or surveys underway. Project managers and principal investigators of those projects will be contacted to establish progress and interim findings applicable to the present project.

The information obtained in this review will be compiled, discussed for implications to the goals of this project, and a list of conclusions relevant to guiding the execution of the following task will be prepared.

A summary document detailing the findings from this task will be prepared and forwarded to the FDOT technical project manager. The document will summarize the state of the art on (i) What are the influential parameters responsible for crack healing in in-place RCP; (ii) What may constitute a maximum crack width amenable to autogenous healing and sufficient to mitigate reinforcement corrosion; and (iii) What specifications, if any, for in-place cracking acceptance criteria are presently used. The document will also include the elements of a draft preliminary pipe crack acceptance criteria. These preliminary criteria will be for discussion only, and are intended to reveal where focused research may assist in resolving uncertainty in application of the present state of the art and avoid costly excessively conservative specifications.

Task 2 - Final research approach.

After delivery of the review findings and preliminary criteria from Task 1, the technical project manager and the PI will organize a discussion teleconference with FDOT stakeholders to firm up the issues to be resolved by research.

Based on the outcome of the teleconference the PI will develop the final plan for needed experimental work and calculations/modeling. The plan will include detailed information on experimental design and methodology and will be submitted to the research review committee for approval. Any findings resulting in revisions to the Scope of Work must be processed through the Research Center. It is emphasized that Tasks 3 and 4 are subject to change as a result of those revisions.

Task 3 - Conduct research upon approval by Review Committee.

The actual plan of research will depend on the outcome of Tasks 1 and 2. However, it is anticipated that work will involve categories and methodologies exemplified by the following:

3.1 <u>A mostly literature-based evaluation of the causes of AH and the extent expected as function of crack width, water and soil characteristics, and type of concrete.</u>

Considering the funding constraints, it is anticipated that the best return will be obtained by analysis of the large body of research already published in the area of AH. In addition to the classic literature in the issue as cited by Neville [2], notable recent detailed studies that can be applied directly to the present issue are exemplified by the work by Ramm et al on extent of AH as function of crack width and water composition [3], Edvarsen on the same parameters as well as concrete composition [11], Parks et al on AH in drinking water piping including effects on chloride transport [12], and Reinhardt on crack width and temperature effects [13]. It is expected that laboratory work on AH by itself will be limited to evaluation of samples of the concrete used for RCP currently supplied for installation in FDOT projects. That evaluation will be to assess composition of pore water using methodology developed by the PI [15], porosity, and related properties determined to be of importance to AH per examination of the above cited literature and to serve as input for calculations of the expected extent of AH in FDOT RCP applications.

The expected outcome of this activity is the development of a quantitative estimate relating environment properties, concrete type, pipe and crack dimensions, and the extent (ranging from inconsequential to full) and time evolution of AH.

3.2 <u>Field assessment of the extent of autogenous healing encountered in FDOT construction projects.</u>

This phase of the work will address detailed examination of the data base available from recent FDOT projects for which extensive remote camera inspection

RCP data as well as direct pipe examination of selected locations exists, together with environmental water and soil composition information. The PI will work cooperatively with FDOT personnel from the Office of Construction, the State Materials Office and other entities within the Department to identify available information. Pending availability of FDOT personnel or its contractors, the PI will specify data to be collected and interpret results, for additional characterization of sites similar to that conducted by FDOT [8] for extent of AH, environmental conditions, and related evidence of corrosion. Travel to selected field sites by the PI or designee will take place if needed.

The expected outcome of this activity will be confirmation and refinement of the relationship between AH and system variables developed under 3.1 above.

If the field assessment does not confirm the literature-based evaluation, then the PI shall propose a new approach based on the newly developed results.

3.3 <u>Assessment of extent of corrosion and associated concrete deterioration due to crack presence.</u>

This portion of the work will address laboratory experiments to determine the extent of reinforcement corrosion that takes place at a reinforcement wire intersected by a crack in a RCP. Steel corroding at a crack location may suffer aggravated corrosion by galvanic coupling with the rest of the nearby passive steel [9] However, there is also evidence that the amount of corrosion that can be tolerated before further cracking ensues from expansive corrosion products is greater if the corroding zone is small [14]. The extent to which those effects may cancel each other is not known, especially if some amount of AH has taken place. Since damage from corrosion of the reinforcement plays a key role in the long term performance outlook, need for experiments with controlled corrosion amount in cracked RCP concrete with and without induced AH is anticipated. These experiments are expected to take the form of tests in sections of RCP (as in Refs. [1,2]) and in small prismatic and cylindrical specimens as detailed in Ref [14].

The expected outcome will be an indication of the amount of time duration before corrosion spalls occur, as function of pipe, crack and concrete properties, extent of AH development, and environmental)soil and water) conditions. The result will be incorporated into a spall predictive model adapted from previous work by the PI [16]

<u>Task 4 - Establish maximum crack width</u>

The information developed under the research conducted in Task 3 will be interpreted toward establishing the maximum crack width that will not result in unacceptable loss of pipe performance over its entire design service life, either through AH or through any other mitigating phenomenon. The maximum crack width will be expressed in terms of pipe size and configuration and type of concrete if it is found to be significant, and environmental service conditions.

In addition to consideration of AH and corrosion, this task will examine possible mechanical performance degradation effects resulting from crack presence. This may become an independent width limiting factor in situations where mild or AH-promoting environmental conditions would otherwise permit relatively wide cracks. Mechanical issues may also require consideration in estimating the long term effects of corrosion.

Task 5 - Draft FDOT specification / guidance document.

Based on the findings from Task 4 the preliminary pipe crack acceptance criteria advanced for discussion in Task 1 will be modified and completed as needed to prepare a Draft FDOT Specification or Guideline document. The document will be delivered to FDOT for consideration and eventual adoption as a criterion for acceptance of in-place RCP.

Roles and responsibilities of Team members.

The Principal Investigator, Dr. Sagüés, will lead in all Task areas including conducting evaluation of the technical literature; interacting with FDOT representatives in direct conversations and at elicitation meetings, direct experimental work, prepare preliminary and final proposed guideline updates and main authorship of the project deliverables and reports.

The Faculty Participant Dr. Grey Mullins will lead in assessing structural implications of the presence of cracks as indicated in Task 4.

Support on accessing literature sources and on processing newly acquired information as well as analysis of FDOT field data will be provided to the PI by a Graduate student Research Assistant and an Undergraduate research assistant. The Graduate Research Assistant will also conduct laboratory experiments and/or field test specimen preparation and analysis under the direction of the PI.

Depending on availability of qualified Graduate Students at the time of project initiation, the PI may engage for the laboratory work instead a technical consultant/ research practitioner with extensive experience in the area of corrosion characterization and control. In such case, organizations exemplified by Concorr Florida, Inc. (Merritt Island, Fl.) or Karins Engineering Group, Inc. (St . Petersburg, Fl.) will be contacted as needed to hire the needed personnel. Funds otherwise budgeted for Graduate Student stipend and tuition will in such case be applied to the consultant/practitioner costs instead. Utilizing a consultant/contractor will require an amendment to the task work order in advance of such occurring, in addition to FDOT approving the consultant/contractor for use in this project.

References

[1] M.A. Pech-Canul and A.A. Sagüés, "Evaluation of Steel Reinforcement Corrosion in Concrete Drainage Culverts", Paper No. 563, 20 pp., Corrosion/99, NACE International, Houston, TX, 1999.

[2] A. A. Sagüés, J. Peña, C. Cotrim, M. Pech-Canul, I. Urdaneta, "Corrosion Resistance and Service Life of Drainage Culverts", Final Report to Florida Dept. of Transportation, Report No. WPI 0510756, Contract No. B-9898, 62 pp., Aug 2001

[3] A. A. Sagüés, "Corrosion Measurement of Aluminum Alloys and Reinforced Concrete for Determination of Culvert Service Life", Final Report to Florida Dept. of Transportation Materials Office, Report No. 99700-7324-010, 62 pp., Dec. 1989

[4] A. Neville, "Autogenous Healing - a Concrete Miracle?", Concrete International, pp. 76-82, Nov. 2002

[5] See for example Resource # 02-712 (09/07), American Concrete Pipe Association, 2007.

[6] W. Ramm and M. Biscoping, " Autogenous Healing and Reinforcement Corrosion of Water-Penetrated Separation Cracks in Reinforced Concrete", Nuclear Engineering and Design , Vol. 179 p. 191–200, 1998.

[7] A. Sagüés, Memorandum to B. Blanchard, FDOT, Feb. 24, 2008.

[8] A. Sagüés, Letter to M. Paredes, FDOT, Dec. 9, 2008.

[9] S.C. Kranc and A.A. Sagüés, "Computation of Corrosion Distribution Of Reinforcing Steel in Cracked Concrete", in Proc. International Conference on Corrosion and Rehabilitation of Reinforced Concrete Structures, Orlando, FL, Dec. 7-11, 1998, CD ROM Publication No. FHWA-SA-99-014, Federal Highway Administration, 1998.

[10] V. Elias, "Corrosion/Degradation of Soil Reinforcements for Mechanically Stabilized Earth Walls and Reinforced Soil Slopes", Publication No. FHWA-NHI-00-044, Federal Highway Administration, Washington, D.C., 2000.

[11] C. Edvarsen, "Water Permeability and Autogenous Healing of Cracks in Concrete", ACI Materials Journal, Vol. 96, p. 448, 1999.

[12] J. Parks, M. Edwards, P. Vikesland, M. Fiss and A,. Dudi, "Autogenous Healing of Concrete in the Drinking Water Industry", AWWA, Denver, 2008.

[13] H. Reinhardt and M. Jooss, "Permeability and sefl-healing of cracked concrete as a function of temperature and crack width", Cement and Concrete Research, Vol. 33, p. 981, 2003.

[14] A. Torres-Acosta and A.A. Sagüés, "Concrete Cracking by Localized Steel Corrosion - Geometric Effects", ACI Materials Journal, Vol. 101, p.501, 2004.

[15] A.A. Sagüés, S.C. Kranc and R.E. Weyers, "In-Situ Leaching Method for Determination of Chloride in Concrete Pore Water" L. Cáseres, Cement and Concrete Research, Vol. 36, p. 492, 2006.

[16] A.A. Sagüés, "Modeling the Effects of Corrosion on the Lifetime of Extended Reinforced Concrete Structures", Corrosion, Vol. 59, p.854, 2003.

Project Schedule

The project schedule is given in the following Table. Entries indicate % completion. Target date for project initiation is July 2009. The execution period is 18 months plus 3 months for Final Report Preparation, Review and Revision.

PROJECT SCHEDULE

Project Title: Reinforced Concrete Pipe Cracks - Acceptance Criteria
FDOT Project No.: RFRP #-08/09-005 FY 2008-9 Month 2/9/2009
Research Agency: University of South Florida
Principal Investigator: Dr.Alberto A. Sagues

RESEARCH TASK	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21				ESTIMATED % COMPLETION
Task 1																									
Lit. Rev.	33	66	100																						
Task 2																									
Final approach				100																					
Task 3																									
Conduct Rsch.					10	20	25	30	40	50	60	70	75	80	85	90	95	100							
Task 4																									
Maximum Width									25	50	75	100													
Task 5															25	50	75	100							
Draft Specificaton																									
																33	66	100							
Final Report																									
																			33	66	100				
Overall % Complete Projected	4%	8%	10%	15%	20%	25%	30%	35%	40%	45%	50%	0.55	0.6	0.65	0.7	0.75	0.8	0.85	0.9	0.95	100				
Overall % Complete Actual																									

FIG. A – OVERALL PROJECT SCHEDULE

FIG. B – CONTRACT FUNDS

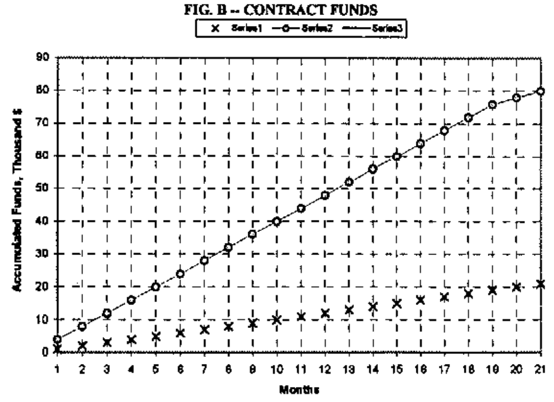
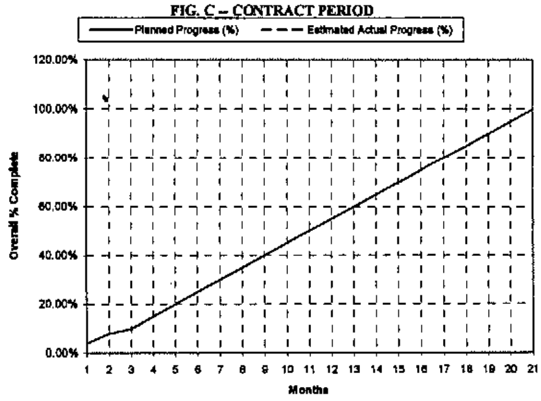


FIG. C – CONTRACT PERIOD



Funds Expended %
Contract Amount $ 80,000
Expended This Month $
Total Exp. to Date $
Balance $

Time expended %
Starting Date 07/01/09
Completion Date 3/31/2011