PRCI LONG-TERM STUDY OF COMPOSITE REPAIR SYSTEMS

PN113586CRA

Prepared for

PRCI and Composite Repair Manufacturers

July 2008

STRESS ENGINEERING SERVICES INC.

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PRCI Long-term Study of Composite Repair Systems

Project Summary Document prepared by Stress Engineering Services, Inc.
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This summary document provides a brief overview of the program being sponsored by the Pipeline Research Council International, Inc. (PRCI) for studying the long-term performance of composite repair systems used to reinforce damaged high pressure carbon steel pipelines. The official title of this PRCI study is *Evaluating the Long-Term Performance of Composite Systems for the Repair of Corrosion and Mechanical Damage.* Discussions associated with this program have taken place over the past 5 years and PRCI members voted in 2007 to execute the program with funding being allocated for 2008.

This document specifically outlines the details associated with the test samples involved in testing. The details provided herein are directly related to discussions that took place as part of the kick-off meeting held at Stress Engineering in Houston, Texas on Wednesday, June 11, 2008.

Project Background

The objective of this program is to evaluate the long-term performance characteristics of the composite repair systems used to repair high pressure transmission gas and liquid pipeline systems. This program involves two phases of study: Phase A is a state of the art assessment including surveys of industry, manufacturers, and literature reviews, while Phase B involves full-scale destructive testing of pipelines with simulated corrosion buried for specific periods of time and removed for burst testing.

Phase A – State of the Art Assessment: The primary focus of this phase of the program is to catalog and survey the performance of available composite repair systems via two paths. As a starting point, a review of the state of the art will be provided. A catalog of manufacturers, their testing results and performance data along with a second survey of the industry experience with composite repair systems will be gathered. Particular attention will be paid to failure histories if they exist. With the large number of composite systems available in the market, industry has difficulty in determining which ones are suitable for the intended service. Since composite repair systems have been approved for use by regulators many potential suppliers have made their products available to industry. While the first entry into the market was tested extensively under the watch of industry and regulators, subsequent potential suppliers have not been scrutinized as closely. Some have performed extensive testing to ensure the performance of their products, while others have not been as thorough. The intent of this effort is to develop a single reference for the composite repair systems that includes a review of the state of the art along with results of all testing performed by the manufacturers and independent laboratories. Knowledge of system failures is also desirable if this information can be obtained from the pipeline industry.

Phase B – In Situ Full-scale Long-term Testing Many pipeline companies use composite repair systems as part of their pipeline maintenance programs for temporary or permanent repairs. For permanent repairs up 50 years, no in situ long-term performance data is available at the present time. For temporary repairs, the data are conservative and penalize defects that could be repaired for a longer-use period. While several operators have performed limited evaluations of the repair technologies, others have elected to trust data and sales-oriented information provided by the manufacturers. To date the only published industry-wide research has been a comprehensive program funded by the Gas Research Institute to assess the performance of the Clock Spring repair system for steel pipelines and involved accelerated tests independently assessing the adhesive and composite. However, this work is over ten years old and did not incorporate long-term testing on buried repair units. Several in-service failures of composite repair systems have reportedly taken place, primarily rooted in failure of the adhesives, poor installation techniques, and development of corrosion beneath the repairs. Short and long-term performance assurance is needed to assess the longevity of the current repair systems. The primary focus of the present program is to confirm the performance of actual composite repair systems on pipes subject to in situ service conditions including cyclic internal pressure, cathodic protection, and environmental soil effects. This will be accomplished by conducting performance evaluations of the current composite repair technologies that have been employed to repair corrosion, dents, and mechanical damage. The desired solution is for industry to avoid replacing perfectly good composite repairs due to a lack of engineering data to support their longevity. This program will also provide a greater understanding about the capabilities and limitations in the short and long term use of composite materials to repair pipelines.

Each manufacturer will be contacted about completing a survey on aspects associated with their particular composite repair system. Included in this survey will be questions regarding their experiences.

General Description of Project Execution
The following general activities will be completed as part of this study.

<u>Activities in the first year of the study will include the following activities.</u>

- Utilize the test matrix selected by the project team including
    - 12.75-inch x 0.375-inch, Grade X42 pipe.
    - Machine corrosion areas with depths of 40%, 60%, and 75% of the pipe's nominal wall with a dimension of 8 inches axially and 6 inches circumferentially.
    - Weld end caps to sample.
    - Sandblast area required for installation.
    - Measure wall thickness in machined corroded region
    - Pressurize samples to induce 90% of the minimum specified yield strength in corroded region (e.g. 556 psi generates stress of 37.8 ksi, which is 90% of 42 ksi, in the 75% corroded region).
    - Install strain gages in machined corroded region.
- Have composite repairs installed by each manufacturer. <u>Each manufacturer should provide to Stress Engineering Services, Inc. a calculation package showing how the repair thickness was determined for each of the three corroded samples.</u>
- Install strain gage on outside surface of composite materials for selected samples.
- Perform the Year 0 (base case) burst tests.
- (OPTION) Coat outside of composite repairs (<u>each manufacturer is responsible for doing this on their repair systems including supplies and personnel</u>).
- Excavate region of SES Waller Test Lab where pipes are to be buried with a target depth for having 18 inches of cover on top of pipe.
- Bury pipe samples as appropriate and connect the pressure system, cathodic protection system, and the data acquisition system for monitoring strain beneath the repairs.
- Pressure cycle and blow down the test samples at the designated periods of time. Record strain gage data monthly during periods of pressure application.

Activities in Years 1 through 3 will include the following activities.

- Pressure cycle and blow down the test samples at the designated periods of time. Record strain gage data monthly. Monthly pressure cycling will include one blow-down pressure to psi and 75 cycles from 36% to 72% SMYS.
- Remove pipe samples and perform burst tests at the ends of Year 1, 2, and 3.
- For those companies participating in the three year study, a total of 12 samples will be fabricated with three samples for each repair being pressurized to failure at 0, 1, 2, and 3 years.

The buried pipes will be monitored over a three-year period. The samples will be cycled once per month (e.g. 75 cycles at 50% MAOP) and blown down and then re-pressurized (e.g. 1 cycle at 100% MAOP) once every month. This combination of pressure cycles is considered to be an aggressive representation of actual pressure conditions for a gas pipeline system over a 50 year period. At the end of each subsequent year (1, 2, and 3) one set of three (3) samples will be removed from the buried soil environment, documented, and then burst tested. For those manufacturers who opt for the 10-year study, additional samples will be fabricated for burst testing at 5, 7.5, and 10 years. For this extended period of testing an additional nine (9) samples will be required for each repair system.

The pipe geometry and grade used in this study will be 12.75-inch x 0.375-inch, Grade X42 pipe with a rectangular corrosion patch that measures 8 inches (longitudinally) by 6-inches (circumferentially). The depths of corrosion to be studied include 40, 60, and 75% of the pipe's nominal wall thickness. The geometry for the machined corrosion region is shown in **Figure 1**.

Strain gages will be installed at specific locations that include the corrosion region beneath the repair, on the base pipe, and on top of the composite material. **Figure 2** shows the layout for these samples. Each sample will be 8 feet in length and include welded end caps with 1-inch NPT pressure port fittings.

Once the samples are fabricated, those samples that are designated for burial will be shipped to the test site. **Figure 3** shows the general layout for the buried test samples. As noted, each group of test samples includes a set of three. This figure is drawn as if three manufacturers will participate for a three year period, while another three manufacturers have elected to participate for the 10-year testing period (a total of six participants are illustrated in this figure).

Activities in Years 3 through 10 will include the following activities.

- This phase of work is a continuation of efforts completed as part of the 3 year study.
- Pressure cycle and blow down the test samples at the designated periods of time. Record strain gage data monthly.
- Remove pipe samples and perform burst tests at the ends of Year 5, 7.5, and 10.
- For those companies participating in the ten year study, a total of 21 samples will be fabricated with three samples for each repair being pressurized to failure at 0, 1, 2, 3, 5, 7.5, and 10 years.

Program Specifics

This section of the package is provided to give specific details on what will be expected from each manufacturer and what each manufacturer can expect during their interactions with SES. Of particular note is the schedule. The current schedule is based on the assumed availability of each manufacturer and currently-scheduled SES staff. It is important that each manufacturer review their allotted time on the schedule and make the necessary arrangement including personnel and supplies for completing all of their repairs (i.e. 12 samples for the 3-year study and 21 samples for the 10-year study participants). Each manufacturer will only be given one week for making their respective repairs.

General schedule

- June/July/August
  - Purchase pipe materials
  - Machine simulated corrosion in pipe samples
  - Sandblast pipes
  - Install strain gage
- September/October/November
  - Make repairs (coordinated scheduling)
  - Perform round of Year 0 burst tests (3 per manufacturer)
  - Prepare buried pipe test site and facility
  - Bury pipe samples (all pipes will be buried at the same time)
  - Connect all required instrumentation, CP systems, and pressure equipment

Listed below are the specifics weeks during which manufacturers will be invited to SES facilities to make repairs. Each manufacturer is expected to provide enough materials and personnel to complete all repairs in a one week period. The numbers shown in parentheses correspond to the number of samples that will be required from each respective manufacturer (12 for the 3-year study and 21 for the 10-year study). Additionally, if a manufacturer would like to have their repair system coated prior to burial, they will be responsible for doing this including providing materials and personnel for doing so.

Fabrication Weeks

Week of July 14	Inspect pipe and cut pipe (1,440 feet of pipe purchased)
Week of July 21	Start machining work
Week of July 28	Start welding end caps and continue machining
Week of August 4	Continue welding end caps and machining (33 complete)
Week of August 11	Continue welding end caps and machining
Week of August 18	Continue welding end caps and machining (66 complete)
Week of August 25	Continue welding end caps and machining
Week of September 1	Continue welding end caps and machining (99 complete)
Week of September 8	Continue welding end caps and machining
Week of September 15	Continue welding end caps and machining (132 complete)
Week of September 22	Continue welding end caps and machining
Week of September 29	Continue welding end caps and machining (165 complete)

Installation Weeks

Week of September 8	Clock Spring (12)	Armor Plate (21)
Week of September 22	Air Logistics (12)	Citadel (21)
Week of October 6	Pipe Wrap (12)	EMS (21)
Week of October 13	Wrap Master (12)	T.D. Williamson (21)
Week of October 20	Walker Technical Resources (12)	3X Engineering (21)

Burst Test Weeks (30 total samples for 10 manufacturers)

Week of October 13	Burst testing
Week of October 20	Burst testing (continued)
Week of October 27	Burst testing (continued)
Week of November 3	Burst testing (continued)

Sample Burial Installation Weeks

Week of October 6	Installation work (site preparation work and other activities)
Week of October 13	Installation work (continued)
Week of October 20	Installation work (continued)
Week of October 27	Installation work (continued)
Week of November 3	Installation work (continued)

Testing Kick-off Weeks

Week of November 10	Pressurize samples and check for leaks and that strain gages are reading properly
Week of November 17	Bury samples, check CP system, and make sure pressure is maintained

<u>Test Sample Preparation</u>

Provide below is a list of specific details associated with each test sample.

- Fabrication of test samples
  - Years of participation:
    - Three (3) year study participants: Four (4) test periods: 0, 1, 2, and 3 years
    - Ten (10) year study participants: Seven (7) test periods: 0, 1, 2, 3, 5, 7.5, and 10 years
  - Three (3) duplicate samples of each repair system
    - 12 samples per manufacturer for 3-year study participants
    - 21 samples per manufacturer for 10-year study participants
  - Machine corrosion to specified depths of 40, 60, and 75 percent of the 0.375-inch nominal pipe wall
- Sandblast samples [1]
- Measure wall thickness in machined corroded region
- Install strain gages
- Pressurize samples to induce minimum specified yield (42 ksi) in corroded region
- Repair samples using composite systems
- Install remaining strain gages as appropriate

<u>Year 0 Burst Tests</u>

- Connect data acquisition (DAQ) system to strain gages and pressure transducer
- Pressurize sample to failure and record data at one scan per second
- Record failure pressures and plot strain as a function of internal pressure for each sample (tabulate maximum strain recorded in repaired region at design pressure and ultimate pressure)

[1] After sandblasting, samples will be shipped to SES's air-conditioned test facility and placed inside for installing strain gages. Every effort will be made to permit repairs to be made inside the test lab. This has been SES's typical mode of operation as long as the repair systems do not contain Volatile Organic Compounds (VOCs). Additionally, some of you have requested that sandblasting be performed within a short period of time (e.g. 24 hours) before the repairs are made; however this is not possible with the current schedule and scope of work that includes strain gage installation.

Long-term Burial Study

- Prepare test area by excavating test site
- Connect samples to pressure system, pressure relief valves, CP system, and strain gages to data acquisition system
- Pressure samples to MAOP
- Bury test samples and monitor/pressure cycles monthly (record with DAQ system)
  - Monthly blow down to 0 psi
  - 75 pressure cycles at 50% MAOP (cycle from 36% to 72% SMYS) once per month
- Maintain pressure in samples at 36% SMYS continuously for all periods except when monthly pressure cycling is being conducted
- Remove samples for testing and burst at specified periods of time (e.g. 1, 2, 3, 5, 7.5, and 10 years)
- Review burst failures and report results

Note that a pressure level of 35% SMYS will be maintained continuously in the pipe samples except during the monthly pressure cycling periods.

Closing Comments

The next several months at Stress Engineering are going to involve a significant amount of work that includes (or has included) purchasing pipe, coordinating machining and fabricating work, sandblasting, pressurizing samples to induce local yielding, installing strain gages, and coordinating with manufacturers time for repair activities.

In anticipation of upcoming events, we request that each manufacturer do the following:

1. Prepare a written design package that details the methods used to determine the required thickness for each corrosion repair depth (i.e. 40, 60, and 75% of the nominal pipe wall thickness). This should be submitted to SES prior to your scheduled installation repair time.
2. Determine and gather the required amount of material for making repairs on all of your test samples (9 samples for the 3-year participants and 21 samples for the 10-year participants).
3. Make sure you have enough staff available in Houston to make all repairs in one week. There will be no exceptions as we have limited space and resources for making these repairs.
4. You are welcome to join us for the times during which we will be pressurizing your test samples to failure. As the time approaches, we will issue a schedule detailing when these burst tests will be made. Based on projected schedule estimations, these will be done between the weeks of October 13 and November 3.

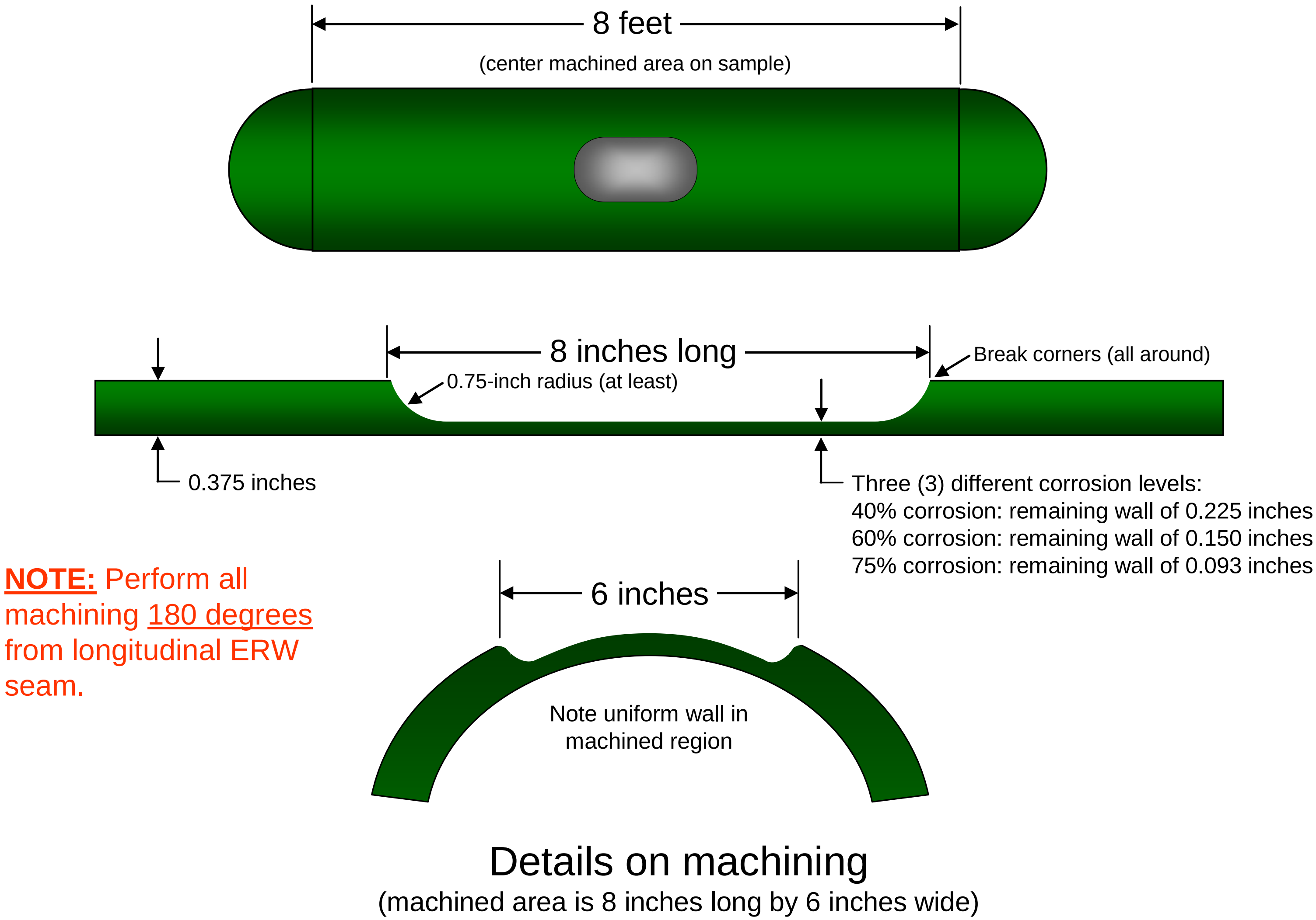

Figure 1 – Details on machining corrosion in 12.75-inch x 0.375-inch, Grade X42 pipe
(target corrosion depth as a percentage of the pipe's nominal wall thickness as shown)

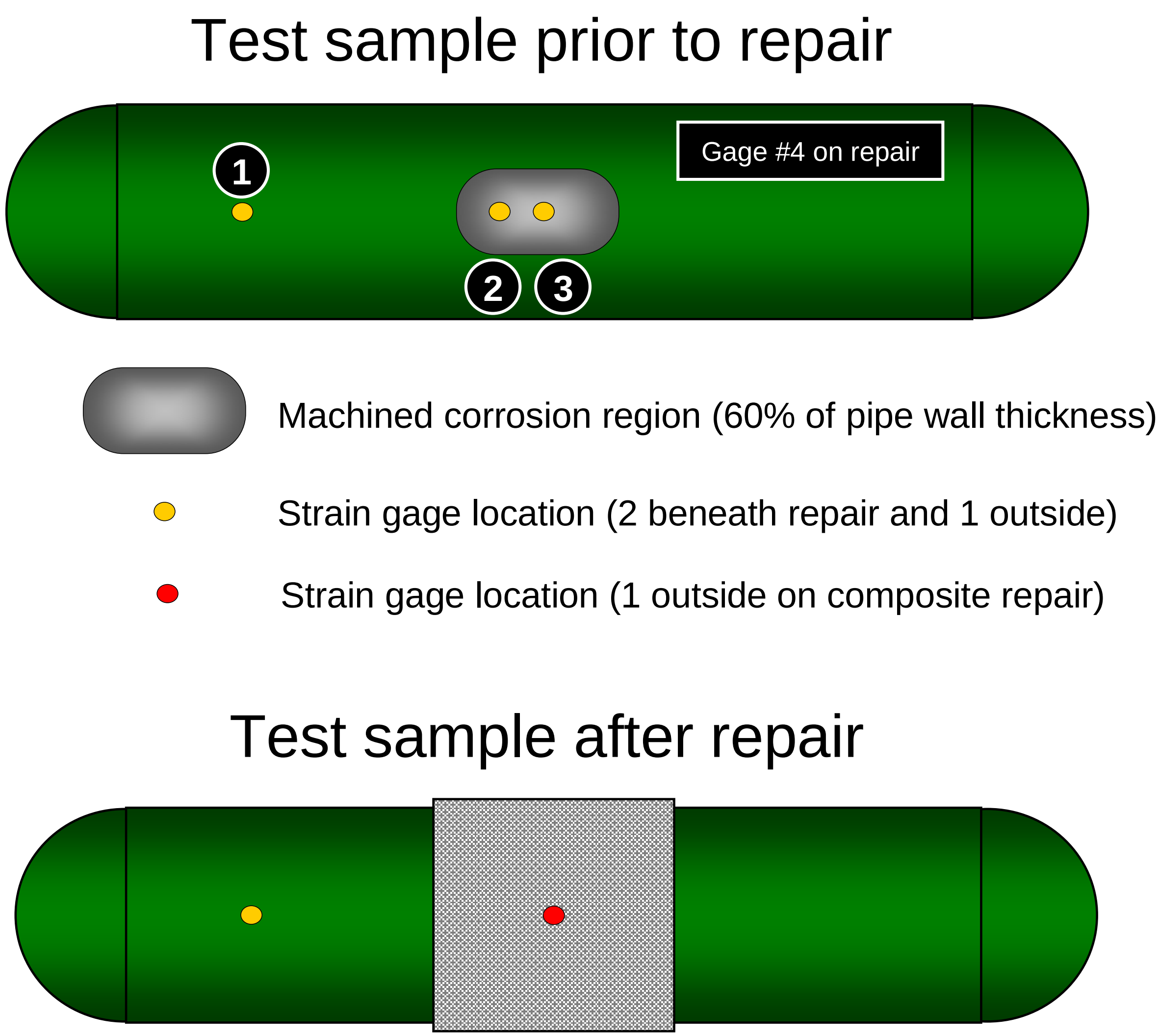

Figure 2 – Test sample layout including strain gage locations

NOTE: The plan for strain gauging is that all samples will have at least one bi-axial gage installed beneath the composite repair (Gage #3 in above figure); however, only one-third of all samples will have all four strain gages installed as shown above. In having strain gages installed beneath all repairs, this will permit SES to monitor the critical information regarding load transfer from the pipe to the composite as a function of time. Every effort will be made to ensure survival of the strain gages, although there are no guarantees that these gages will remain on the samples during all stages of testing.

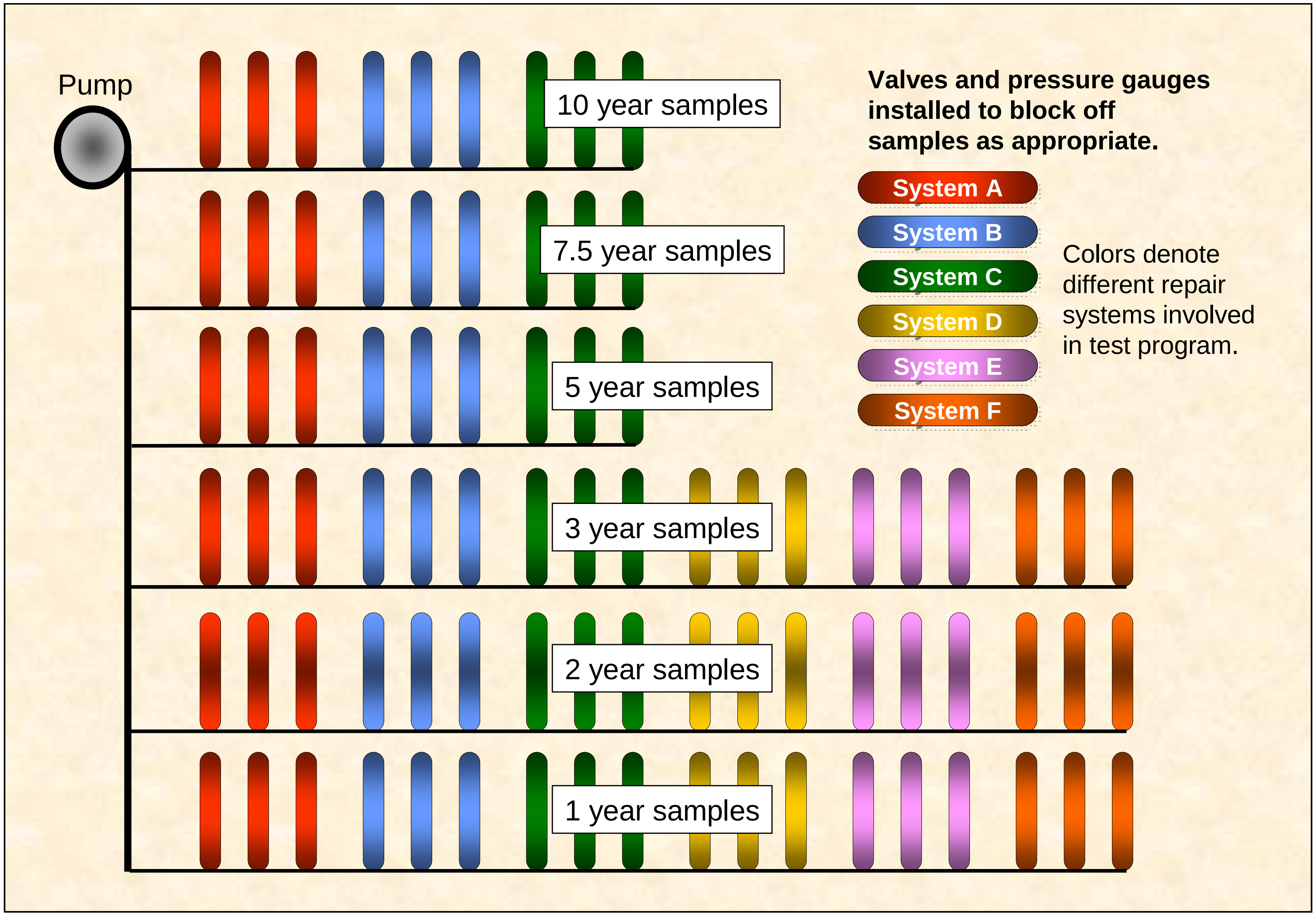

Figure 3 – Layout for buried pipe samples
(the layout shown above only includes six total repair systems: three for the 3-year study and three for the 10-year study)