Enclosure to SBK-L-12129

Seabrook Station

ASR at Seabrook Station – Shear and Lap Splice Testing

ASR AT SEABROOK STATION

SHEAR AND LAP SPLICE TESTING

MARCH 15, 2012

OGUZHAN BAYRAK, PH.D., P.E.
DIRECTOR, FSEL
BAYRAK@MAIL.UTEXAS.EDU

FERGUSON STRUCTURAL ENGINEERING LABORATORY
THE UNIVERSITY OF TEXAS AT AUSTIN
10100 BURNET ROAD, BUILDING 177
AUSTIN, TEXAS USA 78758

512.471.3062 TEL
512.471.1944 FAX

TABLE OF CONTENTS

1 INTRODUCTION

Evaluation and literature review efforts conducted to date have led MPR associates and Dr. Oguzhan Bayrak to conclude that a well-substantiated assessment of the safety-related structures is not possible without additional test data. Data currently available within the literature are generally limited and/or lack relevance to the structural details of Seabrook Station.

The test programs proposed below will provide the data and insights necessary to establish the current and future implications of ASR deterioration within the most vulnerable structural details of Seabrook Station. Specifically, the Shear Test Program (STP) and Lap Splice Test Program (LSTP) will elucidate the effects of ASR with regards to the out-of-plane shear strength of, and lap splice development within, walls without transverse reinforcement. The use of representative scale and materials will ensure that data collected during each of the test programs will be directly applicable to the assessment and management of safety-related structures at Seabrook Station.

Due to similarities in the specimen geometry and test methods, the Shear Test Program and Lap Splice Test Program will be successfully completed in parallel. Descriptions of the test programs are provided below and are followed by a discussion regarding the research methodology common to both test programs (i.e. fabricate, condition, and test).

2 SCOPE OF SHEAR TEST PROGRAM (SPT)

A total of nine (9) reinforced concrete beams will be fabricated to study the effects of ASR on the out-of-plane shear performance of walls found within the B Electrical Tunnel of Seabrook Station. The purpose of each of the nine specimens is outlined below.

- **Control | Establishment of Baseline Shear Performance | One (1) Specimen:** One of the nine beams will be tested to (i) obtain the baseline (undamaged) shear performance of the fully configured specimen and (ii) provide an indication of the margin that exists between the actual (experimentally-determined) strength of the structural wall and the calculated strength by using relevant provisions of ACI 318.
- **Series I | Assessment of Current and Long-Term Degradation | Four (4) Specimens:** Three of the nine beams will be tested to assess the degradation of shear performance at three different levels of ASR deterioration. The first beam will be tested when the severity of the ASR deterioration is representative of the current state of the walls found within the B Electrical Tunnel. Subsequent tests will be conducted at increasing levels of deterioration. The fourth specimen will serve as a spare and testing will be contingent of the results of the other Series I specimens.
- **Series II | Assessment of Wall Retrofit Techniques | Four (4) Specimens:** Three of the nine beams will be tested to assess the efficacy of retrofit techniques (to be

determined) in enhancement of the out-of-plane shear capacity. The retrofit techniques and level(s) of deterioration to be assessed within the three tests will be dependent on the results of the unmodified specimens. The fourth specimen will serve as a spare and testing will be contingent on the results of the other Series II specimens.

The general layout of a specimen for the Shear Test Program is shown in Figure 1. The specimen scale is equivalent to the scale of the walls found within the B Electrical Tunnel. The reinforcement pattern will be designed and detailed to: (i) represent the lack of through-thickness reinforcement within the walls of the B Electrical Tunnel and (ii) enable focused study of unreinforced shear behavior at various levels of ASR degradation.

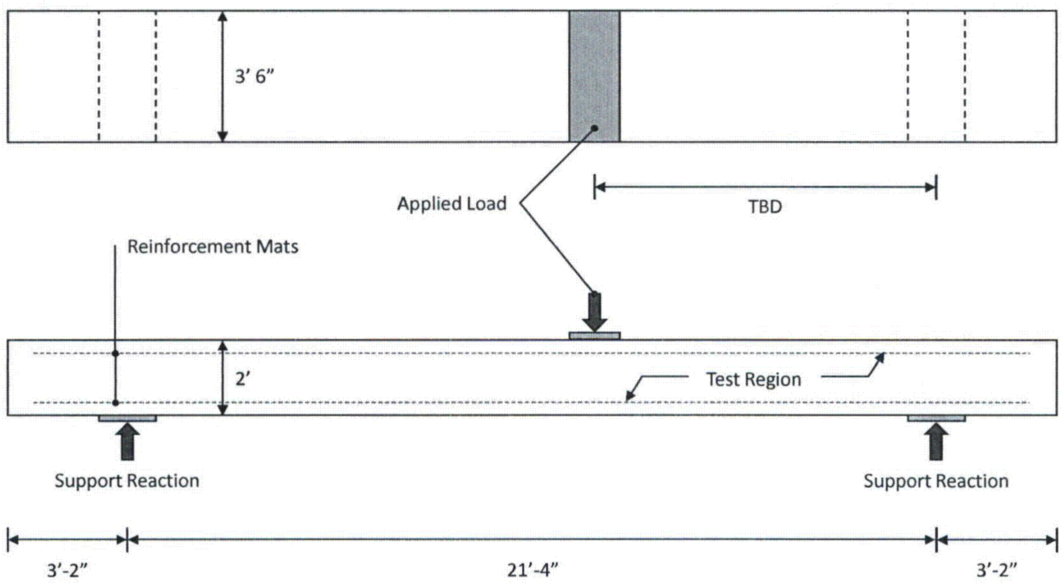

Figure 1: General Layout of Shear Test Specimen

3 SCOPE OF LAP SPLICE TEST PROGRAM (LSTP)

A total of nine (9) reinforced concrete beams will be fabricated to study the effects of ASR on the lap splice development within the walls of the B Electrical Tunnel of Seabrook Station. The purpose of each of the nine specimens is outlined below.

- **Control | Establishment of Baseline Lap Splice Performance | One (1) Specimen:** One of the nine beams will be tested to (i) obtain the baseline (undamaged) lap splice performance of the fully configured specimen and (ii) provide an indication of the margin that exists between the actual (experimentally-determined) strength of the structural wall and the calculated strength by using relevant provisions of ACI 318.

- **Series I | Assessment of Current and Long-Term Degradation | Four (4) Specimens:** Three of the nine beams will be tested to assess the degradation of lap splice performance at three different levels of ASR deterioration. The first beam will be tested when the severity of the ASR deterioration is representative of the current state of the walls found within the B Electrical Tunnel. Subsequent tests will be conducted at increasing levels of deterioration. The fourth specimen will serve as a spare and testing will be contingent of the results of the other Series I specimens.

- **Series II | Assessment of Wall Retrofit Techniques | Four (4) Specimens:** Three of the nine beams will be tested to assess the efficacy of retrofit techniques (to be determined) in enhancement of the lap splice performance. The retrofit techniques and level(s) of deterioration to be assessed within the three tests will be dependent on the results of the unmodified specimens. The fourth specimen will serve as a spare and testing will be contingent on the results of the other Series II specimens.

The general layout of a specimen for the Lap Splice Test Program is shown in Figure 2. The specimen geometry is equivalent to the Shear Test Program and the scale of the walls found within the B Electrical Tunnel. The reinforcement pattern will be designed and detailed to: (i) represent the lack of through-thickness reinforcement within the walls of the B Electrical Tunnel and (ii) enable focused study of lap splice behavior at various levels of ASR degradation. With regards to the second criteria, it will be necessary to provide transverse reinforcement at the specimen ends to preclude the premature shear failures and enforce lap splice failure within the constant moment region (i.e. center of the specimen).

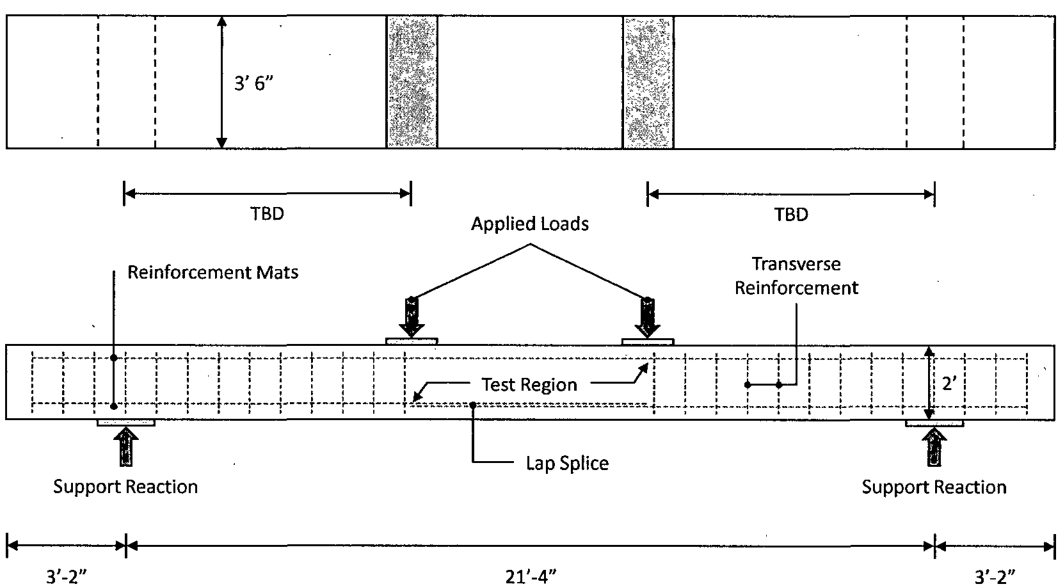

Figure 2: General Layout of Lap Splice Specimen

4 RESEARCH METHODOLOGY

Each test program will feature distinct reinforcement details and testing configurations, but will otherwise adhere to the same workflow: fabrication, conditioning, and structural testing.

Procedures for specimen fabrication will build upon techniques successfully implemented during ASR-related studies at Ferguson Structural Engineering Laboratory. Trial batching will be conducted to develop a concrete mixture that is well-suited to the objectives of the current program. In particular, the final concrete mixture will: (i) rapidly generate ASR damage similar to, and in excess of, that found within the walls of the B Electrical Tunnel, and (ii) result in hardened mechanical performance that is representative of the concrete placed within the B Electrical Tunnel.

All specimens, with the exception of the control beams, will be stored outside of FSEL and subjected to wetting-and-drying cycles to exacerbate/accelerate the ASR deterioration. The time-dependent severity of the ASR deterioration will be characterized by two separate methods. The severity of cracking within the cover concrete will be established through visual inspections and indexing methods. The severity of ASR-related dimensional expansions will be independently recorded by means of reference pins embedded within the structural core of each member. Large-scale shear or lap splice testing will commence when a suitable amount of ASR deterioration has developed. The means of large-scale shear testing at Ferguson Structural Engineering Laboratory are outlined within the sections below.

4.1 LARGE-SCALE BEAM TEST FACILITY

Static loading of each specimen will be conducted within the Large-Scale Beam Testing Facility. Hydraulic ram(s), supported by the strong floor of the testing facility, will exert an upward force at the desired location(s). Simple supports will be provided at the two large steel plate girders (i.e. transfer beams) and high strength threaded rods will transfer the specimen reactions to the floor. The configuration of the test frame for the Shear Test Program is illustrated in Figure 3 through Figure 5. Shear-dominated and flexure-dominated specimens have been successfully tested within the Large-Scale Beam Testing Facility, as illustrated in Figure 6 and Figure 7.

A well-defined, simply-supported testing condition will be created by the installation of roller and pin assemblies at the load(s) and support points, respectively. To permit free rotation and translation at the applied load(s), a three-inch diameter steel bar will be allowed to roll freely between a pair of four-inch thick steel plates. Rotations will be similarly released at each support through the use of two-inch diameter steel bars and two-inch thick steel plates. Axial restraint of the specimens will be limited by the lateral flexibility of the threaded rods at each support.

Each of the specimens will be monotonically loaded to failure in increments equal to approximately one-tenth of the full load-carrying capacity. Structural cracking and other forms of structural distress will be identified and noted between each of the load steps. Photographs of the test region will be used to document the propagation of cracks and the final failure mode will be documented on a video camera.

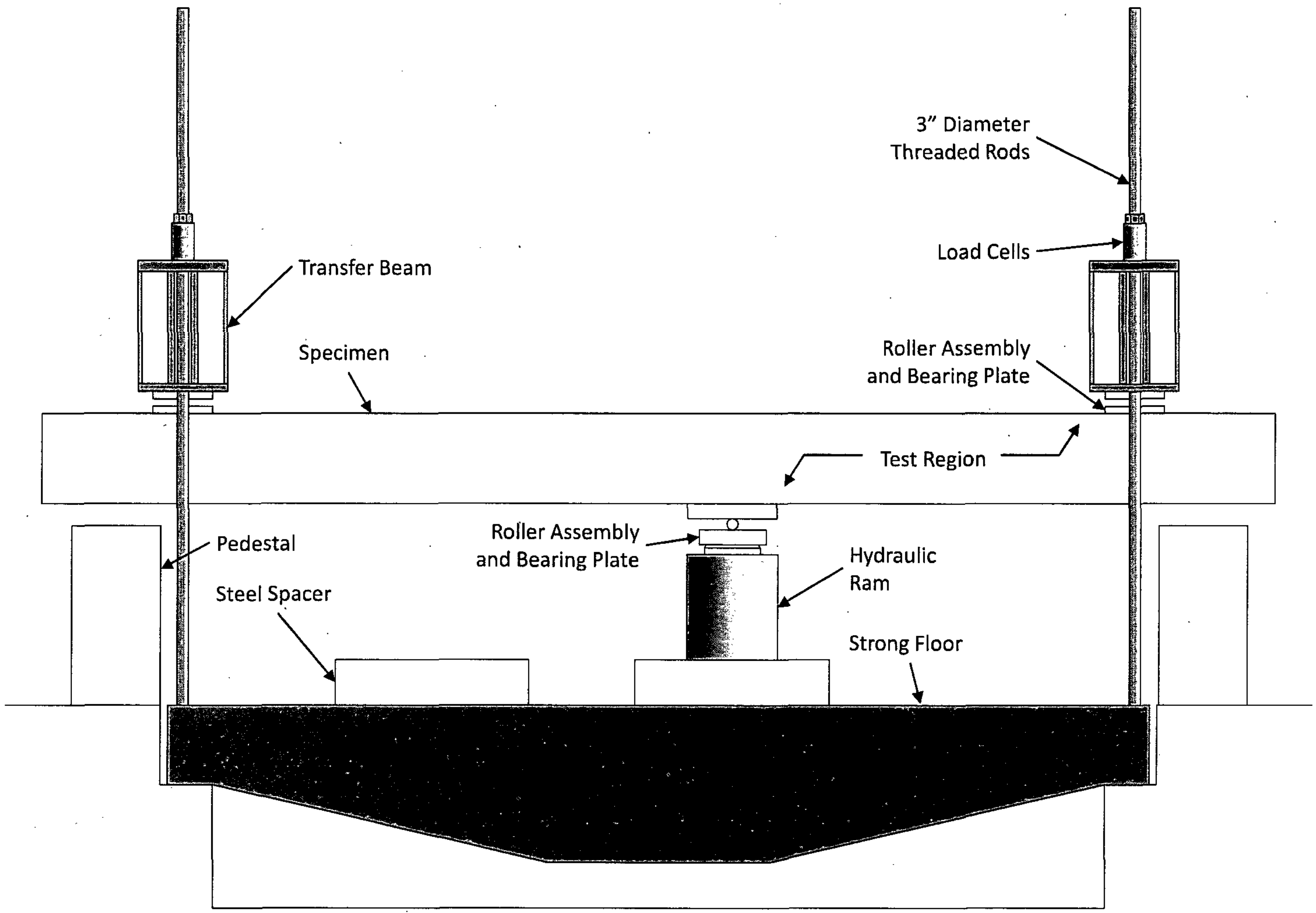

Figure 3: Large-Scale Beam Test Facility for STP, Elevation View

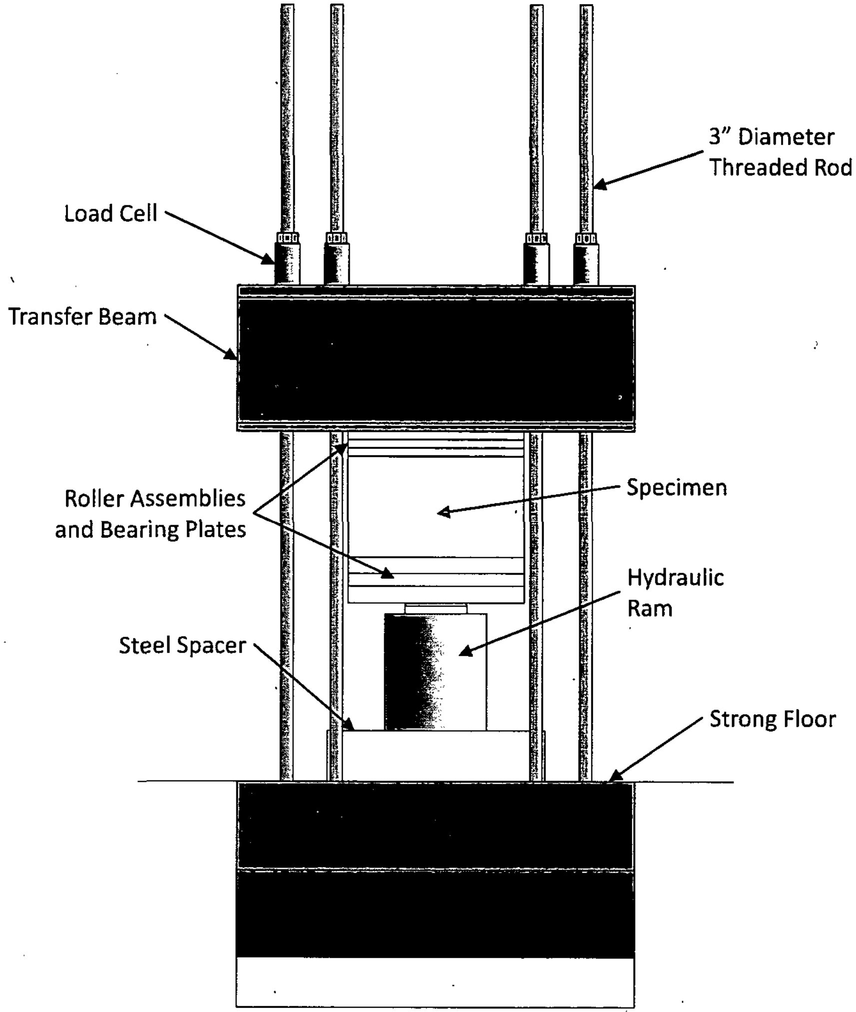

Figure 4: Large-Scale Beam Test Facility, End View

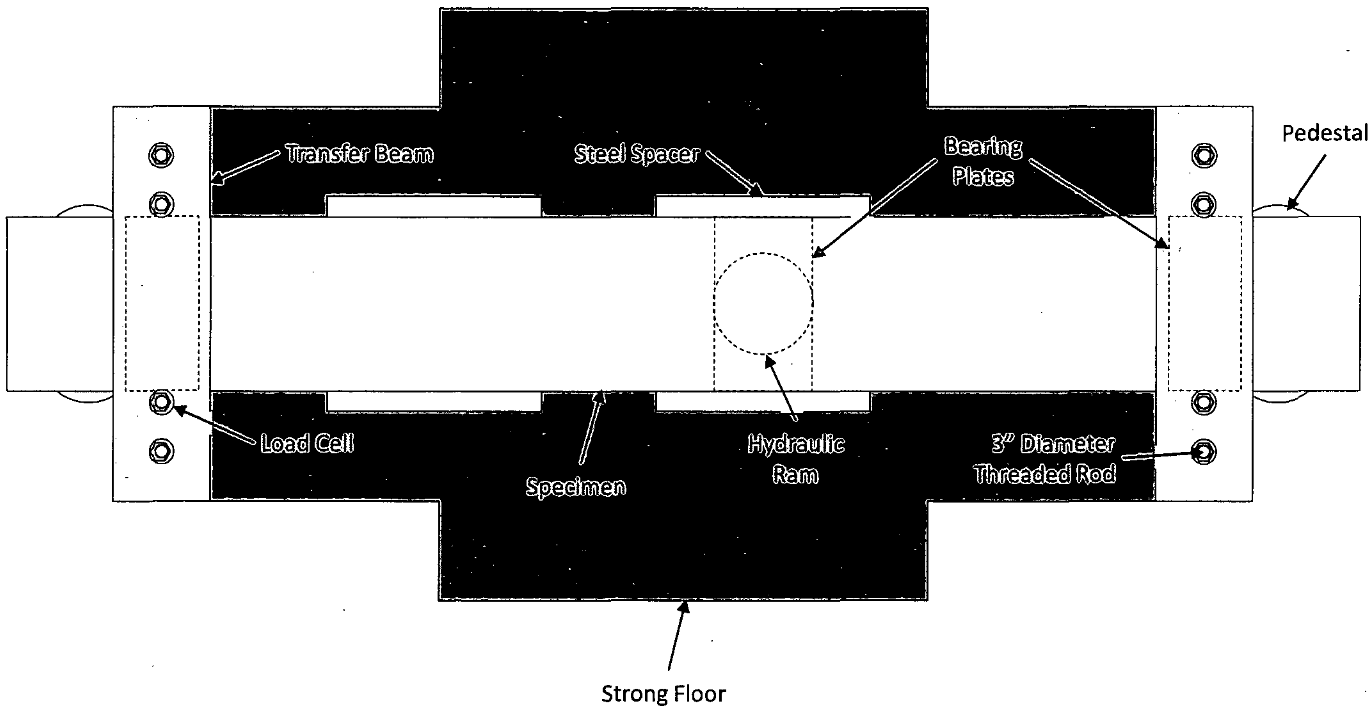

Figure 5: Large-Scale Beam Test Facility for STP, Plan View

Figure 6: Large-Scale Beam Test Facility Configured for Shear-Dominated Testing

Figure 7: Large-Scale Beam Test Facility Configured for Flexure-Dominated Testing

4.2 INSTRUMENTATION AND DATA ACQUISITION

A comprehensive set of instrumentation (Figure 8) will be utilized to capture the data necessary to uniquely characterize the behavior of each specimen. Comparison of the measurements and observations made during the control and damage specimen tests will be vital to identifying the implications of ASR deterioration.

Each of the transducers described below will be wired to bridge completion modules and then interrogated via a 120-channel scanner. The voltage output will be converted into valid engineering data via predetermined calibration factors. A computer with necessary software installations will allow storage and visualization of data in real time. Layouts of the instrumentation for the shear and lap splice test programs are shown in Figure 9.

The reaction at each support will be measured by a set of four load cells. As shown in Figure 8A and Figure 9, the center-hole load cells will be individually placed over each high-strength rod. The reaction nuts and transfer nuts will be leveled prior to applying load to ensure an even distribution of the load among the rods (and corresponding force transducers).

To monitor the displacements, multiple displacement transducers will be positioned along the bottom side of each specimen. Displacements measured at the centerline, load point(s), and each support will be used to isolate the deflection of the specimen. The location of each displacement transducer is illustrated within Figure 9. Typical installation of a displacement transducer is illustrated in Figure 8B.

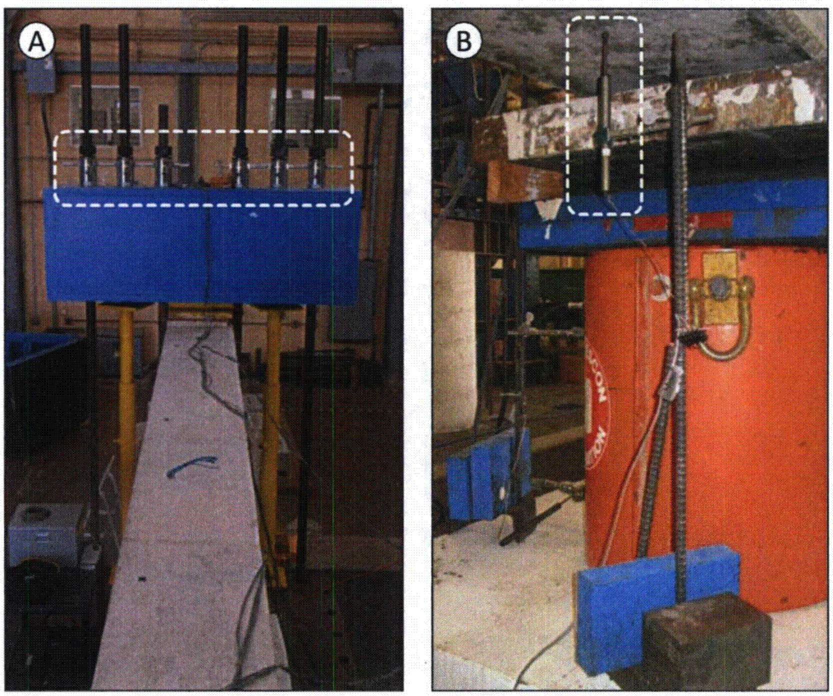

Figure 8: Instrumentation (A) Load Cells (B) Displacement Transducer

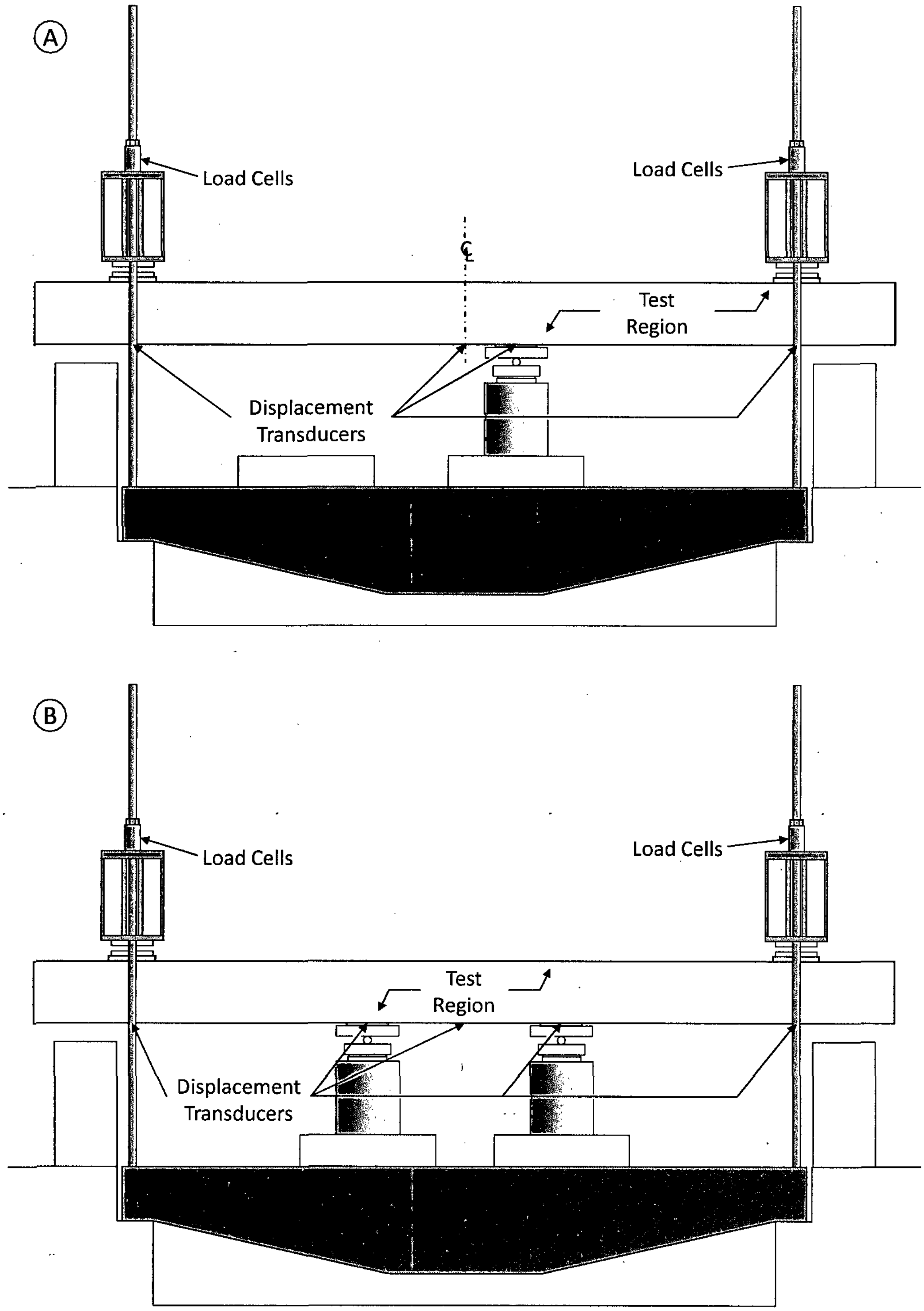

Figure 9: General Instrumentation Layout (A) Shear Test Program (B) Lap Splice Test Program

4.3 POST-TEST ANALYSES: DESIGN MARGIN

Within the context of the Shear Test Program, testing of a control specimen (free from ASR deterioration) will provide an indication of the margin that exists between the in-situ strength of the tunnel walls and the shear capacity calculated by application of ACI 318 Eq. 11-3 ($V_c = 2\sqrt{f'_c} b_w d$). In reference to the control test outcome, the design margin will be inferred from a comparison of the maximum shear carried by the test region (V_{test}) and the calculated shear capacity (V_c).

A comparison of this nature is justified given the similarities that exist between the proposed test program and the empirical bases of ACI 318 Eq. 11-3. More specifically, ACI 318 Eq. 11-3 was derived by ACI Committee 326 (1962) on the basis of test data collected from simply supported shear tests equivalent to the tests proposed here.

Post-test analysis will be necessary to determine the maximum shear carried by the test region, V_{test}. Figure 10 includes the free-body diagram and equations necessary to calculate the full shear force at the critical section. The critical section will be defined at the center of the test region under consideration. It should be noted that the near reaction (R_A) will be taken as the sum of the load cell measurements at that support.

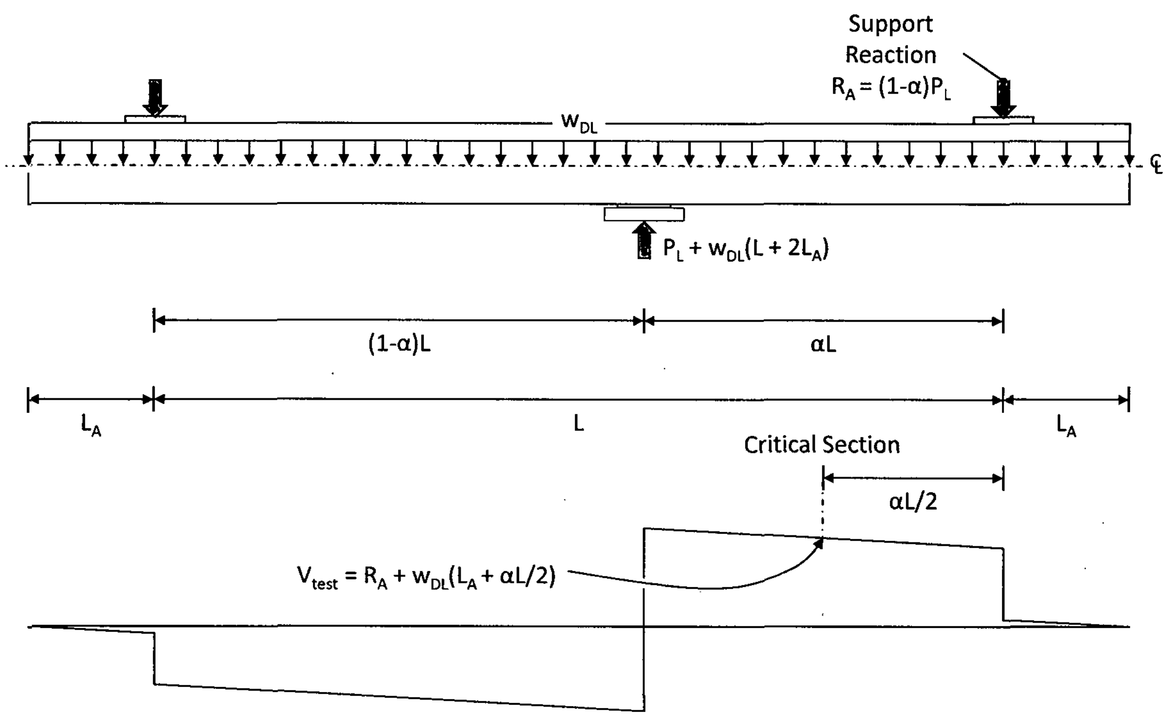

Figure 10: Shear Force Diagram for a Typical Shear Test

Similar analyses can and will be completed for tests conducted under the auspices of the Lap Splice Testing Program. It should be noted that a well-developed lap splice should enable full utilization of the reinforced concrete member in flexure. In reference to the control test outcome, the design margin will be inferred from a comparison of the maximum moment carried by the member (M_{test}) and the flexural capacity (M_n) calculated according to the provisions of ACI 318.

4.4 POST-TEST ANALYSES: FLEXURAL STIFFNESS

Analysis of the load-deflection responses of both shear and lap splice specimens, with and without deterioration, will provide an indication of ASR-related changes in flexural stiffness. As shown in Figure 11, the flexural stiffness (k) of a given member may be inferred from the linear-elastic portion of the load-deflection response. The flexural stiffness of each specimen, control and ASR-affected alike, will be determined in this manner. Comparison of the values will thereby enable a quantitative assessment of the ASR-related changes in flexural stiffness.

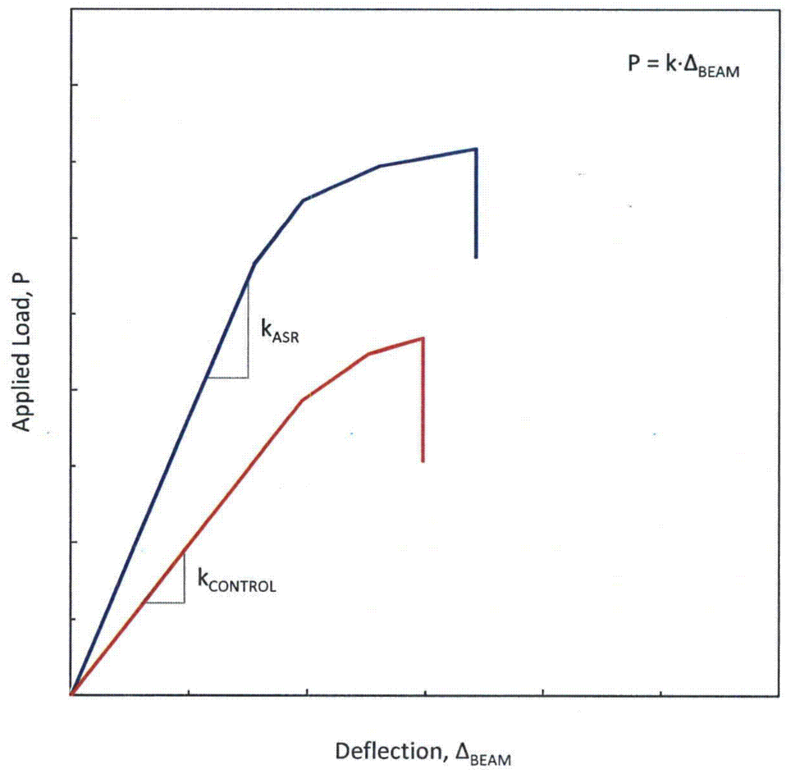

Figure 11: Comparison of Load-Deflection Responses

It should be noted that post-test analysis of the shear test data will be necessary to determine the deflection of the specimen at the load point, Δ_{BEAM}. Rigid body displacement of the specimen at both supports (δ_{NEAR} and δ_{FAR}) will be factored out of the displacement measured at the load point (δ_{LOAD}) as shown in Figure 12. Response of the lap splice specimens will likely be characterized by the displacement at the centerline; similar analyses will be conducted to factor out rigid body displacement of the specimen.

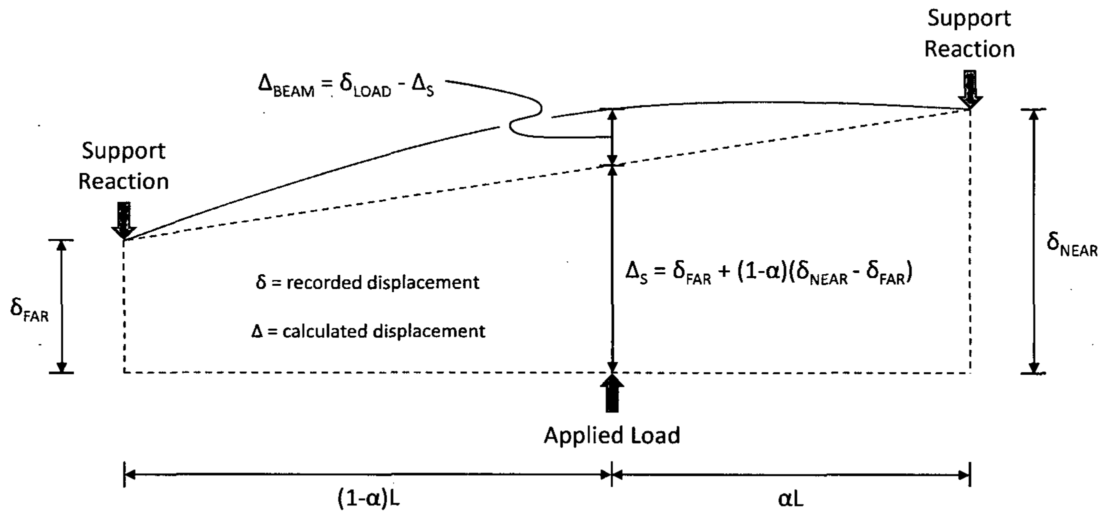

Figure 12: Calculation of Specimen Displacements and Deformations