Demonstrating the Value of Systems Engineering as the Professional Standard of Care

Oliver Hoehne, PMP, CSEP, CSM
Technical Fellow, Systems Engineering
WSP USA
oliver.hoehne@wsp.com

www.incose.org/symp2021
AGENDA

❖ Problem Statement & Offered Solution
  – Project Risk and Liability
  – SE as Liability Protection and Risk Mitigation Strategy

❖ Background & Introduction
❖ Systems Engineering Challenges Faced
❖ Systems Engineering Objectives
❖ Systems Engineering Activities Performed
❖ Summary, Achieved Outcomes & Conclusion
Central Artery/Tunnel Megaproject in Boston, MA

- Commonly known as the **Big-Dig** project
- Rerouted Interstate 93 (I-93) running through the heart of the city into a 1.5-mile tunnel
- Designed and built between 1982 and 2007
- Most expensive highway project in the US at the time (21.5 billion in 2020 US dollars)
- Plagued by thousands of water leaks, design flaws, charges of poor execution, use of substandard materials and other issues
- **Led to the death of a motorist and criminal arrests** when a 24-ton concrete ceiling panel collapsed onto a car

**SOURCE:** [http://www.nbcnews.com/id/22809747/ns/us_news-life/million-settlement-covers-big-dig-tragedy/#.XNQs1hRKi70](http://www.nbcnews.com/id/22809747/ns/us_news-life/million-settlement-covers-big-dig-tragedy/#.XNQs1hRKi70)
$407 million in restitution paid by the consortium managing the project
Several smaller companies agreed to pay a combined sum of approximately $51 million
A settlement agreement included a statement of facts as the basis for liability
The settlement addressed specifically areas of construction management oversight failures:
  – The use of non-specified material
  – The use of substandard materials
  – As well as ignored observations of failing epoxy bolt load tests
The issues identified above are typically addressed in construction specifications describing in detail the scope of work, materials, installation, and quality of workmanship
Professional Standard of Care: defined as the systematic exercise of a reasonable level of care, diligence, and skill

Failure to adhere to the professional standard of care may result in company risk and liability

In the author’s opinion, the Big-Dig issues:
– Describe a common requirements management and verification & validation challenge
– Could have been avoided using a structured systems engineering approach

This presentation:
– Describes the application of SE principles to construction specifications in a large infrastructure project using a case study approach
– Presents the application of systems engineering as the systematic exercise of a reasonable level of care
– Demonstrates the Value of Systems Engineering as a liability protection and risk mitigation strategy
❖ Problem Statement & Offered Solution
❖ **Background & Introduction**
  – Construction Specifications
  – Case Study Project
❖ **Systems Engineering Challenges Faced**
❖ **Systems Engineering Objectives**
❖ **Systems Engineering Activities Performed**
❖ Summary, Achieved Outcomes & Conclusion
Contract documents that govern the construction of building and infrastructure projects (e.g. transportation, water, energy).

Describe in detail the following requirements:
- Scope of work,
- Materials to be used,
- Installation methods, and
- Quality of workmanship (including inspection & testing)

Essential component of the PS&E approach:
- Plans (Drawings),
- Construction Specifications, and
- (Cost) Estimates.

Governed by Construction Specifications Institute (CSI)

INTRODUCTION

CONSTRUCTION SPECIFICATIONS

Part 1 – General: Describes managerial requirements such as applicability, work to be performed, codes and standards, definitions, submittals, quality management, etc.

Part 2 – Products: Describes the (performance) requirements, the acceptable (prescriptive or proprietary) products, materials, and sometimes even specific suppliers. Big-Dig: Would have contained the acceptable materials and material standards.

Part 3 – Execution: Describes the methods of installation and how to measure quality or effectiveness. Big-Dig: Would have identified the inspections and tests to be performed, including the bold load tests.
CASE STUDY PROJECT
CALIFORNIA HIGH-SPEED RAIL SYSTEM

FUTURE CONTRACTS
CASE STUDY PROJECT
CALIFORNIA HIGH-SPEED RAIL SYSTEM (CONT’D)

LEGEN
- CHST Alignment at Grade
- Bridge/Viaduct
- CHST Trench Section
- Work By Others
- Caltrans Scope of Work
- Highway
- Local Road
- River/Creek
- Existing Railroad
- County Limit
- City Limit
- BNSF
- Burlington Northern
- SantaFe Railway
- UP RR
- Union Pacific Railroad
- SJ VR
- San Joaquin Valley Railroad
- OC
- Overcrossing
- OH
- Overhead
- UP
- Underpass

TYPICAL / TYPE OF STRUCTURE

BEGIN PROJECT S 9772+35.08

1. FRESNO RIVER VIADUCT
   - Raymond Rd
   - Fresno River
   - SR 145

2. AVENUE 15-1/2 OH
3. AVENUE 15 OH
4. COTTONWOOD CREEK HST BRIDGE
5. AVENUE 12 HST OH
6. AVENUE 12 BNSF OH
7. AVENUE 11 OH
8. AVENUE 10 OH
9. AVENUE 9 OH
10. AVENUE 8 OH
11. AVENUE 7 OH
12. SAN JOAQUIN RIVER VIADUCT
   - San Joaquin River
   - UPRR

13. W. HERDON AVE HST UP
14. W. HERDON AVE UPRR UP
15. VETERANS BLVD OH (CITY OF FRESNO)
16. W. SHAW AVE OH
17. W. ASHLAN AVE OH (CALTRANS)
18. CLINTON AVE OH (CALTRANS)
19. W. McKinley AVE OH
20. W. OLIVE AVE OH
21. W. BELMONT AVE OH
22. FRESNO TRENCH
CASE STUDY PROJECT
CALIFORNIA HIGH-SPEED RAIL SYSTEM (CONT’D)

225+ MAJOR STRUCTURES
(QUALITY MILESTONES)
❖ Problem Statement & Offered Solution
❖ Background & Introduction
❖ **Systems Engineering Challenges Faced**
  – Typical Industry Approach to Managing Construction Specifications
  – Systems Engineering Challenges
❖ **Systems Engineering Objectives**
❖ **Systems Engineering Activities Performed**
❖ Summary, Achieved Outcomes & Conclusion
Typical Industry Approach to Construction Specs

**Project Delivery Methods & Specification Development**

- **Design – Build Delivery Method**
  - Planning
  - Preliminary Engineering
  - Acquirer / Owner
  - Final Design
  - Construction
  - Operations & Maintenance

**Supplier / Design–Build Firm**

**Owners Standards (Specifications), Part of RFP**

**Standard Specifications**

**Tailored Construction Specifications, Part of Final Design**

**Concrete Sampling Data Report**

**Concrete Compressive Strength Test**

**Objective Evidence, Collected During Construction**

**Concrete Sampling**

**Concrete Strength Test**

Construction Specifications shall be prepared in accordance with the formats of CHSTP Standard Specifications, which are based on Construction Specifications Institute (CSI) MasterFormat™ 2011 edition and SectionFormat™ 2009 edition, and the following requirements: where Contractor has confirmed applicability of CHSTP Standard and Special Specifications sections, with or without modification, Contractor shall incorporate each applicable Standard and Special Specifications section into its Draft Construction Specifications.
Typical Industry Approach to Construction Specs

Construction Quality Management and Procedures

1.7 Quality Assurance/Control

D. Contractor’s Quality Management Plan shall ensure control and uniformity of materials, conformance with accepted mix designs, and prompt and proper delivery of concrete to the jobsite in accordance with applicable requirements of ASTM C94. Include in the plan all tests the Contractor will perform to verify compliance with Specification requirements, and the independent laboratory the Contractor intends to engage to perform the tests.

<table>
<thead>
<tr>
<th>CQP No.</th>
<th>Title</th>
<th>Revision Number</th>
<th>Revision or Issue Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>B1.1</td>
<td>Daily Inspection Reporting</td>
<td>2</td>
<td>03/30/16</td>
</tr>
<tr>
<td>B1.2</td>
<td>Materials Receiving Inspection and Acceptance</td>
<td>2</td>
<td>03/30/16</td>
</tr>
<tr>
<td>B1.3</td>
<td>Pre-Activity Meeting</td>
<td>2</td>
<td>03/30/16</td>
</tr>
<tr>
<td>B1.4</td>
<td>Control of Measuring and Test Equipment</td>
<td>2</td>
<td>03/30/16</td>
</tr>
<tr>
<td>B1.5</td>
<td>Material Storage, Identification and Traceability</td>
<td>2</td>
<td>03/30/16</td>
</tr>
<tr>
<td>B1.6</td>
<td>Material sampling and Testing</td>
<td>2</td>
<td>03/30/16</td>
</tr>
<tr>
<td>B1.7</td>
<td>Off-Site Inspection</td>
<td>2</td>
<td>03/30/16</td>
</tr>
<tr>
<td>B1.8</td>
<td>Management of Construction Subcontractors</td>
<td>2</td>
<td>03/30/16</td>
</tr>
<tr>
<td>B1.9</td>
<td>Inspection and Testing</td>
<td>2</td>
<td>03/30/16</td>
</tr>
<tr>
<td>B1.10</td>
<td>Request For Information</td>
<td>2</td>
<td>03/30/16</td>
</tr>
<tr>
<td>B1.11</td>
<td>Quality Hold Points</td>
<td>2</td>
<td>03/30/16</td>
</tr>
<tr>
<td>B1.12</td>
<td>Field Change Notice</td>
<td>2</td>
<td>03/30/16</td>
</tr>
<tr>
<td>B1.13</td>
<td>Quality Assurance Audit of Construction Activities</td>
<td>2</td>
<td>03/30/16</td>
</tr>
<tr>
<td>B1.14</td>
<td>Construction Surveying</td>
<td>2</td>
<td>03/30/16</td>
</tr>
<tr>
<td>B1.15</td>
<td>Construction Submittal Workflow Process</td>
<td>2</td>
<td>03/30/16</td>
</tr>
</tbody>
</table>

CQP B1.9 Excerpt:

INSTRUCTION & TESTING

- Incoming material or equipment shall be identified, inspected, and tested as required by applicable ITPs and COP B1.2, Materials Receiving, Inspection, and Acceptance.
- Material or equipment manufactured in factories (systems components and equipment) will be subject to factory acceptance tests in accordance with the factory test items list and factory test schedule agreed between TYP and vendors, as defined in COP B1.7, Off-site Inspection. Upon arrival to the project site storage facility, material and/or equipment will be checked visually against shipment documents to verify damage or short quantities.
- Incoming material or equipment will not be used until the required inspection and tests are completed or the necessary inspection and test reports are received and verified.
- Material or services not conforming to specified requirements will be identified and subsequent corrective action will be treated in accordance with COP B1.2, Materials Receiving, Inspection, and Acceptance.

In-process inspection and Testing

- During construction, inspection and testing will be carried out in accordance with the requirements of the ITP and Quality Inspection Schedule. Various elements will be checked for compliance with the Technical Contract Requirements established in DOORS. The requirements for each specific activity will be filtered and exported on an RVTM hard/electronic copy in Microsoft Word, Excel, and Adobe PDF format that will be verified by the inspection staff providing objective evidence that inspection and test plans and procedures meet Technical Contract Requirements (see Form COP B1.9B).
- Works subject to the requirements of the Inspection and Testing, the nominated personnel upon completion of the operation and prior to commencement of the next operation.
- The inspection and testing specified in the ITP will be confirmed with the signature of the nominated personnel upon completion of the operation and prior to commencement of the next operation.
- Inspection checklists could be developed for certain activities. Checklists will show the concerned parties have checked the required points.
- Non-conformances identified during an in-process inspection will be handled and recorded in accordance with COP B1.2. Materials Receiving, Inspection, and Acceptance.

Final Inspection and Testing

This will include the review of inspection records to verify that the product or service has been inspected
## Typical Industry Approach to Construction Specs

### Construction Quality Forms

#### Section 03 05 15

**Portland Cement Concrete**

## Part 1 - General

### 1.6 Submittals

**A. Concrete Mix Designs:** Submit mix designs as herein specified.
- Include laboratory test reports of trial strength and shrinkage minimum of 30 days prior to batching or delivering concrete.

**B. Product Data:** Submit manufacturer's product data for proposed concrete.

**C. Aggregate Source:** Submit aggregate source.

## Part 2 - Products

### 2.3 Mix Designs

**A.** Selection of mix proportions shall conform to the applicable ACI 211.2. Concrete shall comply with ACI 301 and ACI 318 designs which will produce concrete suited for proper placement. Mixes shall include recommended amounts of admixture and air-entraining admixture.

**B.** Mix design for subway structures and below-grade retaining walls shall include 15 percent replacement of the cement with admixture conforming to ASTM C1017, to provide a dense, impermeable, and water-repellent concrete.

**C.** Mix design for architectural concrete and formed concrete to ensure that the finished work shall include a minimum 10 percent replacement of the cement with fly ash, along with a plasticizing admixture conforming with ASTM C1017, to provide a dense and impermeable concrete.

### Concrete Placement Checklist (Pour Card)

**Note:** Once it has been determined that the work meets the project requirements and all relevant items below have been accepted
- Construction Superintendent or designee and the TPZP QC Inspector will sign this Pour Card allowing concrete placement to a Holding Point Release Report and kept with the quality records on SharePoint.

<table>
<thead>
<tr>
<th>Item #</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Access/Work Plans: Reviewed and approved</td>
</tr>
<tr>
<td>2</td>
<td>Layout: Horizontal &amp; vertical control verified</td>
</tr>
<tr>
<td>3</td>
<td>Concrete Mix Design: Submitted and approved for use</td>
</tr>
<tr>
<td>4</td>
<td>Specifications: Confirmation of the governing agency specifications</td>
</tr>
<tr>
<td>5</td>
<td>Layout: Checked for compliance with plans and details</td>
</tr>
</tbody>
</table>

**Contractor:**

**Milestone:**

**Project Documents Used For Inspection:**

**Date:**

**Structure Type:**

**APPROVED SUBMITTAL**
### Typical Industry Approach to Construction Specs

**Inspection & Testing Plans (ITP)**

#### PORTLAND CEMENT CONCRETE

### Part 3 - Execution

#### 3.1 Field Quality Control

**B. Methods of Sampling and Testing:**

1. **Sampling:** Representative concrete samples shall be taken according to ASTM C122. Each sample shall be obtained from a different batch of concrete. At least one test shall be performed at the delivery truck and at the delivery to the job site.

2. **Slump Tests:** The above-specified Contractor shall perform slump tests of concrete at the time of placing of concrete, as required by ASTM C143. At least one test shall be performed at the delivery truck and at the delivery to the job site.

3. **Uniformity Tests:** The same testing laboratory shall perform uniformity tests in accordance with ASTM C94, Annex A1. Each test shall be performed on a different batch of concrete. Refer to Article 17 herein for hot and cold weather remedial requirements.

4. **Temperature Tests:** freshly mixed concrete shall be tested at the time of placement and at the delivery truck. The concrete temperature shall be determined by ASTM C94, Annex A1.

5. **Strength Tests:**
   a. Prepare, cast, and deliver to the same independent testing laboratory for compression test cylinders. Cylinders shall be tested according to ASTM C31. Cylinders shall be tested according to ASTM C31.
   b. Concrete shall be strength tested at the time of placement and at the delivery truck. Each batch of concrete shall be tested according to ASTM C31.
   c. Four cylinders for each 100 cubic yards or fraction thereof of concrete shall be tested at the time of placement, and at the delivery truck. Each batch of concrete shall be tested according to ASTM C31.

<table>
<thead>
<tr>
<th>Test</th>
<th>Test Method</th>
<th>Sample Size</th>
<th>Sampling Location</th>
<th>QC Test Frequency</th>
<th>QA Test Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slump</td>
<td>ASTM C143</td>
<td>See test method</td>
<td>Concrete truck discharge chute</td>
<td>One test per each 50 CY of concrete delivered</td>
<td>One at FAI, or as determined by CQAM</td>
</tr>
<tr>
<td>Uniformity</td>
<td>ASTM C94, Annex A1</td>
<td>See test method</td>
<td>Concrete truck discharge chute</td>
<td>Each batch of concrete</td>
<td>One at FAI, or as determined by CQAM</td>
</tr>
<tr>
<td>Temperature</td>
<td></td>
<td></td>
<td></td>
<td>Test hourly when concrete temp is below 40 degrees F and above 80 degrees F, and each time compression test cylinders are made.</td>
<td>One at FAI, or as determined by CQAM</td>
</tr>
<tr>
<td>Compressive Strength</td>
<td>ASTM C31, ASTM C39</td>
<td>See test method</td>
<td>Concrete truck discharge</td>
<td>Four cylinders for each 100 cubic yards or fraction thereof of concrete</td>
<td>One at FAI, or as determined by CQAM</td>
</tr>
</tbody>
</table>
TYPICAL INDUSTRY APPROACH TO CONSTRUCTION SPECS

QUALITY RECORDS

CONCRETE MIX DESIGN

DATE: 07/1/2018 (revised 02/05/2017)
PROJECT: California High Speed Rail - CP1

USE: Drilled Shaft: Wet Hole Mix

| AGG 1: 1" x 94' Gravel | BLEND 0 % 0% COARSE |
| AGG 2: 3/4" x 84' Pea Gravel | BLEND 57 % 100% COARSE |
| AGG 3: Concrete Band | BLEND 43 % Source: Granite, Coating |

BREVE: 420'  ARG 2: 500'  AGS: 750'  COARSE: 420' COMBINED

SIZE, mm: GRADING  GRADING  GRADING  GRADING  GRADING

1 1/2"  100  100  100  100  100
1"  100  100  100  100  100
3/4"  100  100  100  100  100
1/2"  100  100  100  97  97

CONCRETE TRUCK LOG

MILESTONE: ✔

THEORETICAL VOLUME:

<table>
<thead>
<tr>
<th>ACTIVITY NO.</th>
<th>ACTIVITY DESCRIPTION</th>
<th>THEORETICAL VOLUME:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Tim Logan, Batch operator</td>
<td>214.43 cu. ft</td>
</tr>
</tbody>
</table>

CONCRETE Placement Checklist

MILESTONE: ✔

SHAPED CONCRETE SHAFT

<table>
<thead>
<tr>
<th>ITEM #</th>
<th>DESCRIPTION</th>
<th>TP3PPC</th>
<th>TP37 CC</th>
<th>RVTM #</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Concrete mix design approved?</td>
<td>✔ 3/8/16</td>
<td>✔ 3/8/16</td>
<td>✔ 3/8/16</td>
</tr>
<tr>
<td>2</td>
<td>Slurry mix design approved and used per plan?</td>
<td>✔ 3/8/16</td>
<td>✔ 3/8/16</td>
<td>✔ 3/8/16</td>
</tr>
<tr>
<td>3</td>
<td>Materials produced domestically and comply with GPM 40, 12</td>
<td>✔ 3/8/16</td>
<td>✔ 3/8/16</td>
<td></td>
</tr>
</tbody>
</table>

SHAFT EXCAVATION

<table>
<thead>
<tr>
<th>ITEM #</th>
<th>DESCRIPTION</th>
<th>TP3PPC</th>
<th>TP37 CC</th>
<th>RVTM #</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Shaft dimensions, depth, alignment</td>
<td>✔ 3/8/16</td>
<td>✔ 3/8/16</td>
<td>✔ 3/8/16</td>
</tr>
<tr>
<td>2</td>
<td>Tested, inspected</td>
<td>✔ 3/8/16</td>
<td>✔ 3/8/16</td>
<td>✔ 3/8/16</td>
</tr>
</tbody>
</table>
### Typical Industry Approach to Construction Specs

#### Additional CHSRS Verification & Validation Requirements

<table>
<thead>
<tr>
<th>Doc. ID</th>
<th>Document Section</th>
<th>Requirements Specification Assigned to Avenue 11 Overhead</th>
<th>Allocation</th>
<th>Quality Record</th>
<th>Reference Folder</th>
</tr>
</thead>
<tbody>
<tr>
<td>Portland Cement</td>
<td>3.1B.1 Field</td>
<td><strong>Sampling:</strong> Representative composite samples shall be taken in accordance with ASTM C172. Each sample shall be obtained from a different batch of concrete on a random basis.</td>
<td>CIDH</td>
<td>QR-CON2</td>
<td>8.1 Construction Quality Records <a href="https://example.com/quality/8.1%20Construction">Link</a></td>
</tr>
<tr>
<td>Concrete 03 05 15</td>
<td>Quality Control</td>
<td></td>
<td>Abutment</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Retaining</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Walls</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Wing Walls</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Deck</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Portland Cement</td>
<td>3.1B.2 Field</td>
<td><strong>Slump Tests:</strong> ACI-certified personnel shall perform slump tests of concrete during placing of concrete, as required, in accordance with ASTM C143. At least one test shall be performed at the delivery trucks for each 100 cubic yards of concrete delivered.</td>
<td>CIDH</td>
<td>QR-CON2</td>
<td>8.1 Construction Quality Records <a href="https://example.com/quality/8.1%20Construction">Link</a></td>
</tr>
<tr>
<td>Concrete 03 05 15</td>
<td>Quality Control</td>
<td></td>
<td>Abutment</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Retaining</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Walls</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Wing Walls</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Deck</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Concrete 03 05 15</td>
<td>Quality Control</td>
<td></td>
<td>Abutment</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Retaining</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Walls</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Wing Walls</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Deck</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Portland Cement</td>
<td>3.1B.4 Field</td>
<td><strong>Tests for Concrete Temperature:</strong> Freshly mixed concrete shall be tested hourly when the ambient temperature is below 40 degrees F and above 80 degrees F, and each time compression test cylinders are made. The concrete temperature shall be recorded on all compression test cylinders.</td>
<td>CIDH</td>
<td>QR-CON2</td>
<td>8.1 Construction Quality Records <a href="https://example.com/quality/8.1%20Construction">Link</a></td>
</tr>
<tr>
<td>Concrete 03 05 15</td>
<td>Quality Control</td>
<td></td>
<td>Abutment</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Retaining</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Walls</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Wing Walls</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Deck</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Portland Cement</td>
<td>3.1B.5 Field</td>
<td><strong>Strength Tests:</strong> a. Prepare, cast, and deliver to the same independent testing laboratory, cylinders for laboratory-cured compression test samples. Cylinders shall be made and cured in accordance with ASTM C31. Cylinders shall be tested in accordance with ASTM C39.</td>
<td>CIDH</td>
<td>QR-CON3</td>
<td>8.1 Construction Quality Records <a href="https://example.com/quality/8.1%20Construction">Link</a></td>
</tr>
<tr>
<td>Concrete 03 05 15</td>
<td>Quality Control</td>
<td></td>
<td>Abutment</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Retaining</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Walls</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Wing Walls</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**References & Traces to Objective Evidence (Quality Records)**

**Requirements Verification Traceability Matrix (RVTM)**
❖ Problem Statement & Offered Solution
❖ Background & Introduction
❖ Systems Engineering Challenges Faced
  – Typical Industry Approach to Managing Construction Specifications
  – Systems Engineering Challenges
❖ Systems Engineering Objectives
❖ Systems Engineering Activities Performed
❖ Summary, Achieved Outcomes & Conclusion
Selected Challenges:

❖ Large Number of Contract Documents and Requirements
❖ Specification and Requirements Applicability
❖ Different Implementation by each Contractor
❖ Submittal Fragmentation and Submittal Log
❖ Availability of Construction Phase Submittals
❖ Organization of Quality Records
❖ Traceability to Objective Evidence
Which of the 1,000s of Requirements apply to Ave 10 Overhead?
Which Concrete Mix Design(s) apply to Ave 10 Overhead?
**Objectives**

- Slump Tests?
- 1,250+ Quality Records?

**Quality Milestone Data Pack (QMDP)**

<table>
<thead>
<tr>
<th>Doc. ID</th>
<th>Document Section</th>
<th>Requirements Specification Assigned to Avenue 11 Overhead</th>
<th>Allocation</th>
<th>Quality Record</th>
<th>Reference Folder</th>
</tr>
</thead>
<tbody>
<tr>
<td>Portland Cement Concrete 03 05 15</td>
<td>3.1B.2 Field Quality Control</td>
<td>Slump Tests: ACI-certified personnel shall perform slump tests of concrete during placing of concrete, as required, in accordance with ASTM C143. At least one test shall be performed at the delivery trucks for each 100 cubic yards of concrete delivered.</td>
<td>CIDH Abutment Retaining Wall Wing Walls Deck</td>
<td>QR-CON2</td>
<td>8.1 Construction Quality Records <a href="https://egnyte.com/Sin">https://egnyte.com/Sin</a> 200A QC NCRs/7.0%20-%20MIL 200H/8.0%20Quality/8.1%20Consl</td>
</tr>
</tbody>
</table>

**8.1 Construction Quality Records**

- 1,256 Files
- 1,250+ Quality Records?

**Subcontractor's Daily Report**

<table>
<thead>
<tr>
<th>Category</th>
<th># HOURS</th>
<th>Category</th>
<th># HOURS</th>
<th>Category</th>
<th># HOURS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Laborers</td>
<td>0</td>
<td>Equipment</td>
<td>0</td>
<td>Vendors</td>
<td>0</td>
</tr>
<tr>
<td>Materials</td>
<td>0</td>
<td>Crew</td>
<td>0</td>
<td>Subcontractors</td>
<td>0</td>
</tr>
<tr>
<td>总价</td>
<td>0</td>
<td>总价</td>
<td>0</td>
<td>总价</td>
<td>0</td>
</tr>
<tr>
<td>Total Work Force</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Slump Tests?**
SYSTEMS ENGINEERING CHALLENGES

SUMMARY

REQUIREMENTS

TRACEABILITY

OBJECTIVE EVIDENCE
PROGRESS

❖ Problem Statement & Offered Solution
❖ Background & Introduction
❖ Systems Engineering Challenges Faced
❖ Systems Engineering Objectives
  – Objectives
  – Constraints & Considerations
  – Envisioned Solution
❖ Systems Engineering Activities Performed
❖ Summary, Achieved Outcomes & Conclusion
1. Address the Systems Engineering Challenges described above
   - Determine governing construction specifications and requirements
   - Analyze and allocate applicable requirements to individual HSR milestones and HSR milestone elements (e.g. foundations, columns, deck, etc.)
   - Create a structured quality record storage system suitable for the large amount of records
   - Provide effective traceability between requirements and objective evidence

2. Demonstrate the Professional Standard of Care
   - Systematically exercise a reasonable level of care, diligence, and skill

3. Avoid the cautionary tale of the Big-Dig scenario
   - Provide a requirement-based approach demonstrating the correct use of specified materials and the successful execution of all specified inspections and tests

4. Deliver the successful HSR milestones Acceptance and Certification
   - Handed over / input into the next HSR track and systems contractor

SYSTEMS ENGINEERING OBJECTIVES

OBJECTIVES
1. Construction Industry
   - Used to plans, specifications, and estimates (PS&E) approach, CSI MasterFormat
   - Average annual gross domestic product (GDP) of more than $636B, 7.2 million employees
   - Consider continued use of the construction specifications

2. Quality Management vs. Systems Engineering
   - Systems engineering (incl. Verification & Validation) widely unknown in construction industry
   - Consider integration of the quality management system including plans, procedures, forms, inspection and test plans and procedures, and resulting quality records

3. Contract Management
   - Any change to an executed contract has the potential to result in contractor claims
   - Consider re-use of construction specifications, quality documents, submittal log, ITPs, QMDP, etc.

4. Contractor Deliverables
   - Consider re-using existing specifications, requirements analysis, breakdown structures, etc.

5. Human Aspect
   - Consider resistance to change, adding value through improved, more effective / efficient processes

**SYSTEMS ENGINEERING OBJECTIVES**

**CONSTRAINTS & CONSIDERATIONS**
SYSTEMS ENGINEERING OBJECTIVES

ENVISIONED SOLUTION: FOUR (4) STEP APPROACH

(1) Requirements Management

(2) System Breakdown Structure

(3) Verification & Validation

(4) Traceability

Contract Documents

System Specifications

Allocated Requirements

Construction Package

Subsystem #1

Subsystem #2

Subsystem #n

System Element #1

System Element #2

System Element #n

Construction Quality Records

www.incose.org/symp2021
PROGRESS

❖ Problem Statement & Offered Solution
❖ Background & Introduction
❖ Systems Engineering Challenges Faced
❖ Systems Engineering Objectives
❖ Systems Engineering Activities Performed
  1. Requirements Management
  2. System Breakdown Structure
  3. Verification and Validation
  4. Traceability
❖ Summary, Achieved Outcomes & Conclusion
**Systems Engineering Activities Performed**

**Step 1: Requirements Management – Req. Mgmt. Database Model**

[Diagram showing the process of requirements management with different specifications and contracts.

- **Contract Documents**
  - TCR
  - Techn. Contract Requirements
  - Alloc. Attribute
  - General / Typical Requirements
  - Sub Alloc. Attribute
  - Site Alloc. Attribute
  - Site/Submittal Specific Req. (RVTM)
  - Objective Evidence

- **TCR**
  - Yes
  - No

- **Contract Document #1**
  - Standard Specifications
  - Special Specifications
  - Other Specifications
  - Contract Document #n

- **Alloc. Attribute**
  - AG (At-Grade Requirements)
  - AS (Aerial Structure Requirements)
  - TR (Trench Structure Requirements)
  - RDW (RDW Overhead Requirements)

- **Sub Alloc. Attribute**
  - Subgrade
  - Parapet
  - Fresno RV
  - Fresno Tr.
  - CIDH
  - Tuolumne St

- **Site Alloc. Attribute**
  - Guideway 1
  - Guideway n
  - Fresno R. Viaduct
  - Fresno Trench
  - Avenue 07 OH
  - Avenue 10 OH

- **Objective Evidence**
  - Quality Records contained in QMDP Folders

**Case Study Project: California High-Speed Rail System (Cont’d)**

**Typical Industry Approach to Construction Specs Quality Records**
SYSTEMS ENGINEERING ACTIVITIES PERFORMED

STEP 1: REQUIREMENTS MANAGEMENT – ANALYSIS & ALLOCATION

- 40 Construction Specs being tracked for CP1
- 17 Construction Specs applicable to Overheads
- 6 Construction Specs applicable to CIDHs

65 Standard & Special Specifications in Contract

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes No</td>
<td></td>
<td>Technical Contract Requirements</td>
<td></td>
<td>At-Grade Requirements</td>
<td>Subgrade</td>
<td>Guideway 1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(Tailored Construction Specifications)</td>
<td>AS</td>
<td>Aerial Structure Requirements</td>
<td>Parapet</td>
<td>Guideway 1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>AG</td>
<td>Trench Structure Requirements</td>
<td>Base Slab</td>
<td>Fresno RV</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>TR</td>
<td>RDW Overhead Requirements</td>
<td>CIDH</td>
<td>Fresno Tr.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>RDW Overhead Requirements</td>
<td></td>
<td></td>
<td>Tuolumne St</td>
</tr>
</tbody>
</table>

California High-Speed Train Design-Build Project
Construction Package 1

CONSTRUCTION SPECIFICATIONS
READY FOR CONSTRUCTION (RFC)
VOLUME 1
CONSTRUCTION PACKAGE 1 SPECIFICATIONS
April 2023

California High-Speed Train Design-Build Project
Construction Package 1

CONSTRUCTION SPECIFICATIONS
READY FOR CONSTRUCTION (RFC)
VOLUME 1
CONSTRUCTION PACKAGE 1 SPECIFICATIONS
April 2023

California High-Speed Train Design-Build Project
Construction Package 1

CONSTRUCTION SPECIFICATIONS
READY FOR CONSTRUCTION (RFC)
VOLUME 1
CONSTRUCTION PACKAGE 1 SPECIFICATIONS
April 2023

Agreement No.: HSR 13-06
Standard Specifications

Contract Document #1

...
SYSTEMS ENGINEERING ACTIVITIES PERFORMED

STEP 1: REQUIREMENTS MANAGEMENT – APPLICABLE SPECIFICATIONS

California High-Speed Train Project
Construction Package 1

1.2 Reference Documents
The referenced documents are considered mandatory as determined applicable by TPZP and for those sections or portion thereof identified in this ITP. The list may be updated to conform to the CP 1 Project Construction Specifications.

- CP 1 Construction Specifications Ready for Construction (RFC), Volume 1
  - 03 05 15 – Portland Cement Concrete
  - 03 11 00 – Concrete Forming
  - 03 20 00 – Concrete Reinforcing
  - 03 30 00 – Cast-In-Place Concrete
  - 31 63 29 – Drilled Concrete Piers and Shafts
  - 26 05 26 Grounding and Bonding

Approved RFC or Early Start of Construction (ESOC) Plans
Approved Shop Drawings
Quality Management Plan (QMP), Rev 1 – April, 2016
2010 Standard Specifications & Special Amendments – State of California

INJECTION AND TEST PLAN
FOR PRODUCTION DRILLED CONCRETE SHAFT
Revision 1
July, 2016

CP1 INSPECTION & TEST PLAN
Prepared by:

6 CONSTRUCTION SPECS APPLICABLE TO CIDHs
FOCUS ON REQUIREMENTS:  
- Submittals
- Products / Materials
- Quality (Inspection & Testing)
SYSTEMS ENGINEERING ACTIVITIES PERFORMED

STEP 2: SYSTEM BREAKDOWN STRUCTURE (SBS)

**SUPERSTRUCTURE**
- Retaining Wall
- Access Road Clearance

**SUBSTRUCTURE**
- Abutment [22]
- Pile Cap [23]
- Column [21]
- Pier Cap [24]
- CIDH [25]

**ROADWAY OVERHEAD (AVE 07)**
- Total length of bridge = 196'-0" measured along A07 line
- EB
- FF
- FS, NS

**TYPES**
- 10 At-Grade
- 20 Aerial Structure
- 30 Trench
- 40 Roadway Overhead

**ELEMENTS**
- 010 Structure_Wide
- 020 Superstructure
- 030 Substructure
- 040 Bearings
- 050 Expansion_Joints
- 060 Polystyrene
- 070 Utilities
- 080 Lighting

**CONSTRUCTION SPECIFICATIONS**
- 03_05_15-PCC
- 03_20_00-CR
- 03_30_00-CIP
- 03_35_00-CF
- 26_05_26-G&B
- 31_63_29-DCP&S

**LOWEST LEVEL REPLACEMENT UNITS (LLRU)**
- 21 Reinforced_Concrete_Columns
- 22 Reinforced_Concrete_Aboutments
- 23 Reinforced_Concrete_Pile Caps
- 24 Reinforced_Concrete_Pier Caps
- 25_CIDH

**TYPES**
- 03_05_15-PCC
- 03_20_00-CR
- 03_30_00-CIP
- 03_35_00-CF
- 26_05_26-G&B
- 31_63_29-DCP&S

**4 Construction Specs Applicable to CIDHs**

**CIDH**
### Table 1 - RAM Allocation Matrix

<table>
<thead>
<tr>
<th>Item</th>
<th>RAM ID #</th>
<th>Discipline</th>
<th>Category</th>
<th>Element</th>
<th>Lowest Level Replacement Unit</th>
<th>RAM Attributes</th>
<th>Design Life/Reliability</th>
<th>Maintainability</th>
<th>Accessibility</th>
<th>Maintenance Window</th>
<th>MTTR (5 hours window or not)</th>
<th>Discipline Allocation</th>
<th>Subcontractor/Supplier Cut Sheet/Product Data</th>
<th>Historical Data/Similar Element Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>18</td>
<td>RAM 18</td>
<td>Site Work</td>
<td>Structures</td>
<td>Grade Separations (HST overpass and underpass)</td>
<td>Substructure</td>
<td>Reinforced concrete bridge rail</td>
<td>100 years</td>
<td>Yes, from the bridge deck</td>
<td>This is always accessible from top of the bridge</td>
<td>Between 12:01 am and 05:00 am daily</td>
<td>Less than 5 hours</td>
<td>Structures</td>
<td>TBD</td>
<td>TBD</td>
</tr>
<tr>
<td>19</td>
<td>RAM 19</td>
<td>Site Work</td>
<td>Structures</td>
<td>Grade Separations (HST overpass and underpass)</td>
<td>Substructure</td>
<td>Metal fencing</td>
<td>100 years</td>
<td>Yes, from the bridge deck</td>
<td>This is always accessible from the bridge deck</td>
<td>Between 12:01 am and 05:00 am daily</td>
<td>Less than 5 hours</td>
<td>Structures</td>
<td>TBD</td>
<td>TBD</td>
</tr>
<tr>
<td>20</td>
<td>RAM 20</td>
<td>Site Work</td>
<td>Structures</td>
<td>Grade Separations (HST overpass and underpass)</td>
<td>Substructure</td>
<td>Metal fencing</td>
<td>100 years</td>
<td>Yes, from the bridge deck</td>
<td>This is always accessible from the bridge deck</td>
<td>Between 12:01 am and 05:00 am daily</td>
<td>Less than 5 hours</td>
<td>Structures</td>
<td>TBD</td>
<td>TBD</td>
</tr>
<tr>
<td>21</td>
<td>RAM 21</td>
<td>Site Work</td>
<td>Structures</td>
<td>Grade Separations (HST overpass and underpass)</td>
<td>Substructure</td>
<td>Reinforced concrete bridge rail</td>
<td>100 years</td>
<td>Yes, from the bridge deck</td>
<td>This is always accessible from the bridge deck</td>
<td>Between 12:01 am and 05:00 am daily</td>
<td>Less than 5 hours</td>
<td>Structures</td>
<td>TBD</td>
<td>TBD</td>
</tr>
<tr>
<td>22</td>
<td>RAM 22</td>
<td>Site Work</td>
<td>Structures</td>
<td>Grade Separations (HST overpass and underpass)</td>
<td>Substructure</td>
<td>Reinforced concrete bridge rail</td>
<td>100 years</td>
<td>Yes, from the bridge deck</td>
<td>This is always accessible from the bridge deck</td>
<td>Between 12:01 am and 05:00 am daily</td>
<td>Less than 5 hours</td>
<td>Structures</td>
<td>TBD</td>
<td>TBD</td>
</tr>
<tr>
<td>23</td>
<td>RAM 23</td>
<td>Site Work</td>
<td>Structures</td>
<td>Grade Separations (HST overpass and underpass)</td>
<td>Substructure</td>
<td>Reinforced concrete bridge rail</td>
<td>100 years</td>
<td>Yes, from the bridge deck</td>
<td>This is always accessible from the bridge deck</td>
<td>Between 12:01 am and 05:00 am daily</td>
<td>Less than 5 hours</td>
<td>Structures</td>
<td>TBD</td>
<td>TBD</td>
</tr>
<tr>
<td>24</td>
<td>RAM 24</td>
<td>Site Work</td>
<td>Structures</td>
<td>Grade Separations (HST overpass and underpass)</td>
<td>Substructure</td>
<td>Reinforced concrete bridge rail</td>
<td>100 years</td>
<td>Yes, from the bridge deck</td>
<td>This is always accessible from the bridge deck</td>
<td>Between 12:01 am and 05:00 am daily</td>
<td>Less than 5 hours</td>
<td>Structures</td>
<td>TBD</td>
<td>TBD</td>
</tr>
<tr>
<td>25</td>
<td>RAM 25</td>
<td>Site Work</td>
<td>Structures</td>
<td>Grade Separations (HST overpass and underpass)</td>
<td>Substructure</td>
<td>CIDH</td>
<td>No</td>
<td>This is buried and essentially inaccessible Element is designed as</td>
<td>N/A</td>
<td>N/A</td>
<td>Structures</td>
<td>TBD</td>
<td>TBD</td>
<td>TBD</td>
</tr>
</tbody>
</table>

**Element**
- 010_Structure_Wide
- 020_Superstructure
- 030_Substructure
- 040_Bearings
- 050_Expansion_Joints
- 060_Polystyrene
- 070_Utilities
- 080_Lighting

**LLRU**
- 21_Reinforced_Concrete_Columns
- 22_Reinforced_Concrete_Abutments
- 23_Reinforced_Concrete_Pile_Caps
- 24_Reinforced_Concrete_Pier_Caps
- 25_CIDH
**Systems Engineering Activities Performed**

**Step 2: Using SBS for Requirements Allocation**

<table>
<thead>
<tr>
<th>Document Section</th>
<th>Requirements Text</th>
<th>Sub Allocation #1</th>
<th>Sub Allocation #2</th>
</tr>
</thead>
</table>
| 3.1.8.5 Field Quality Control | 5. Strength Tests:  
a. Prepare, cast, and deliver to the same independent testing laboratory, cylinders for laboratory-cured compression test samples. Cylinders shall be made and cured in accordance with ASTM C31. Cylinders shall be tested in accordance with ASTM C39.  
b. The minimum number of test cylinders to be made for each class of concrete and for each placement shall be four cylinders for each 300 cubic yards or fraction thereof. When additional cylinders are required beyond the normal 7- and 28-day test cylinders, the minimum of two test cylinders.  
c. All cylinders in this number on the Contractor's index. From each set of cylinders at 28 days tests are satisfactory, the first test shall be recorded on the unique number on one end. Record the cylinders shall be cured by the Contractor's index.  
d. In the event that the Laboratory shall test the cylinders and/or the Engineer. | 010_Structure_Wide  
020_Superstructure  
030_Substructure  
040_Bearings  
050_Expansion_Joints  
060_Polystyrene  
070_Utilities  
080_Lighting  
030_Substructure | 00_Structure_Wide_Document  
17_Reinforced_Concrete  
18_Reinforced_concrete_bridge_rail  
20_Prestressed_concrete_beams  
21_Reinforced_concrete_columns  
22_Reinforced_concrete_abutments  
23_Reinforced_concrete_pile_caps  
24_Reinforced_concrete_pier_caps  
25_CIDH  
200_Superstructure  
205_Superstructure  
210_Superstructure  
215_Superstructure  
220_Superstructure  
225_Superstructure  
230_Superstructure  
235_Superstructure  
240_Superstructure  
245_Superstructure  
250_Superstructure  
255_Superstructure  
260_Superstructure  
265_Superstructure  
270_Superstructure  
275_Superstructure  
280_Superstructure  
285_Superstructure  
290_Superstructure  
295_Superstructure  
300_Superstructure  
305_Superstructure  
310_Superstructure  
315_Superstructure  
320_Superstructure  
325_Superstructure  
330_Superstructure  
335_Superstructure  
340_Superstructure  
345_Superstructure  
350_Superstructure  
355_Superstructure  
360_Superstructure  
365_Superstructure  
370_Superstructure  
375_Superstructure  
380_Superstructure  
385_Superstructure  
390_Superstructure  
395_Superstructure  
400_Superstructure  
405_Superstructure  
410_Superstructure  
415_Superstructure  
420_Superstructure  
425_Superstructure  
430_Superstructure  
435_Superstructure  
440_Superstructure  
445_Superstructure  
450_Superstructure  
455_Superstructure  
460_Superstructure  
465_Superstructure  
470_Superstructure  
475_Superstructure  
480_Superstructure  
485_Superstructure  
490_Superstructure  
495_Superstructure  
500_Superstructure  
505_Superstructure  
510_Superstructure  
515_Superstructure  
520_Superstructure  
525_Superstructure  
530_Superstructure  
535_Superstructure  
540_Superstructure  
545_Superstructure  
550_Superstructure  
555_Superstructure  
560_Superstructure  
565_Superstructure  
570_Superstructure  
575_Superstructure  
580_Superstructure  
585_Superstructure  
590_Superstructure  
595_Superstructure  
600_Superstructure  
605_Superstructure  
610_Superstructure  
615_Superstructure  
620_Superstructure  
625_Superstructure  
630_Superstructure  
635_Superstructure  
640_Superstructure  
645_Superstructure  
650_Superstructure  
655_Superstructure  
660_Superstructure  
665_Superstructure  
670_Superstructure  
675_Superstructure  
680_Superstructure  
685_Superstructure  
690_Superstructure  
695_Superstructure  
700_Superstructure  
705_Superstructure  
710_Superstructure  
715_Superstructure  
720_Superstructure  
725_Superstructure  
730_Superstructure  
735_Superstructure  
740_Superstructure  
745_Superstructure  
750_Superstructure  
755_Superstructure  
760_Superstructure  
765_Superstructure  
770_Superstructure  
775_Superstructure  
780_Superstructure  
785_Superstructure  
790_Superstructure  
795_Superstructure  
800_Superstructure  
805_Superstructure  
810_Superstructure  
815_Superstructure  
820_Superstructure  
825_Superstructure  
830_Superstructure  
835_Superstructure  
840_Superstructure  
845_Superstructure  
850_Superstructure  
855_Superstructure  
860_Superstructure  
865_Superstructure  
870_Superstructure  
875_Superstructure  
880_Superstructure  
885_Superstructure  
890_Superstructure  
895_Superstructure  
900_Superstructure  
905_Superstructure  
910_Superstructure  
915_Superstructure  
920_Superstructure  
925_Superstructure  
930_Superstructure  
935_Superstructure  
940_Superstructure  
945_Superstructure  
950_Superstructure  
955_Superstructure  
960_Superstructure  
965_Superstructure  
970_Superstructure  
975_Superstructure  
980_Superstructure  
985_Superstructure  
990_Superstructure  
995_Superstructure  |

03 05 15 – Portland Cement Concrete (PCC)
SYSTEMS ENGINEERING ACTIVITIES PERFORMED

STEP 2: USING SBS FOR QMDP FOLDER STRUCTURE

- 1.0 Executive Summary
- 2.0 Environmental Compliance
- 3.0 Verification, Validation, and Self Certification
- 4.0 Third Party Requirements
- 5.0 Milestones Photographic Evidence
- 6.0 Operations and Maintenance Requirements
- 7.0 Disposition of Comments
- 8.0 Quality
- 9.0 Drawings, Documents, and Records

QMDP FOLDER STRUCTURE

- 030 Substructure
  - 21 Reinforced Concrete Columns
  - 22 Reinforced Concrete Abutments
  - 23 Reinforced Concrete Pile Caps
  - 24 Reinforced Concrete Pier Caps

- 030 03_05_15-PCC

- 25 CIDH

- LLRU

- CORRESPONDING "TEST CASES" (EXPECTED OBJECTIVE EVIDENCE)
**SYSTEMS ENGINEERING ACTIVITIES PERFORMED**

**STEP 3: VERIFICATION & VALIDATION – LOCATING THE QUALITY RECORDS**

<table>
<thead>
<tr>
<th>General</th>
<th>1.6 Submittals</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Concrete Mix Design: Submit mix designs as herein specified in Article entitled “Mix” to include laboratory test reports of trial strength and shrinkage tests. Submit mix designs minimum of 30 days prior to batching.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Products</th>
<th>2.1 Materials</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Portland Cement: ASTM C150, Type IV, where high early strength is required.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Execution</th>
<th>3.1 Field Quality Control</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1. Preparation, cast, and deliver to the job site laboratory- and compression testing in accordance with ASTM C31, C39.</td>
</tr>
<tr>
<td></td>
<td>2. The minimum number of test cylinders shall be two cylinders for each placement.</td>
</tr>
<tr>
<td></td>
<td>3. Additional laboratory test cylinders shall be tested at 28 days.</td>
</tr>
<tr>
<td></td>
<td>4. The cylinders shall be marked with the job number and the date of casting.</td>
</tr>
<tr>
<td></td>
<td>5. The strength tests shall be performed in accordance with ASTM C31, C39.</td>
</tr>
</tbody>
</table>

Note: Corresponding “Test Cases” (Expected Objective Evidence)
**Systems Engineering Activities Performed**

**Step 3: Verification & Validation – Performing the Actual Review**

<table>
<thead>
<tr>
<th>1 GENERAL</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1.6 Submittals</strong></td>
</tr>
<tr>
<td>A. Concrete Mix Designs: Submit mix designs as herein specified in Article entitled &quot;Mix Designs&quot;. Yes include laboratory test reports of trial strength and shrinkage tests. Submit mix designs a minimum of 30 days prior to batching or delivering concrete.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>2 Products</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>2.1 Materials</strong></td>
</tr>
<tr>
<td>A. Portland Cement: ASTM C150, Type II, low alkali. Type III Portland cement may be used where high early strength concrete is a requirement as approved by the Contractor’s engineer.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>3 Execution</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>3.1 Field Quality Control</strong></td>
</tr>
<tr>
<td>B. Methods of Sampling and Testing:</td>
</tr>
<tr>
<td>1. Sampling: Representative composite samples shall be taken in accordance with ASTM C172. Each sample shall be obtained from a different batch of concrete on a random basis.</td>
</tr>
<tr>
<td>3. Strength Tests:</td>
</tr>
<tr>
<td>a. Prepare, cast, and deliver to the same independent testing laboratory, cylinders for laboratory-cured compression test samples. Cylinders shall be made and cured in accordance with ASTM C31. Cylinders shall be tested in accordance with ASTM C39.</td>
</tr>
<tr>
<td>b. The minimum number of test cylinders to be made for each class of concrete and for each placement shall be four cylinders for each 100 cubic yards or fraction thereof. When additional sets of test cylinders are required beyond the normal 7- and 28-day tests, each set shall consist of a minimum of two test cylinders.</td>
</tr>
<tr>
<td>c. All cylinders in a set shall be marked with a unique number on one end. Record this number on the record of concrete placed. All cylinders shall be cured by the Contractor’s independent testing laboratory.</td>
</tr>
<tr>
<td>d. From each set of cylinders cast, one cylinder shall be tested at 7 days and two cylinders at 28 days in accordance with ASTM C39. If the 28-day tests are satisfactory, the fourth cylinder shall be discarded.</td>
</tr>
<tr>
<td>e. In the event the 28-day tests are below the specified strength requirements, the Laboratory shall then test the fourth cylinder at the age selected by the Contractor’s demonstration of compliance.</td>
</tr>
</tbody>
</table>

---

**03 05 15 – Portland Cement Concrete (PCC)**

**Submit: Concrete Mix Design**

**Material: Portland Cement**

**Field Quality Control: Strength Test**

**Demonstration of Compliance**
SYSTEMS ENGINEERING ACTIVITIES PERFORMED

STEP 4: TRACEABILITY – USING REQ. MGMT. TOOL (AUTOMATED TRACING)

S. Traceability – Using Req. Mgmt. Tool (Automated Tracing)

**Document Section:** 3.1.B.5 Field Quality Control

**Requirements Text:**

5. Strength Tests:

- 020_Superstructure/17_Reinforced_Concrete
- 020_Superstructure/18_Reinforced_concrete_bridge_rail
- 020_Superstructure/20_Prestressed_concrete_beams
- 030_Substructure/21_Reinforced_concrete_columns
- 030_Substructure/22_Reinforced_concrete_abutments
- 030_Substructure/23_Reinforced_concrete_pile_caps
- 030_Substructure/24_Reinforced_concrete_pier_caps

**Trace from RM Tool to Quality Record**

- 030_Substructure/25_CIDH

**System Elements**

- 010_Structure_Wide
- 020_Superstructure
- 030_Substructure

**Field Quality Control: Strength Test**

- 03 05 15 – PORTLAND CEMENT CONCRETE (PCC)

**Quality Record in QMDP Folder Structure**

- 03_05_15-PCC
# Systems Engineering Activities Performed

## Step 4: Traceability – Inherent Traceability (w/o RM Tool)

<table>
<thead>
<tr>
<th>03 05 15 Portland Cement Concrete (PCC)</th>
</tr>
</thead>
</table>

### 1.6 Submittals

- **A. Concrete Mix Design**: Submit mix designs as herein specified in Article entitled “Mix Design”. Include laboratory test reports of trial strength and shrinkage tests. Submit mix design minimum of 30 days prior to batching.

### 2.1 Materials

- **A. Portland Cement**: ASTM C150, Type I, where high early strength concrete is required.

### 3.1 Field Quality Control

- **B. Methods of Sampling and Testing**
  - **1. Sampling**: Representative composite samples from each unit shall be obtained from a batch or lot of materials and shall be representative of the entire batch or lot.
  - **2. Testing**: Each sample shall consist of a minimum of three test cylinders or cores. Cylinders shall be tested in accordance with ASTM C31, C39, C39, C39.
  - **3. Strength Tests**
    - **a.** Prepare, cast, and deliver to the laboratory and compression concrete cylinders in accordance with ASTM C31, C39, C39, C39.
    - **b.** The minimum number of test cylinders to be tested from each placement shall be four cylinders. Each test cylinder shall consist of two additional sets of test cylinders a set of test cylinder shall be placed in a manner to test four cylinders as independent tests.
    - **c.** All cylinders in a set shall be numbered on the record of concrete for that strength test.
    - **d.** From each set of test cylinders, cylinders shall be placed in a manner to test four cylinders as independent tests.
    - **e.** In the event the 28-day test-data is not available, laboratory shall then test the field-

### 5.0 03 05 15 – Portland Cement Concrete (PCC)

- **1.6_SUB-A-Concrete_Mix_Design.pdf**
- **1.6_SUB-B-Product_Data.pdf**
- **1.6_SUB-C-Aggregate_Sources.pdf**
- **1.6_SUB-D-Certificates.pdf**
- **1.6_SUB-E-Batch_Tickets.pdf**
- **1.7_QAC-A-Quality_Control.pdf**
- **1.7_QAC-B-Concrete_Supplier.pdf**
- **1.7_QAC-C-Mix_Designs.pdf**
- **1.7_QAC-D-Contractors_Quality_Management.pdf**
- **1.7_QAC-E-Cement_and_Aggregates.pdf**
- **1.8_ENV-B-Cold_Weather_Report.pdf**

### 2.1 MAT-A Portland Cement.pdf

- **2.1 MAT-B Aggregates.pdf**
- **2.1 MAT-C-Special_Aggregates_for_Reducing_Slump.pdf**
- **2.1 MAT-D-Admixtures_and_Cementitious.pdf**
- **2.1 MAT-E-Water.pdf**
- **2.1 MAT-F-Reinforcement_Fibers.pdf**
- **2.2 MAT-G-Test_and_Analysis_Samples.pdf**
- **2.2 MAT-H-Samples.pdf**
- **2.3 MAT-Mix_Designs.pdf**
- **3.1_FQC-A-Inspection_and_Test_Services.pdf**
- **3.1_FQC-B-1_Methods_of_Sampling_and_Testing.pdf**
- **3.1_FQC-B-2_Methods_of_Sampling_and_Testing_Slab.pdf**
- **3.1_FQC-B-3_Methods_of_Sampling_and_Testing_Cement.pdf**
- **3.1_FQC-B-4_Methods_of_Sampling_and_Testing_Concrete.pdf**
- **3.1_FQC-B-5_Methods_of_Sampling_and_Testing_Underground.pdf**
- **3.1_FQC-B-6_Methods_of_Sampling_and_Testing_Contractions.pdf**
- **3.1_FQC-C-Evaluation_and_Acceptance_of_Tests.pdf**
- **3.1_FQC-D-Acceptance_of_Structure.pdf**

### Material:
- **Portland Cement**

### Field Quality Control:
- **Strength Test**
PROGRESS

❖ Problem Statement & Offered Solution
❖ Background & Introduction
❖ Systems Engineering Challenges Faced
❖ Systems Engineering Objectives
❖ Systems Engineering Activities Performed
❖ **Summary, Achieved Outcomes & Conclusion**
SUMMARY

PROBLEM STATEMENT
EXAMPLE: THE “BIG DIG” PROJECT

- Central Artery/Tunnel Megaproject in Boston, MA that rerouted Interstate 93 (I-93) running through the heart of the city into a 1.5-mile tunnel
- Commonly known as the Big-Dig project
- Designed and built between 1982 and 2007
- Most expensive highway project in the US at the time (21.5 billion in 2020 US dollars)
- Plagued by thousands of water leaks, design flaws, charges of poor execution, use of substandard materials and other issues
- Led to the death of a motorist and criminal arrests when a 24-ton concrete ceiling panel

CASE STUDY PROJECT
CALIFORNIA HIGH-SPEED RAIL SYSTEM (CONT’D)

OFFERED SOLUTION
SYSTEMS ENGINEERING AS THE PROFESSIONAL STANDARD OF CARE

- Professional Standard of Care: defined as the systematic exercise of a reasonable level of care, diligence and skill
- Failure to adhere to the professional standard of care may result in company risk and liability
- In the author’s opinion, the Big-Dig issues:
  - Describe a common requirements management and verification & validation challenge
  - Could have been avoided using a structured systems engineering approach
- This presentation:
  - Describes the application of SE principles to construction specifications in a large infrastructure project using a case study approach
  - Presents the application of systems engineering as the systematic exercise of a reasonable level of care

Demonstrates the Value of Systems Engineering as a Liability protection and

TYPICAL INDUSTRY APPROACH TO CONSTRUCTION SPECS
CONSTRUCTION QUALITY MANAGEMENT AND PROCEDURES

INTRODUCTION
CONSTRUCTION SPECIFICATIONS

Part 1 – General: Describes managerial requirements such as applicability, work to be performed, codes and standards, qualifications, submittals, quality management, etc.

Part 2 – Product: Describes the performance requirements, the acceptable (prescriptive or proprietary) products, materials, and sometimes even specific suppliers. Big-Dig would have contained the acceptable materials and material standards.

Part 3 – Execution: Describes the methods of installation and how to measure quality or effectiveness. Big-Dig would have identified the inspections and tests to be performed.

SYSTEMS ENGINEERING CHALLENGES
TRACING, LOCATING, AND VERIFYING TO OBJECTIVE EVIDENCE

SYSTEMS ENGINEERING OBJECTIVES
ENVISIONED SOLUTION: FOUR (4) STEP APPROACH

SYSTEMS ENGINEERING ACTIVITIES PERFORMED
STEP 1: REQUIREMENTS MANAGEMENT – ANALYSIS & ALLOCATION

SYSTEMS ENGINEERING ACTIVITIES PERFORMED
STEP 3: VERIFICATION & VALIDATION – LOCATING THE QUALITY RECORDS
ACHIEVED OUTCOMES & CONCLUSION

❖ Addresses the Systems Engineering Challenges
  – Implemented pilot project for Ave 10 Roadway Overhead as proof of concept
  – Enabled reviewers to efficiently and effectively identify relevant quality records
  – Produced excellent review comments against construction specification requirements

❖ Avoids the cautionary tale of the Big-Dig scenario
  – Provides a requirement-based approach demonstrating the correct use of specified materials and the successful execution of all specified inspections and tests

❖ Will Delivers the successful HSR Milestones Acceptance and Certification
  – Offers the assurance that the infrastructure HSR milestones have been built in accordance with the construction specifications
  – Will lead to successful acceptance, certification, and handover to the next HSR track and systems contractors, thereby reducing performance, schedule, and cost risk to the Authority and the public

❖ Demonstrates the Professional Standard of Care
  – Structured & systematic application of systems engineering principles to construction specifications illustrates the systematic exercise of a reasonable level of care, diligence, and skill, referred to as the professional standard of care, thereby demonstrating the Value of Systems Engineering as a successful liability protection and risk mitigation strategy
31st Annual INCOSE International Symposium
virtual event
July 17 - 22, 2021
www.incose.org/symp2021