IDAHO TRANSPORTATION DEPARTMENT

RESEARCH REPORT

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RP 255

Recommendations for Applying a Risk-based Quality Assurance Approach for Reinforcing Steel

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16. Abstract
The Idaho Transportation Department (ITD) seeks to make quality assurance practices for using reinforcing steel at Idaho job sites more efficient and cost effective while retaining safe and reliable outcomes. The Boise State University report examines current ITD practices, evaluates practices in 20 other state departments of transportation, and then offers recommendations for implementing a new risk assessment method called the Collegial Analysis method, and (2) a manufacturer certification program. The research team recommends further development and validation research before ITD considers adapting the Collegial Analysis method.

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METRIC (SI*) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS					APPROXIMATE CONVERSIONS FROM SI UNITS				
Symbol	When You Know	Multiply By	To Find	Symbol	Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH					LENGTH		
in	inches	25.4		mm	mm	millimeters	0.039	inches	in
ft	feet	0.3048		m	m	meters	3.28	feet	ft
yd	yards	0.914		m	m	meters	1.09	yards	yd
mi	Miles (statute)	1.61		km	km	kilometers	0.621	Miles (statute)	mi
		AREA					AREA		
in^2	square inches	645.2	millimeters squared	cm^2	mm^2	millimeters squared	0.0016	square inches	in^2
ft^2	square feet	0.0929	meters squared	m^2	m^2	meters squared	10.764	square feet	ft^2
yd^2	square yards	0.836	meters squared	m^2	km^2	kilometers squared	0.39	square miles	mi^2
mi^2	square miles	2.59	kilometers squared	km^2	ha	hectares (10,000 m^2)	2.471	acres	ac
ac	acres	0.4046	hectares	ha					
		MASS (weight)					MASS (weight)		
oz	Ounces (avdp)	28.35	grams	g	g	grams	0.0353	Ounces (avdp)	oz
lb	Pounds (avdp)	0.454	kilograms	kg	kg	kilograms	2.205	Pounds (avdp)	lb
T	Short tons (2000 lb)	0.907	megagrams	mg	mg	megagrams (1000 kg)	1.103	short tons	T
		VOLUME					VOLUME		
fl oz	fluid ounces (US)	29.57	milliliters	mL	mL	milliliters	0.034	fluid ounces (US)	fl oz
gal	Gallons (liq)	3.785	liters	liters	liters	liters	0.264	Gallons (liq)	gal
ft^3	cubic feet	0.0283	meters cubed	m^3	m^3	meters cubed	35.315	cubic feet	ft^3
yd^3	cubic yards	0.765	meters cubed	m^3	m^3	meters cubed	1.308	cubic yards	yd^3
Note: Volumes greater than 1000 L shall be shown in m^3									
		TEMPERATURE (exact)					TEMPERATURE (exact)		
^oF	Fahrenheit temperature	5/9 (^{o}F-32)	Celsius temperature	^oC	^oC	Celsius temperature	9/5 ^{o}C+32	Fahrenheit temperature	^oF
		ILLUMINATION					ILLUMINATION		
fc	Foot-candles	10.76	lux	lx	lx	lux	0.0929	foot-candles	fc
fl	foot-lamberts	3.426	candela/m^2	cd/cm^2	cd/cm^2	candela/m^2	0.2919	foot-lamberts	fl
		FORCE and PRESSURE or STRESS					FORCE and PRESSURE or STRESS		
lbf	pound-force	4.45	newtons	N	N	newtons	0.225	pound-force	lbf
psi	pound-force per square inch	6.89	kilopascals	kPa	kPa	kilopascals	0.145	pound-force per square inch	psi

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Technical Advisory Committee

Each research project is overseen by a technical advisory committee (TAC), which is led by an ITD project sponsor and project manager. The Technical Advisory Committee (TAC) is responsible for monitoring project progress, reviewing deliverables, ensuring that study objective are met, and facilitating implementation of research recommendations, as appropriate. ITD's Research Program Manager appreciates the work of the following TAC members in guiding this research study.

Project Sponsor – Ed Bala, P.E.

Project Manager – Dan Harelson, P.E.

TAC Members
Pat Grayson,
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Shawna King, P.E.
Elizabeth Shannon. P.E.

FHWA-Idaho Advisor – Kyle Holman

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List of Acronyms

AASHTO: American Association of State Highway and Transportation Officials
APL: Approved Product List
ASTM: American Society for Testing and Materials
BMPR: Bureau of Materials and Physical Research
Caltrans: California Department of Transportation
CDOT: Colorado Department of Transportation
CFR: Code of Federal Regulations
CRSI: Concrete Reinforcing Steel Institute
CQAP: Construction Quality Assurance Program
DOT: Department of Transportation
FDOT: Florida Department of Transportation
IDOT: Illinois Department of Transportation
INDOT: Indiana Department of Transportation
ITD: Idaho Transportation Department
KNTC: Kentucky Transportation Cabinet
ksi: Kilopound for Square Inch
MBTA: Massachusetts Bay Transportation Authority
MDOT: Michigan Department of Transportation
MDT: Montana Department of Transportation
MnDOT: Minnesota Department of Transportation
NAQTC: Nevada Alliance for Quality Transportation Construction
NDDOT: North Dakota Department of Transportation
NDOR: Nebraska Department of Roads
NDOT: Nevada Department of Transportation
NTPEP: National Transportation Product Evaluation Program
NYSDOT: New York State Department of Transportation
ODOT: Oregon Department of Transportation
PCI: Precast Concrete Institute
PEC: Product Evaluation Coordinator
QCP: Quality Control Plan
QML: Qualified Manufacturer List
QMP: Quality Management Plan
SDDOT: South Dakota Department of Transportation
UDOT: Utah Department of Transportation
WAQTC: Western Alliance of Quality Transportation Construction
WSDOT: Washington State Department of Transportation
WYDOT: Wyoming Department of Transportation

Executive Summary

Introduction

The objective of this report is to evaluate current Idaho Transportation Department (ITD) practices to ensure the quality of reinforcing steel, validate them when feasible, and recommend modifications based on acceptable risk. Our analysis of ITD practices revealed that steel reinforcement in concrete on job sites conforms to Idaho standards, but that exceptionally low non-conformance may suggest that practices are likely excessive; testing is time consuming and expensive, and engineers may be required to test more material than is necessary to ensure safe, reliable, and low maintenance transportation infrastructure. Testing quantity also directly impacts project completion costs and schedules, as well as staffing and work capacity for ITD testing laboratories.

Researchers in the Department of Civil Engineering at Boise State University in Boise, Idaho analyzed quality assurance practices for using reinforcing steel in Idaho and then compared them against 20 selected states to consider how other state practices may inform ITD practices. We chose 20 states to ensure that all Pacific Northwest states as well as other states from around the country would be included in the study.

Key Findings and Conclusions

Here are key findings and conclusions about: (1) current quality assurance testing practices in Idaho, and (2) quality assurance practices among the 20 states included in the literature review.

Current Quality Assurance Testing Practices in Idaho

Failure rates are very low. In recent years, samples have failed the bend test approximately twice a year. In addition, upon receiving a second sample, the reinforcing steel almost always passes both tests. In part because of these results, ITD inspection staff reported that in practice, contractors rarely wait for test results, and the resident engineer generally allows contractors to "proceed at their own risk" in advance of results. It should be noted here that any delays that may occur do not occur at the lab; samples are tested the day of or the day after receipt.

An ITD inspector responsible for field inspections felt that factors affecting quality after manufacturing would generally be limited to surface defects and that field personnel can reject obviously defective material or require additional testing if warranted.

To evaluate ITD quality assurance practices for reinforcing steel use in the state, the research team reviewed the ITD Quality Assurance Manual, and conducted an onsite survey with a senior ITD inspection staff member in ITD's Central Laboratory. [1] There are substantive activities to complete three phases of quality assurance testing: (1) materials inspection at the job site, (2) sampling at the job site, and (3) testing at the ITD Structural Laboratory. Personnel include contractors at the worksite and project engineer serving as point of contact for inspection, ITD inspectors collecting samples at the worksite, and quality assurance testers who conduct testing at the ITD Central Laboratory. As per the ITD Quality Assurance Manual, once inspectors have tested the samples and each passes a tensile and bend test, contractors may use reinforcing steel in ITD projects. (1)

Quality Assurance Testing Practices Across 20 Other States

Analysis results support the assessment that ITD may be conducting more quality assurance testing than is necessary. We arrived at this conclusion because ITD is one of the states which has adopted an “extensive sampling program”, described later in Chapter 3. Other states with their own state-specific testing standards use sampling based on manufacturer certification and/or sampling based on frequency of failure. States that use sampling based on frequency of failure include Indiana, Michigan, Maryland, Nebraska, and New York. Washington and California use sampling based on statistical analysis of potential risk. Based on our review of testing practices at 20 other states, we conclude that adopting some of these sampling techniques will be beneficial for Idaho.

As we evaluated each state, we identified quality assurance guidelines and practices, test frequency and methods, and any unique state requirements and practices. A common practice was for each state to adhere to standards identified by the Code of Federal Regulations (CFR), American Association of State Highway and Transportation Officials (AASHTO), and the American Society for Testing and Materials (ASTM). Generally, all the states follow quality assurance guidelines documented in the 23 CFR sections 634 and 637. In addition, several states use the ASTM A615, A706 and A775, and AASHTO M31, M55, M221, and M284. (2,3,4) They frequently describe material sampling, test frequency and test methods in qualitative terms, referencing the AASHTO and ASTM standards for specific test parameters.

California and Washington practices were unique in that these two states systematically identify severity of loss in the event of material failure. For example, the Washington State Department of Transportation uses an analysis method called the ***Delphi method*** to determine the potential for failure risk. (5) Such practices affect how each state establishes requirements for future sampling, test frequency, and work practices. California and Washington also participate in a certification program to ensure that reinforcing steel conforms to standards.

Key Recommendations and Implementation Issues

While it is important to note that the state-by-state comparison was the primary focus of this report, our team did identify potential recommendations that both encompass as well as look beyond the initial review. Based on findings from this state-by-state literature review, we have three primary recommendations to enhance Idaho Department of Transportation quality assurance practices for using reinforcing steel. These include implementing: (1) refinements to current Idaho practices, (2) a manufacturer certification program, and (3) a new risk assessment method we call the ***Collegial Analysis Method***.

1. Implement Refinements to current Idaho Quality Assurance Practices

Our foundational review of current ITD practices suggests that the ITD can make a few refinements to improve the mislabeling of samples, using steel from the same heat number at multiple job sites, and factors affecting quality after products leave the manufacturer.

Under the current program, the most common error that occurs during sampling—and a frequent one—is the mislabeling of samples. ITD may be able to minimize such errors by more thoroughly training individuals responsible for sample collection or by ensuring that more than one person checks sample tags before being sent off site.

Since quality may also be affected by factors that occur after manufacturing, ITD should identify factors affecting quality after manufacturing and develop guidelines for field personnel to identify defective material and determine whether additional testing is warranted.

2. Implement a Manufacturer Certification Program

A second recommendation is that ITD employ a more formal manufacturer certification program. A manufacturer certification program already exists at ITD but is not structured to take advantage of the submittals from manufacturers. The revised program will establish frequencies for testing materials at each participating manufacturer, where material will be subject to verification testing, and then placed with a visual inspection at the job site at the discretion of the resident engineer. Implementation of this program will require someone to administer it; ITD will need some staffing reorganization to make this happen.

3. Implement Collegial Analysis for Risk Assessment

Our team also has a third recommendation as basis for selecting which quality assurance procedures to apply and when. To offer a more systematic approach to quality assurance for steel reinforcement use in state transportation systems, we suggest what we call the Collegial Analysis method. This method: (1) adapts the Washington State Department of Transportation Delphi method along with sampling and testing frequencies similar to those used in California and Washington State, and (2) uses risk analysis of material failure to identify tests needed, thereby maintaining high reinforcing steel conformance and reliability, but more efficiently and at lowered expense.

The Collegial Analysis method is a risk-based quality assurance method that we believe will help ITD to be more selective about which quality assurance procedures to apply and when. It adapts a qualitative (expert survey) method and enriches it with quantitative values obtained from a numerical risk analysis. Using this method will offer qualitative information from experts, as well as quantitative empirical data from allowed variances established in AASHTO and ASTM standards and potentially result in a numerical value for tensile strength given various statistical distributions. Results will ensure that should Idaho choose to reduce the frequency of testing from current standards that doing so will not diminish material quality and performance outcomes.

While we have conducted a ***preliminary study*** using the Collegial Analysis method to demonstrate its potential, it is essential that ITD more fully evaluate and validate the proposed approach before using it or drawing broader conclusions.

In addition, while an experienced chief metallurgist confirmed the validity of outcomes for our numerical risk analysis based on chemical composition, further development will need to include assessing the influence from other parameters (for example, rebar diameter and epoxy-coating film thickness) rather than chemical composition to further validate the method. We can continue to work with ITD engineers to search for available test datasets that document the chemical content and associated material mechanical testing results.

We believe taking such actions to validate this initial study and eventually implement the proposed Collegial Analysis method is likely to maintain performance outcomes while also reducing test frequency requirements, improving staff efficiency, and saving money.

Future Questions

While the preliminary study demonstrates Collegial Analysis method potential, given a limited expert sample size and limited materials specifications, it is essential that ITD more fully evaluate and validate the proposed approach before using it. To do this work, our team could continue collaborating with ITD to help answer two interdependent questions:

1. Do prior ITD test results validate qualitative and quantitative results from the Collegial Analysis method?
2. What number of samples and tests would be minimally required to fully address necessary quality assurance practices for various ITD construction projects?

Chapter 1
Introduction

Background

The objective of this report is to evaluate current Idaho Transportation Department (ITD) practices to ensure the quality of reinforcing steel in concrete on job sites, validate efficacy when feasible, and recommend improvements when justified.

The ITD maintains exceptional performance outcomes with exceptionally low non-conformance to Idaho standards. However, there is the potential that such low non-conformance may indicate that the ITD is doing too much testing. Testing is time consuming and expensive, and could be more than is necessary to ensure safe, reliable, and low maintenance transportation infrastructure. Testing quantity also directly impacts project completion costs and schedules, as well as staffing and work capacity for ITD testing laboratories.

Therefore, this report from researchers in the Department of Civil Engineering at Boise State University in Boise, Idaho analyzes how transportation departments across 20 states use reinforcing steel in concrete on transportation department job sites and considers how other state practices may inform Idaho practices.

Project Approach

To identify critical quality assurance test parameters and identify quality assurance practices that may be more cost-effective and systematic, our research team evaluated current Idaho quality practices and then conducted a comprehensive literature review to compare Idaho practices against practices in 20 other states. We chose 20 states to ensure that all Pacific Northwest states as well as other large states from around the country would be included in the study. Climatic, terrain, and traffic conditions in Idaho and the Pacific Northwest states are similar, so important to assess. In addition, we believed that the other large states would have well developed procedures and processes that could further inform ITD quality assurance policy and work process decisions.

Scope and Limits of Research

To set a realistic project scope, this research effort does not review transportation departments across all U.S. states. Rather, we selected 20 states to that like Idaho, address requirements particular to the Pacific Northwest, or that were large states likely to have robust and quality assurance programs.

This state-by-state comparison via a literature review was the primary focus of this report. However, our team did identify potential recommendations that both encompass as well as look beyond the initial review. This includes recommending what we call the Collegial Analysis method as basis for selecting which quality assurance procedures to apply and when. This method includes both an expert survey (qualitative) and a numerical risk (quantitative) assessment.

While we have conducted a ***preliminary study*** using the Collegial Analysis method to demonstrate its potential, it is essential that ITD more fully evaluate and validate the proposed approach before using it or drawing broader conclusions. To ensure that the survey is valid, ITD will need to obtain a larger sample size than we were able to include in our study. Further, to ensure that the numerical risk analysis is accurate, ITD will need to collect steel reinforcement material property data from previous tests. Results should include as much information as possible, such as chemical makeup, yield strength, tensile strength, and all the physical attributes of the steel such as diameter, weight, and length.

In addition, while an experienced chief metallurgist confirmed the validity of outcomes for our numerical risk analysis based on chemical composition, further development will need to include assessing the influence from other parameters rather than chemical composition to further validate the method. We can continue to work with ITD engineers to search for available test datasets that document the chemical content and associated material mechanical testing results.

How This Report is Organized

The chapters that follow address: (1) details about our initial analysis of ITD work practices and associated findings, (2) findings about department of transportation (DOT) quality assurance practices derived from the literature review, (3) details about our recommendation to employ the Collegial Analysis method, and (4) details about a preliminary Collegial Analysis method study.

In the appendixes that follow the first five chapters, we report the literature review of the 20 states evaluated in this study, each in a separate appendix. Each appendix includes uniform information: quality assurance guidelines and practices, test frequency and methods, and any unique state requirements and practices. We also evaluated any related published work, when available.

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Chapter 2
Findings: Current Quality Assurance Testing Practices in Idaho

Background

Before gathering state-by-state data, our team formed the basis for comparison by evaluating current quality assurance testing practices for reinforcing steel in Idaho. The Idaho Transportation Department (ITD) performs testing of all reinforcing steel samples before allowing for its use in any ITD projects. However, quality assurance sampling and testing is time consuming and expensive. To fully evaluate ITD quality assurance practices for reinforcing steel use in the state, the research team: (1) reviewed the ITD quality assurance manual, and (2) conducted an onsite survey with a senior ITD inspection staff member in ITD's Central Laboratory. Quality assurance testing begins with materials inspection and sampling in the field, followed by testing at the ITD Structural Laboratory. Personnel involved include the contractors at the worksite and project engineer acting as the point of contact for inspection, ITD inspectors collecting samples at the worksite, and quality assurance testers who conduct testing at the ITD Central Laboratory, with oversight from the resident engineer. As per the ITD Quality Assurance Manual, once inspectors have tested the samples and each passes a tensile and bend test, contractors may use reinforcing steel in ITD projects. [1]

Phase 1: Materials Inspection at the Job Site

The Idaho Transportation Department's quality assurance process begins when an ITD inspector arrives at the job site and makes a materials check. He or she closely evaluates reinforcing steel grade, type, size, shape, and length, and immediately reports when it does not match manufacture specifications or where there are discrepancies. Reinforcing steel must meet specifications from ASTM A615/A615M and AASHTO M 31M/M 31-15 Standard Specification for Deformed and Plain Carbon-Steel Bars for Concrete Reinforcement. There are five grades for reinforcing steel: 40, 60, 75, 80, and 100. The grades correspond to the minimum yield strength in kilopound per square inch (ksi). The grades also have a respective minimum ultimate strength of 60, 90, 100, 105, and 115 ksi. In addition to the minimum specified strength, each grade has a minimum specified elongation percentage.

Phase 2: Sampling at the Job Site

When a steel shipment arrives at the project site and the ITD inspector is present, the contractor must remove samples for testing from the shipment at random. ITD Inspectors *must* witness the sampling at the job site. An appropriate sample set is two 36-inch pieces of steel cut from materials of the same size and heat number (Idaho Transportation Department, 2015). [1] As stated in the ITD Standard Specifications for Highway Construction, Section 503, project engineers must provide samples for every heat number and bar size. The heat number is a unique identifying code stamped on a piece of metal when it is rolled at a steel mill and provides information about its origins. This number provides a method for tracing materials and is an important part of quality assurance and control. In addition, the contractor must anticipate sampling and supply extra bars for sampling or a project bar will be destroyed and the contractor will therefore need to reorder it. Occasionally the replacement bar is from a different heat number and when this happens, the ITD destroys it as well.

The contractor must properly tag samples and include the ITD-914 (filled out by project personnel) and mill certifications. Every heat is pre-tested at the manufacturer and the mill certifications supplied with the samples also include manufacturer-measured yield, tensile, percent elongation and bend test results. Epoxy-coated reinforcing steel must also include a certification statement that the epoxy coating complies with AASHTO M 284 *Epoxy-Coated Reinforcing Bars: Materials and Coating Requirements* as well as with epoxy test results that are representative of the shipment. The ITD Quality Assurance Manual requires that the ITD inspector ship samples within two working days to the Central Materials Lab for testing; however, interviews with inspection personnel indicated that this deadline is often missed because documentation from the contractor is incomplete. [1] Contractors do not view incomplete paperwork and the absence of test results as a barrier to placing concrete, and ITD personnel assigned to the project typically allow concrete placement at the contractor's risk.

Phase 3: Testing at the ITD Laboratory

When samples arrive at the Central Laboratory, personnel deliver them to the Structures Laboratory. On an ongoing basis, the laboratory manager must ensure that quality assurance testers are properly trained to inspect reinforcing steel during all placement phases. Then, for each job, quality assurance inspectors test the samples.

Test personnel begin by inspecting each review sample and tags for consistency. Before testing begins, inspectors record parameters for each sample on an ITD 912 form. These include the heat number, bar number, sample length in feet and inches, sample weight, actual unit weight, theoretical unit weight, and cross-sectional area. They also use information from the Concrete Reinforcing Steel Institute (CRSI) Manual of Standard Practice to properly identify different types of rebar.

Next, testers conduct a tensile test on the sample in accordance with AASHTO T 68/T68-09 and ASTM E8/E8M. [6,7] For each sample, they calibrate the test machine and then mark the sample by measuring and marking an eight-inch segment in the middle of the sample. The tester then divides the eight-inch segment into three equal segments and marks it accordingly. He or she places the sample into the testing apparatus so that the eight-inch segment is the only portion of the sample that will be in tension during testing. The tester initiates the tensile test, and the testing machine increases tension at a constant rate. During testing, the testing apparatus records tension and stress until the sample fractures. The tester removes the sample from the apparatus, and on the ITD 912 form, records the location of the fracture as well as the yield point in pounds and pounds per square inch (psi), tensile strength in pounds and psi, and elongation.

Testers use the remaining portion of the sample to perform a bend test. For each sample, testers calibrate the testing machine for the bend test and place the sample in the testing apparatus in accordance with the AASHTO T 285 *Standard Method of Test for Bend Test for Bars for Concrete*

Reinforcement. [8] Each reinforcing steel grade has a corresponding pin diameter around which the tester bends the sample. The test begins by bending the sample by applying a continuous and uniform force. The test is completed when the tester has bent the sample to the angle of bend specified for the material. After completing the bend test, the tester checks the sample for fracturing, cracking, and a deep ringing when tapped against a solid metal object. If the sample is fracture and crack free, and rings when tapped, the sample has passed the bend test. The tester records results on the ITD-912 form.

A sample fails testing when its yield point, tensile strength or elongation is below the minimum grade standard. If bend test failure occurs, retesting is required for either bend or tension testing failure. The retesting requests another sample from the same steel shipment from which the contractor obtained the failed sample. The tester then tests the sample again under the same specifications. If three samples from the same shipment fail, then the contractor may not use reinforcing steel from that shipment in ITD projects. After completing the testing, the tester records results and relevant parameters onto an ITD-912 form. This form specifies whether the sample is acceptable and upon completion, the tester uploads it to ITD's Intranet and mails a copy to the project engineer.

Testing Results

As per the ITD Quality Assurance Manual, once inspectors have tested the samples and each sample passes a tensile and bend test, contractors may use reinforcing steel in ITD projects. [1] As documented test records demonstrate, ITD's reinforcing steel testing procedures are very thorough. Lab personnel test thousands of samples yearly and the vast majority pass the testing. While test failures are very rare, they have prevented the use of bad reinforcing steel in ITD projects.

A Structures Laboratory tester at ITD could only recall a single incident in the seven years he has been with the Structures Laboratory when three samples from a project failed tensile testing and all reinforcing steel with that heat number had to be removed from a project; the second sample from the project site passed the tensile test as well as the bend test and was cleared for use in ITD projects. In recent years, samples have failed the bend test approximately twice a year. Upon receiving a second sample, the reinforcing steel almost always passes both tests. In the past, epoxy-coated reinforcing steel bend test failures were more common, but in recent years the failures of epoxy coated reinforcing steel have become very rare.

In part because of these results, ITD inspection staff reported that in practice, contractors rarely wait for test results, and the resident engineer at the construction site generally allows contractors to "proceed at their own risk" in advance of results.

Potential Areas of Improvement

Even without comparing quality inspection methods in Idaho against other states, a few potential areas for improvement may present themselves. The current methods for testing reinforcing steel are very comprehensive. However, the high reliability of reinforcing steel and low failure rate may be cause to lower sampling rates based on risk analysis methods or ITD enacting a more structured manufacturer certification program. Under the current program, the most common error that occurs during sampling is the mislabeling of samples. This happens frequently and inspectors at the ITD Structures Laboratory typically identify this when they review the sample tags and they do not match the identification markers on the reinforcing steel samples. When samples are mislabeled, employees at the Structures Laboratory must contact the person who took the sample and acquire the correct information. This can be time consuming and confusing. ITD may be able to minimize such errors by more thoroughly training individuals responsible for sample collection or by ensuring that more than one person checks sample tags before being sent off site. Potential areas of improvement that the ITD Inspector we interviewed mentioned were taking more care with tagging samples and testing more samples from the same heat number, if used on multiple projects.

Chapter 3
Findings: Department of Transportation Quality Assurance Practices from Select States

Introduction

After conducting a literature review and evaluating any related published work to gather department of transportation data across the 20 states described in the appendixes, we analyzed the variety of quality assurance practices for using reinforcing steel at transportation construction sites. Some transportation departments have begun selecting samples using various stochastic methods to reduce the number of samples tested and the expenses that come with extensive testing. Others are creating manufacturer certification programs that minimize the testing their transportation departments must perform. Our analysis goal is to identify commonalities and practices we regard as effective strategies in the hope that the analysis will reveal effective practices we can use here in Idaho. Here are our findings.

Commonly Used Quality Assurance Practices

The most commonly used quality assurance practices are to adhere to established federal and industry standards. Some states accompany such approaches with state-specific testing standards, certification program guidelines, sampling based on the frequency of failure, and statistical analysis to identify the amount of sampling required.

Established Federal and Industry Standards

A common practice throughout all states reviewed is to adhere to the standards of quality assurance established in the Code of Federal Regulations (CFR), the American Association of State Highway and Transportation Officials manuals (AASHTO), and the American Society for Testing and Material (ASTM). Federal regulations act as a general guideline for quality assurance each state must follow for highway construction, while AASHTO manuals and ASTM guidelines tend to provide more detail as of materials handling and specific quality assurance test parameters.

The CFR provides general quality assurance guidelines to which state quality assurance programs must adhere for states to construct state roads and interstate highways for projects that use federal funding. [9] The guidelines within the CFR state the methods for material sampling, authorized personnel to conduct the sampling, and laboratory personnel qualifications. Most states refer to the CFR as a baseline guide when establishing their own regulations for construction. Most the states that our team reviewed extended AASHTO manual guidance with additional testing regulation details.

AASHTO manuals provide a more detailed overview of material handling than the CFR. AASHTO Manuals outline certain specifics and standards that are necessary to properly handle, and test reinforcement steel. Although states apply many AASHTO standards , the most common AASHTO standards we saw applied for reinforcement steel are the M 31M/M 31-15 *Standard Specification for Deformed and Plain Carbon-Steel Bars for Concrete Reinforcement*; M 55M/M0 55-09 *Standard Specification for Steel Welded Wire Reinforcement, Plain, for Concrete*; M 221M/M 221-09 *Standard Specification for Steel Welded Wire Reinforcement, Deformed, for Concrete*; and M 284M/M 284-09 *Standard Specification for Epoxy-Coated Reinforcing Bars: Materials and Coating Requirements*. As per the AASHTO bookstore website, the AASHTO M 284M/M 284-09 has been discontinued, and users are to apply the ASTM standard A775/A 775M instead. The most prominent and relevant AASHTO Standard Specification that addresses reinforcing steel is the Manual M 31M/M 31-15. It identifies the varied parameters users need to follow to ensure the quality of material being used in construction.

Special considerations AASHTO M 31M/M 31-15 identifies are the types of reinforcement steel that is to be tested for use. These types are 40ksi Grade 40, 60ksi, Grade 60, 75ksi Grade 75, and 80ksi Grade 80. These values identify the minimum yield strength levels for reinforcement steel bars. The M031 Manual also states that the extension of the steel under tensile loading shall be 0.5 percent of gauge length for Grades 40 and 60, and 0.35 percent for Grade 75. Also, the variation in weight shall not be greater than 6% except for bars that are smaller than $\frac{3}{8}$ of an inch.

For both AASHTO M 55M/M 55-09, and M 221M/M 221-09, special considerations are as follows: (1) the frequency of weld shear strength testing will be four welds from each specimen, (2) the minimum shear value shall not be less than 241 Newton or 35000 pounds-force, and (3) that the AASHTO testing parameters for the Epoxy-Coated Reinforcing Bars, AASHTO M 284M/M 284-09, will be replaced with the ASTM standard ASTM A775/A775M-07b.

In addition to the testing requirements outlined in the CFR and AASHTO manuals, several states reviewed also applied ASTM standards. There are many ASTM standards used, however three were common throughout many states. The common ASTM standards used were A615/A615M *− 16 Standard Specification for Deformed and Plain Carbon Steel Bars for Concrete Reinforcement*; A706/A706M – 16 *Standard Specification for Deformed and Plain Low-Alloy Steel Bars for Concrete Reinforcement*; and A775/A775M – 16 *Standard Specification for Epoxy-Coated Steel Reinforcing Bars.*

Specific parameters to test deformed and plain carbon-steel bars are outlined in ASTM A615. These parameters are detailed as they identify aspects like the minimum yield strengths like that of the AASHTO M 31M/M 31-15. The same grades used in the AASHTO manual are accepted, with the addition of 100ksi Grade 100 yield strength. As noted in ASTM A615 section 1.2, this additional grade sets the tensile strength range ratio to 1.15. Further, the ASTM standard A615 outlines the designation numbers with corresponding nominal weights, dimensions, and deformation requirements in its Table 1, and the alternate bar sizes in its Table A1.1. Tensile and bending test parameters are shown in its Tables 2 and 3, respectively. A special parameter in ASTM A615 is that the phosphorus content is not to exceed 0.06 percent. Florida and Kentucky made special note of this parameter, suggesting that it is of some importance.

Like the ASTM standard A615, the standard A706 outlines nominal parameters for designation numbers. The standard A706 also outlines the minimum and maximum yield strengths for Grade 60 and Grade 80 steel bars. Special requirements outlined in A706 regulate the maximum amounts of elemental content within the steel. These requirements are identified in section 6.4 and 6.5 of the standard A706. [10] Maximum carbon equivalency shall be 0.55 percent, and determined by the use of the formula:

$$C.E. = \%C + \frac{\%Mn}{6} + \frac{\%Cu}{40} + \frac{\%Ni}{20} + \frac{\%Cr}{10} - \frac{\%Mo}{50} - \frac{\%V}{10}$$

where C.E. is the carbon equivalency. $\%Mn$ is the percent of manganese, $\%Cu$ is the percent of copper, $\%Ni$ is the percent of nickel, $\%Cr$ is the percent of chromium, $\%Mo$ is the percent of molybdenum, and $\%V$ is the percent of vanadium.

Also, the maximum percentages for elements contained within the alloy steel are as follows: carbon must be less than 0.33 percent, manganese less than 1.56 percent, phosphorus less than 0.043 percent, sulfur less than 0.053 percent, and silicon less than 0.55 percent. Further specifications on alloy steel reinforcement are stated throughout the ASTM standard A615.

As per the AASHTO bookstore, the ASTM standard A775/A775M – 16 is to be used in lieu of AASHTO M 284M/M 284-09. The ASTM standard A775 outlines the required parameters for application of epoxy coating on steel reinforcement. These parameters include the material specifications, which refers to the standards A615 and A706. Also included are the application of the coating, testing of the coating, and the acceptance criteria based on inspection and testing. Further identified are the guidelines on number of tests, rejection of material, and certification requirements along with epoxy coating parameters. Section X1 of the ASTM standard A775 identifies the guidelines for construction practices. These practices include the storage, handling, repair, and acceptance of steel reinforcement with epoxy coating. One of the special requirements outlined in this section is that if the epoxy coating is damaged to an extent greater than 2 percent of the surface area in any 1-ft length, then quality assurance testers should reject the bar from use. If there is damage and it does not exceed 2%, then the epoxy coating should be repaired in accordance with the standard A775.

State-specific Sampling, Inspection, and Acceptance Standards

In addition to the testing and acceptance parameters in the CFR, AASHTO, and ASTM manuals, a few states have implemented their own methods of sampling, inspection, and acceptance. For example, to extend federal and industry guidelines with specific procedures to test reinforcement steel, California includes tests that include measuring epoxy coating thickness on steel reinforcing bars (California Test 687), holiday detection in epoxy coating (California Test 685), bend testing (California Test 686), and tensile testing (California Test 670). These tests build from and reference several ASTM standards.

States determine the frequency of sampling using the test methods stated by either the AASHTO Manuals, ASTM standards, or a supplemental series of tests specific to an individual state. Each has identified a methodology on how to implement sample selection, test frequency, and acceptance, based on one of the previously mentioned guidelines.

Sample collection frequency methods include the sampling of every single heat number, size, and type of reinforcement. States may also base sampling requirements on manufacturer certification programs outlined by quality assurance manuals. Sampling based on the frequency of failure, such as a reduction in sampling tests for manufacturers that habitually conform to standards, is at the discretion of the engineer. Sampling based on potential severity requires that the state transportation agency complete a risk analysis and put a tiered system in place to determine the risk level of material.

Extensive Sampling Programs

Several states, including Idaho, sample every single heat number, lot, size, and type of reinforcement that is shipped to each construction site. This method ensures that the quality of the material conforms to standards established in the project contract. However, we believe this approach may oversample and that states could potentially reduce the amount of testing and test redundancy by using statistical modeling to pinpoint the amount of sampling required.

Sampling Based on Certification Programs

Sampling based on certification programs is another prominent form of sample collection used by several states. This method employs the use of a certification program in which an approved authority inspects reinforcing steel products from individual manufacturers and then certifies all products from the manufacturer as a whole instead of products for individual projects. In these cases, an engineer or other experienced authority certified to conduct inspections establishes the inspection rate. Certifying a manufacturer reduces time and expense at the jobsite by allowing project teams to use material produced from a certified manufacturer without extensive testing or at a minimum just a visual inspection. This method relies heavily on the experience and professional opinions of the engineer and inspectors conducting the sampling. The method also employs the concept that the state's engineer may sample and test any material at any time, at no cost to the state transportation department. Also, if any material is to be found deficient, then typically that manufacturer loses his or her certification, and is subject to a higher frequency of testing to obtain recertification. Also, typical with this method is for states to use an established timeframe of recertification testing, such as a yearly inspection that selects random samples to maintain manufacturer certification.

Sampling Based on Frequency of Failure

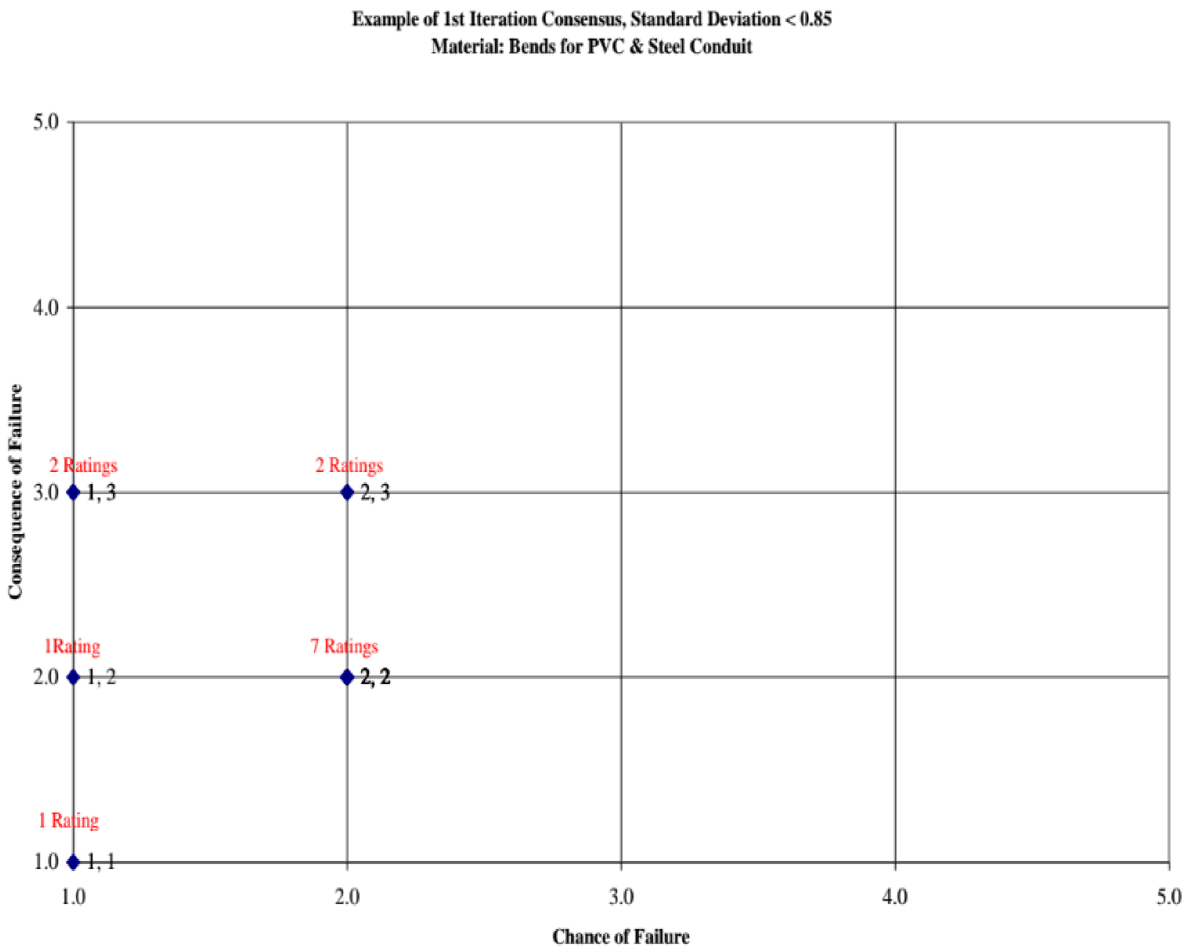
A less common sampling method used by only eight of the states surveyed was to conduct sampling based on frequency of failure. This method to verify material typically outlines the testing of each heat number, lot, size, and type of reinforcement from each manufacturer and is mostly used in conjunction with other sampling methods. Using this approach is similar to using the certification programs previously mentioned, where material is subject to visual inspection only if obtained from a trusted source. Transportation departments in Indiana, Michigan, Maryland, Kentucky, New York, Utah, North Dakota, and Nebraska use this approach.

Sampling Based on Statistical Analysis of Potential Risk

California and Washington use statistical analysis of material failure to determine sample frequency. This systematic sampling and testing method establishes a set of categories that assess the likelihood of failure, potential loss, and the potential severity associated with the loss. These states use a tiered system, where transportation departments assign each material a risk value identifying the potential of loss and its severity should failure occur. The state of California establishes the potential for loss in its Caltrans Construction Manual, listing the parameters that determine the tier level for a given material. Please see Appendix A to see this parameter table. Washington uses a similar tiered system, employing the use of a risk analysis method to determine the severity of loss, and subsequently the frequency for testing.

The state of Washington has published two main documents to assist in determining risk, its "Materials Risk Analysis," and "Project Risk Management Guide." These documents outline the parameters the state transportation department uses to establish test frequency and outlines the categories for materials acceptance in its materials risk analysis by level. There are four levels, with one being the highest and requiring the most sampling and testing, while four is the lowest; job sites may use level 4 material identified after only a simple visual inspection.

The method Washington uses to identify which level a material is associated with is its "Documentation and Exchange of Lively and Pure Homeopathic Information," which they identify as the Delphi Method (Abbreviations.com, 2016). This approach is that of an expert review. The transportation office gathers input from a group of persons who are considered resident experts on the subject material, and has established a ranking system based on their input; it includes determining factors on which test frequency and sampling methods are dependent. To gather expert opinions, Washington uses a survey with two questions, "what is the risk of failure?", and "what is the consequence of that risk?" (Washington State Department of Transportation, 2010). The transportation department posed these questions to a group of engineers with specialties in structural design, hydraulics, pavement design, and electrical, as well as project inspectors and other department employees who might be familiar with the material. Survey data allowed department personnel to identify the average risk of failure with a standard deviation. The transportation department then plotted the findings on a graph that shows the consequence of failure vs. the chance of failure. Using this method, Washington conducted at least two rounds of surveys. Figure 1 shows the plotted ratings after obtaining survey results. Rating values are plotted in the first quadrant of a Cartesian coordinate system, where the y-axis corresponds to the consequence of failure, and the x-axis is the chance of failure. The purpose was to establish consistency, with minimal deviation. After completing these rounds, Washington was able to formulate the associated risk identified in accordance with impact, and probability of occurrence.



Source: Washington State Department of Transportation, 2010

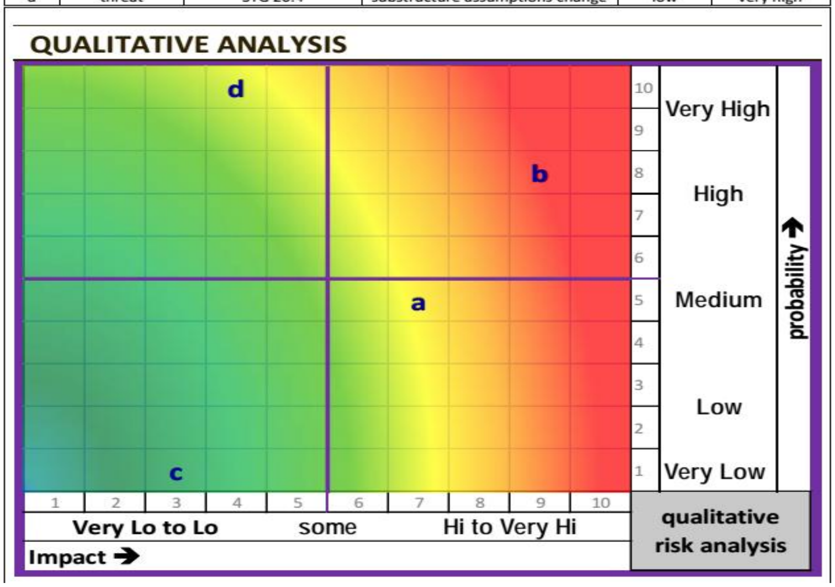
Figure 1. Risk Analysis Survey Results

Washington then uses a risk matrix, what transportation department personnel call a *Qualitative Analysis Graph*, to determine the value of the identified risk. As shown in ***Figure 2***, this graph shows the impact of material failure based on probability of failure. The state has responded to analysis results by increasing test frequency for those materials shown more likely to fail and with a higher potential negative impact resulting (Washington State Department of Transportation, 2014).

The graph shows an arch of color, ranging from green, to yellow, to red. The green color at left is localized from the bottom left corner of the graph to the upper left corner and indicates a low risk area. Red is localized on the right edge of the graph, and indicates a high risk. Separating the green and red portions of the graph is a yellow band. The yellow band is an indication of moderate risk, which therefore recommends that an engineer assess the material by making an individual materials evaluation. One drawback to using this method is that a risk that may classify as high impact, but low probability may not be given the attention that it deserves. This may also be because the expected value of the risk is not properly ranked on the risk matrix.

Qualitative Risk List

Risk	Threat or Opportunity	Risk Breakdown Structure RBS #	Risk Title	Impact	Probability
a	threat	ROW 40.1	managed access challenge	high	medium
b	threat	ENV 30.1	permits and permit appeals	very high	high
c	threat	UTL 20.1	unidentified utilities – conflicts	low	very low
d	threat	STG 20.4	substructure assumptions change	low	very high



Source: Washington State Department of Transportation, 2014

Figure 2. WSDOT Qualitative Analysis graph.

Chapter 4
Recommendation: Proposed Collegial Analysis Method for Determining QA Test Frequency Requirements

Introduction

We believe findings from the state-by-state literature review presented in this report recommend an optimal course of action for determining test frequency; they identify risk associated with material failure and its potential significance should failure occur. As a result, we are recommending that Idaho employ a method we are calling ***Collegial Analysis*** to assist in addressing Idaho's primary quality assurance concern of how much quality testing it should perform and how frequently, potentially improving efficiency and lowering expense while maintaining its outstanding record of reliable material performance at Idaho construction sites. We recommend both an expert survey (qualitative) and a numerical risk (quantitative) assessment. This approach adapts the ***Delphi method*** used by the Washington State Department of Transportation, supplemented with quantitative values obtained from a numerical risk analysis.

It is important to note that the state-by-state review was the primary focus of this report. As described in the next chapter, our team has conducted a ***preliminary study*** using the Collegial Analysis method with a small sample size to demonstrate its potential. However, it is essential that ITD more fully evaluate and validate the proposed approach before using it.

Rationale

We believe that combining a subjective and objective assessment in the proposed Collegial Analysis will result in a viable method to determine the risk of a construction material, and therefore only the necessary quality assurance frequency and type.

Both the subjective and objective assessment procedures are independent of each other; the subjective assessment collects empirical data to assess certain risk, and the objective method conducts numerical risk analysis to substantiate the empirical assessment. Under the proposed concept, the numerical stage of the Collegial Analysis should be implemented using reasonable simplifying assumptions; this establishes a linear relationship between the steel rebar chemical content to provide the input values and the tensile strength for the output values. This linear association can be assumed using a linear correlation function and implemented in Matlab mathematics software. ITD can obtain the chemical content variation in multiple distributions with the assumption that the manufacturing process for quality steel reinforcement has already been refined to the point where deviations will be minimal.

Phase 1: Complete Expert Survey Using Adapted Delphi Method

To establish test frequency and type, we recommend a survey from which to make statistical analyses of risk assessment. We developed this approach based in part on other state practices that use similar methods to determine test frequency determination. These other states are California and Washington. Similar to the Washington State Department of Transportation Delphi method, we suggest a two-question survey directed to ITD engineers with expert knowledge of the material. Use the modified questions, “What is the consequence if a failure occurs?”, and “What is the severity of damage in the event of any single steel reinforcement failure.” Select experts for the survey with sufficient knowledge about frequency of material failure and level of impact in the event of material failure. We recommend that ITD collect these questions anonymously, and give each a numerical value to differentiate one from another. To ensure validity, we recommend ITD collect at least 50 responses from this survey.

After completing the survey, ITD can then compare responses against the computational values calculated from the second part of this method, a numerical risk analysis. ITD can then compare the survey values against the numerical risk analysis results to determine the most probable occurrence of failure by steel reinforcing bars, and the most probable severity should material failure occur. ITD can then construct a risk matrix graph illustrating the frequency of sampling and testing which engineers can then use as a guide to set quality assurance testing frequency and type.

About the Delphi Method

The Rand Corporation developed the Delphi method in the 1950s. The method employs a survey that users send to experts on a particular subject; administrators then categorize responses to obtain an empirical risk assessment. The survey is then re-administered to the same group of experts multiple times to obtain an average of the responses. The purpose of this method is to gain a general representation of a group consensus from anonymous experts. This is an indication that the trust associated with the results is sufficient to make significant predictions on outcomes given certain parameters. A drawback of this method is that it is not objective and is based solely on the opinions of those who are perceived to be resident experts. This method uses qualitative information effectively and manipulates it to obtain quantitative results.

The state of Washington’s Department of Transportation uses the Delphi method to assist in determining risk assessment. Since the outcomes from such a method may not be exact, Washington uses several other factors to determine optimal material test frequency. Manuals such as the “Project Risk Management Guide,” “Materials Risk Analysis,” and the “Standard Specifications for Road, Bridge, and Municipal Construction” all provide requirements for assessing risk and for setting test frequencies (Washington State Department of Transportation, 2010) (Washington State Department of Transportation, 2014) (Washington State Department of Transportation, 2016).

Phase 2: Conduct Numerical Risk Analysis

For the second part of the Collegial Analysis, we recommend a statistical analysis that obtains numerical risk evaluation outputs from the given data. Analysis results depend heavily on robust inputs. To ensure that the numerical risk analysis is accurate, ITD will need to collect steel reinforcement material property data from previous tests. Results should include as much information as possible, such as chemical makeup, yield strength, ultimate strength, and all the physical attributes of the steel such as diameter and weight.

We used @Risk software to conduct our statistical analysis. [(11)] ITD can obtain the risk level by evaluating test statistics, including minimum and maximum values, mean, median, mode, standard deviation, variance of distributions, and skewness.

Include material property data obtained from the ASTM standard 1035/A1035M -16a. The values collected in response to the ASTM standards include minimum tensile and yield strengths, as well as maximum content of specific chemicals that make up the steel. The chemicals could then be deviated by a 10% reduction in their maximum values stated in the ASTM, under the assumption that the steel manufacturing process is a highly-controlled process with minimal deviation in quality; thus, the deviation of the tensile and yield strengths may be determined based on the distributions associated with the chemical inputs.

We recommend running this numerical risk analysis at least 30 times on the same sets of data. It may be beneficial to allow ITD to change the distributions manually each time to obtain an average of the probabilistic outputs given a variance in the type of distributions.

Phase 3: Combining Methods

We recommend that a decision support tool that combines the results from the two previous phases be developed. Since no work on this phase has been completed yet, examples showing how this combination will occur are not available now.

Chapter 5
Preliminary Study Using the Collegial Analysis Method

Introduction

To effectively implement the ***Collegial Analysis*** method and generate a well-rounded risk assessment picture, we recommend both an expert survey (qualitative) and a numerical risk (quantitative) assessment. To evaluate the potential of this method, we applied it in a small, preliminary study described here. To ensure that the survey is valid, ITD will need to obtain a larger sample size than is illustrated here. Then, to ensure that the numerical risk analysis is accurate, ITD will need to collect steel reinforcement material property data from previous tests. Results should include as much information as possible, such as chemical makeup, yield strength, ultimate strength, bend test strength and all the physical attributes of the steel such as diameter and weight.

Preliminary Studies

Our preliminary numerical risk analysis showed reasonable results given the linear correlation function assumption we put in place to compensate for a lack of steel reinforcement material property data. Further, an experienced chief metallurgist confirmed the validity of outcomes for our numerical risk analysis based on chemical composition. Given that we were short of testing data and survey results, and also because the risk analysis methodology development was not included in this project scope, the Collegial Analysis method remains a prototype method that we recommend ITD further develop and validate in follow-up projects. Further development is also needed before ITD can obtain results on probable tensile strength ranges from the numerical risk analysis computations.

Phase 1: Complete Expert Survey Using Adapted Delphi Method

To complete the expert survey, we used Qualtrics software available for students and faculty use here at Boise State University and delivered a survey to local individuals with expert knowledge of steel reinforcement testing and failure conditions. Using the software, we sent participants the survey through email and received responses the same way. Our objective was to use this software to collect participant responses and develop statistical analyses of the collected results. Our desire was to receive 50–100 responses; however, given limited time in which to examine this method and limited availability from ITD personnel, we were only able to collect responses from two qualified ITD participants. This response is not sufficient to draw any conclusion.

Our survey used the two questions, “What is the consequence if a failure occurs?”, and “What is the severity of damage in the event of any single steel reinforcement failure.” We provided participants with definitions, establishing structural failure of a steel reinforcement bar as being when its strength is tested to be less than the required minimum strength. We define the severity by structural failure caused by any single steel rebar as being with a testing strength less than the required minimum strength. We asked respondents to restrict their answers to a simple 0–10 ranking.

Phase 2: Conduct Numerical Risk Analysis

Analysis results depend heavily on robust inputs. In this case, we had little information about chemical makeup, yield strength, tensile strength, and all the physical attributes of the reinforced steel such as diameter and weight. To gain a clear picture of what the probabilistic outcome will be for the numerical risk assessment, we ran the numerical risk simulations multiple times, with different types of statistical distributions and random number generation.

A numerical risk analysis software, @Risk, was used to conduct the quantitative risk analysis, which is based on Monte-Carlo simulation. [11] We used several types of statistical distributions to describe uncertain values to present results. These cover the basic distributions such as Normal, Uniform, Triangular, Geometric, Histogram, and Poisson. After selecting a distribution type, we are able to determine other parameters of the simulation as well. With the numerical risk analysis, we can explicitly include the uncertainty brought by chemical components to estimate the steel strength with probability distributions and establish a most probable outcome for the given values.

Linear Correlation Function

Since we lacked steel testing data for numerical risk analysis, we derived the methodology using a linear correlation function, shown in Figure 3, to correlate multiple chemical content with tensile strength. Note that $\boldsymbol{A}$ is the chemical composition matrix, while $\boldsymbol{Y}$ is the tensile strength vector. $\boldsymbol{X}$ denotes the conversion factor vector.

$$\boldsymbol{AX} = \boldsymbol{Y}$$

Figure 3. Chemical Composition and Chemical Composition Correlation

The equation in Figure 3 can be written in a matrix form as shown in Figure 4.

$$\begin{bmatrix} A_{11} & \cdots & A_{1n} \\ A_{i1} & \ddots & A_{in} \\ A_{m1} & \cdots & A_{mn} \end{bmatrix} \begin{Bmatrix} x_1 \\ x_i \\ x_m \end{Bmatrix} = \begin{Bmatrix} y_1 \\ y_i \\ y_m \end{Bmatrix}$$

Figure 4. Correlation Function in Matrix Form

Where A_{1i}, represents each individual chemical component percentage data and is the element in the matrix, $A_{m\times n}$. y_i is the tensile strength at this combination of chemical contents. x_i is the conversion factor to correlate individual chemical composition to the tensile strength. The conversion factor should be determined by solving a linear equation of $\boldsymbol{X} = \boldsymbol{A}^{-1}\boldsymbol{Y}$. Note that $\boldsymbol{A}$ and $\boldsymbol{Y}$ are a set of data from specific steel reinforcement tests. If there is no available data set, to simplify the calculation we can assume a linear correlation between $\boldsymbol{A}$ and $\boldsymbol{Y}$ for proof of concept analysis. In case that the linear assumption is not applicable to capture the correlation, artificial intelligence approaches will be used to characterize the correlation in the follow up QA projects. In follow up projects, we will collect plenty of data and run numerical risk simulations to quantify the correlation between the variance of multiple contributing factors (i.e. chemical components and diameter) and distribution of tensile strength.

Once we assign values for $\boldsymbol{A}$ and $\boldsymbol{Y}$, the conversion factor vector, $\boldsymbol{X}$, can be determined by use of Matlab software.

Identifying Quantitative Results

The discussion that follows is a discussion of the proposed method in the event data are available. After the conversion factor for each steel rebar is determined, we can correlate each chemical content distribution with tensile strength using the equation shown in Figure 5.

$$A_{i1}x_1 + A_{i2}x_2 + A_{i3}x_3 + \cdots + A_{in}x_n = y_i$$

Figure 5. Correlation Function for a Steel Rebar

Since each element in matrix $A_{m\times n}$ is a certain distribution (not a determined number) and x_i is a determined conversion factor from Equation [2], we can run @Risk numerous times to get a numerical distribution of each y_i, $i \in [1, n]$. The physical meaning of Equation [3] is that the multiple chemical contents distribution can be directly correlated to its own tensile strength. The material strength results are based on multiple contributing factors and each of these factors has a distribution. y_i is a most probable single value of tensile strength and is not a range. Consequently, the numerical risk simulation can run many times and calculate many y_i. All these y_i will form a distribution of most probable strength of steel bar, which will provide a reliable range of strength values to us. Note that n denotes the number of chemical contents in one steel rebar, while m denotes the number of sample rebar.

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Appendix A
California DOT Quality Assurance Practices

Background

To establish consistency in quality for construction, the California Department of Transportation (Caltrans) identifies several parameters for material quality control. These include the sampling of material, the frequency of sampling, the test methods, identifying responsible parties for testing, acceptance criteria for material, use of the material in question and the severity of the consequences in the possible event of a failure. Methods to maintain quality and uniformity in construction are outlined in several publications identified in this review, the primary document being the "Construction Quality Assurance Program (CQAP)" manual. [(12)]

State Requirements and Standards

California establishes state standards in its CQAP manual. The manual also identifies that the state of California complies with federal regulation 23 CFR 637. The state requires that all materials used be new and stored in a manner that makes the material readily available for testing. The requirements establish consistency in quality by using inspection and test frequencies necessary to ensure compliance. Material selection and acceptance relies upon adequately trained personnel who conduct testing and inspection. The CQAP and 23 CFR 637 establish personnel standards.

For steel reinforcement testing, the CQAP identifies sample parameters. For rebar, size #9 and smaller, the sample length must be 4ft. For rebar sizes #10 or larger, the sample length must be at least 6.5ft. [(13)]

California also implements a standard of buying and using American made products as per standard specifications, section 6. Using locally produced materials ensures that production methods and personnel comply with practices that maintain uniformity in products and quality.

Using Contractors to Inspect and Test Materials

Finally, as part of quality control processes, the state requires the project contractor to maintain responsibility for material quality, and whose responsibilities address material fabrication, sampling, inspection, testing, production, delivery, storage, construction, and placement. The responsibility of the state of California in turn is to accept material that contractors have approved as confirmation that materials meet quality assurance standards. Contractors are instructed in methods of proper identification of material, along with proper sampling and testing.

California indicates in its CQAP the two main reasons for using contractors to oversee quality control efforts with minimal intervention from the state. The first is that if Caltrans controls the contractor's process, then Caltrans would be obligated to accept the work regardless of the quality. The second is that the contractor is the one in control of the equipment and personnel, and therefore deemed the most proficient in quality control. This separation allows for the state to minimize efforts and to maintain a uniform standard.

Quality Assurance Guidelines and Practices

As noted earlier, Caltrans uses its CQAP manual as a guide. This manual identifies the traceability of materials and components as the inspection activity through measurement, observation, testing, and engineering judgment of a material to determine compliance with specified requirements. The state also looks to contractors to oversee inspection and testing, monitoring and assess material at a time when corrective action may be taken. As materials pass inspection and testing, Caltrans provides its acceptance for the inspection of material at various stages of use, such as upon delivery, installation, and at completion of construction. Caltrans follows the Code of Federal Regulations 23 (23 CFR) for adherence to the acceptance program. This dictates that acceptance of materials is done so with sufficient inspection to adequately identify characteristics of the material that determine the overall quality of the product. Inspection is then followed up with adequate testing to verify the inspection.

To assist in determining quality assurance, Caltrans has adopted a tiered system that sets quality assurance inspection and testing priorities based on the likelihood of material failure, potential loss, and the potential severity associated with that loss. [12] See ***Figure 6***. Severity levels are catastrophic loss, safety loss, interrupted service, and monetary loss. The consequence of a failure determines Tier levels. For example, Tier Level 1 identifies material risks that pose the greatest consequence of a failure, whereas Tier Level 4 has the least. The parameters for determining tier level are outlined in the contract items table section 2.2.4 in the Caltrans Construction Quality Assurance Program Manual. [12]

Test Frequency

Caltrans sets frequency of testing and sample investigation based on the level of severity in the event of a failure. Resident engineers conduct inspections dependent upon the construction project requirements. To ensure that the quality is maintained, the sampling and inspection is done so as to identify the properties essential to product design and performance. Consideration is made for frequency if supply of material is from a source that has a history of consistently accurate material production. However, if a source has a varying quality in material, or produces material infrequently, then testing frequency is increased to minimize potential for material failure. Relating test frequency to consistency in production allows for elimination of redundant tests being performed on material that may be consistently uniform, and allows for the increase of tests on questionable material that may be subject to test failure. As outlined in the CQAP, testing at the jobsite is reserved for Tier levels 1, 2, and 3. This is due to high potential for loss if a failure occurs, and potential for material variability due to shipping and handling. Based on the parameters established in the Caltrans Bridge Construction

Records and Procedures Manual, Volume 2, Section 165, splices will be tested in reference to the number of lots used in construction. [14]

CONSTRUCTION QUALITY ASSURANCE PROGRAM MANUAL

Chapter 2—Construction Quality Assurance Roadmap

Table 2.2.4. Tier Levels for Contract Items

Tier Level	Failure Category	Consequence of Failure	Example Items	Quality Assurance Requirements
1	Catastrophic	Greatest consequence of failure. Failure is likely to cause loss of life or serious injury.	Typically, fabricated structural-type products, such as structural steel, precast girders, pre-stressing.	Quality assurance methods designed to provide the maximum level of confidence in the quality control efforts of both the contractor and the producer.
2	Safety	Although not catastrophic, failure creates a safety hazard for employees or the public.	Manufactured and fabricated safety-related products, such as delineation, safety barriers, lighting, signal controllers.	Quality assurance methods designed to provide a high level of confidence in the quality control efforts of both the contractor and the producer through extensive use of pre-qualified materials from the authorized material list.
3	Interrupt Service	Failure or repair may cause an interruption in service, or environmental impact.	Jobsite-produced base and pavement structure, embankment, and drainage items; and environmental items, including stormwater pollution prevention plan best management practice devices.	Quality assurance methods based on 23 CFR 637 requirements for jobsite-produced items, applicable rules and regulations included in the contract for the environmental items; and certificates of compliance from the contractor or producer combined with intermittent inspection, sampling, and testing of in-progress work for drainage items.
4	Monetary	Monetary loss only. Consequence of failure is considered minimal in terms of project performance.	Grass seed, drainage and irrigation products, fencing.	Quality assurance methods typically based on use of commercial quality products or extensive use of certificates of compliance from the contractor or producer combined with periodical random inspection of in-progress work.

Source: State of California Department of Transportation Division of Construction, 2015.[12]

Figure 6. Caltrans Tier Levels for Contract Items

Test Methods

Contractors conducting testing on collected materials may perform testing at either the job site, or at an approved laboratory. Tests include the measuring of epoxy coating thickness on steel reinforcing bars (California Test 687), holiday detection in epoxy coating (California Test 685), bend testing (California Test 686), and tensile testing (California Test 670). [15,16,17]

Testing is conducted on material when it is as close to the job site as possible. This is done so by following the requirements outlined in the testing procedures listed above. Sample collection is typically done by obtaining two samples of predetermined length based on test specifics. The samples are to resemble the final product, as well as come from the same lot and source.

Test 687 encompasses steel reinforcing bars, welded wire mesh, and dowel bars, for use with type 2 gages. This test references several ASTM standards, such as ASTM A 775/775M, ASTM A 884/884M, ASTM A 934/934M, ASTM B 499, ASTM E 29, and ASTM E 376. Also, the test references Caltrans Standard Specifications section 52, and SSPC-PA 2 and SSPC Coating Application Standard No. 2. Test 687 identifies procedures for testing in the laboratory, as well as quality assurance testing in the field. It also identifies several general requirements for testing, such as the test for bending must be conducted between 68°F and 86°F. [15]

Test 685 is the test for holiday detection in epoxy-coated reinforcing steel products. This test references ASTM A 775/775M, ASTM A 884/884M, ASTM A 934/934M, and ASTM G 62, as well as Caltrans standard specification section 50 and section 52. Samples obtained from the field must be dry and free from contamination. Test 685 is a non-destructive test that allows for the detection of voids in coatings identified by the low resistance path, which triggers an audible alarm. The low voltage detector should have a source of 67.5 to 100 V DC, in accordance with ASTM G 62, section 1.2, method A. [16]

Test 686 identifies the method of evaluating the bend test results of fusion-bonded epoxy coatings. This test references ASTM A 934/934M, as well as Caltrans standard specifications section 52. [17]

Test 670 identifies the procedures for conducting the tensile test in accordance with ASTM A 370. This test also outlines inspection of failures and calculations to determine percent strain at failure. [17]

Appendix B
Colorado DOT Quality Assurance Practices

Background

Guidelines to maintain uniformity in quality for the state of Colorado Department of Transportation (CDOT) are outlined in several publications. The primary regulations stem from the “Standard Specifications for Road and Bridge Construction.” [18] The Approved Products List Program is managed by CDOT’s Product Evaluation Coordinator (PEC). CDOT adheres closely to AASHTO and ASTM standards for quality assurance. All governance of process is decided upon based on such manuals.

State Requirements and Standards

The state of Colorado requires that there be a Quality Control Plan (QCP) established before the start of any project. The contractor completing the construction project will submit the QCP to the state transportation department. The QCP is subject to approval of the state engineer before any work can start. The state also requires that material be subject to testing prior to placement or use, and any material not inspected, to be deemed unauthorized. It is indicated that all material will be tested by random sampling.

Along with the QCP, a complete list of reinforcing steel will be supplied to the engineer. This list will include the bending diagrams and plans. The list will identify the placement, quantity, and size and shape of the reinforcement. Also, all bending of reinforcement bars is required to be done cold. The bending of bars partially submerged into concrete will not be allowed in the field except where otherwise permitted. Bending will be done only with the approval of the engineer to ensure that the quality of the material is not altered due to the bending. This practice is to minimize scratches, pits, or holidays from being introduced to the material during use.

The state of Colorado only accepts material that has been produced from approved sources listed in the Qualified Manufacturer List (QML). To be determined an approved source, the manufacturer must comply with standards identified in the QCP. This ensures a consistency in production and quality. The QML requirement is identified in the “Standard Specification of Road and Bridge Construction” manual, section 602. [18] The QML is also listed on the Colorado Department of Transportation’s website, listed under the CP 11.

Field inspections will indicate all aspects of the material that are detrimental to product quality. This will include visual inspection of epoxy-coatings, scratches, cracks, and cleanliness. Also, the inspector will indicate if the material is of sufficient grade and size.

Material substitution may be considered if the substitute material has sufficient yield strength identified within the “Standard Specification of Road and Bridge Construction” manual, section 602. [18]

Quality Assurance Guidelines and Practices

Quality assurance is determined wholly by the authority of the state transportation office engineer. The engineer is stated as having the authority to decide on all matters relating to the contract and materials therein. This authority allows for the engineer to suspend work as needed if any of the specifications on the work are not being met (Colorado Department of Transportation, 2011). [19]

Any material used during construction is subject to inspection and testing by the resident engineer. This includes material that has already been placed. If in the case material has been placed, and is in need of inspection, the cost of exposing the material will be the responsibility of the contractor. Any work that is conducted with untested material is then considered at the liability of the contractor, and deemed unacceptable and unauthorized work (Colorado Department of Transportation, 2011). [19]

Test samples that are required for quality assurance will be obtained within the presence of the engineer, and the contractor may retain a portion of the sample. The tests and inspection will then be at the cost of the CDOT.

Test Frequency

The frequency of testing is identified within the Quality Control Plan before the start of each project. The frequency of sampling will be random and will not consist of fewer tests than the minimum outlined in the “Standard Specification of Road and Bridge Construction.”

Test Methods

As per the “Standard Specification of Road and Bridge Construction” manual, testing of material will conform to the AASHTO Manuals M31, R 38, T 244, M 55, and M 221. [3] Testers also use the ASTM standards A 184, A 370, A 615, A 706, A 996, and D 3665. [2] These tests outline the parameters and guidelines for sample size, selection, and testing.

Appendix C
Florida DOT Quality Assurance Practices

Background

The state of Florida establishes the methods and practices for using reinforcing steel in several publications. The most prevalent is the "Standard Specifications for Road and Bridge Construction." [20] This publication defines for the Florida Department of Transportation (FDOT) the procurement and use of reinforcing steel, as well as other materials used in construction. It also provides quality assurance procedures and identifies the ASTM and AASHTO standards used in materials testing.

State Requirements and Standards

Prior to use of material, FDOT requires that the contractors submit proposals and drawings which identify how the material will be used. Acceptance of work is subject to the engineer's approval at any time throughout the process of work. This indicates that defective material can be rejected at any time, including any material that was previously accepted.

Florida requires that reinforcement steel meet ASTM 615 Grade 60 requirements. Also, as per section 931 of the "Standard Specifications for Road and Bridge Construction," the steel that is tested with processes other than that of the ASTM A615 will be limited to 0.08% phosphorus content. Special requirements for reinforcing steel are listed in section 931, which encompass deformed bars, twisted bars, purchasers, samples, and tests.

Methods for sampling and testing of steel are outlined by the state materials office in the "Reinforcing Steel Sample Instructions" (State Materials Office, 2012). [15] FDOT practice is to adhere to ASTM standards regarding test methods. Also, FDOT is reliant on the expertise and authority of the resident engineer. The engineer is responsible for the type of work completed, materials used, and interpretation of construction completed. In consideration of the material, the engineer is to reference publications such as Appendix B of PCI Manual MNL and the "Standard Specifications for Road and Bridge Construction." [22,20] Also, sampling and testing will follow the standards set by the state materials office in the reinforcing steel sample instructions.

Quality Assurance Guidelines and Practices

Contractors must obtain construction reinforcing steel from manufacturers listed in the Approved Product List, (APL). The APL is obtained from the Product Evaluation Section in the State Specifications and Estimates Office. FDOT establishes parameters for quality assurance and control in the "Standard Specifications for Road and Bridge Construction." [20] Its Section 5 outlines control of work and is intended for the contractor to help him or her comply with FDOT quality control regulations. Section 6 identifies the process for control of materials. Section 6 identifies the criteria for acceptance, sampling, testing, approved manufacturer lists as well as storage and handling.

Several sections in the "Standard Specifications for Road and Bridge Construction" identify quality control and assurance measures. [20] The sections list each type of application of the reinforcement steel along with parameters identified with each application, such as tolerances.

Section 450-2 outlines the quality control program for the FDOT. Section 450-2 also references Appendix B of the PCI Manual MNL-116 ("Manual for Quality Control for Plants and Production of Structural Precast Concrete Products") as a source for the dimensions and conformance tolerances. [22]

Section 415 specifically refers to the use of reinforcing steel. This section is thorough in its applications and use of steel. Bar reinforcement and Welded Wire Reinforcement are listed in sections 931-1.1 and 931-1.2 respectively.

Section 931 of the "Standard Specifications for Road and Bridge Construction" lists the acceptance criteria for reinforcement steel. [20] Also, the section lists the methods for identification and sampling for tests of the steel.

Outlined in section 462-2, the engineer controls acceptance of material at any time throughout construction. This allows for the potential rejection of material if damaged or in any way found insufficient for use in any way.

Test Frequency

Florida uses its "Reinforcing Steel Sample Instructions" to determine the sampling for testing. This method identifies that sampling will be done on one sample in every 80 tons of material. Further, the type of steel and certified mill analysis determine test frequency, (State Materials Office, 2012). [21] Section 460-7.9 of the "Standard Specifications for Road and Bridge Construction" outlines the inspection and final acceptance of steel for construction. [20] Section 460-7.9 states that the frequency of the sampling and testing for construction material will be conducted at a sufficient rate to ensure the material is within requirements specified in the Quality Control Plan. The quality control plan identifies that the responsible party will conduct daily inspection of all phases of work and ensure that the material meets the requirements outlined in contractual agreement. Weekly meetings are required to allow the engineer to review the process and identify any improvements or refinements needed.

Test Methods

Florida uses three different appointments for testing. These are the Point of Production Test, Point of Distribution Test, and Point of Use Test. Each test allows for material quality to be determined as per contractual documentation. At any testing point, the department reserves the right to reject material if it does not conform to the specified requirements. Section 933 outlines the required tests for pre-stressing steel.

Appendix D
Illinois DOT Quality Assurance Practices

Background

Illinois employs several methods to ensure quality in reinforcement steel. The Illinois Department of Transportation (IDOT), has put in place a certification program for plants and manufacturers of material who want to supply IDOT projects. This program helps to ensure consistency and quality of material without significant variation. The IDOT engineer or other inspecting authority will conduct inspections of material at the production site by following guidelines provided by various manuals IDOT publishes related to reinforcing steel, notably the materials inspection manual and the standard specifications manual that address inspector authority as well as methods for sample selection and testing. [23,24]

State Requirements and Standards

Each IDOT highway district is required to take random samples from each producer furnishing bar for use in construction in their district. Contractors must conform to standards identified in the material inspection manual.

Requirements specific to Illinois are that the epoxy coating on reinforcement bars be 7–20 mils in thickness. Also, it is stated in the materials inspection manual that reinforcement steel will conform to the Federal Buy America Act, as well as the Illinois Steel Products Procurement Act (Illinois Department of Transportation, Bureau of Materials and Physical Research, 2015). [23]

Steel reinforcement that has a small layer of rust on the surface due to standard storage practices will not be subject to rejection. However, reinforcement that has been subject to improper storage and handling such that large quantities of rust or deformities have formed will be rejected. Stated in part 2 of the materials inspection manual is the acceptance criteria for engineers on the material size and sample methods. [23] This publication also states that the inspectors are able to collect samples of any material regardless of size at any time.

Certification Program

Reinforcement steel must also be obtained from producers that are considered to be in good standing. The list of qualified producers is to be determined through the CRSI epoxy coating certification program. Any inspector accepting material is to be made familiar with the epoxy coating certification program. The certification procedure for manufacturers of material requires that the plant conform to the National Transportation Product Evaluation Program, (NTPEP) as well as IDOT Standard Specifications for Road and Bridge construction. [24]

Quality Assurance Guidelines and Practices

IDOT uses its standard specifications manual to identify road and bridge construction for requirements and guidelines for material handling. (24) This publication is supplemented with various testing methods and standards which conform to ASTM methods. Further descriptions of sampling and testing methods are outlined in the materials inspection manual. (23) This manual is a guideline that inexperienced inspectors can use to determine frequency of sampling, sample size, and method of acceptance of steel reinforcement.

Regulations with regard to bar designation and handling in the field are outlined in section 3.1.4 of the Illinois "Bridge Manual" (Illinois Department of Transportation Bureau of Bridges and Structures, 2012). (25) This manual also identifies the sizes and lengths of bar reinforcement and the acceptable substitutions for each bar.

In addition, the Illinois Department of transportation has published several memorandums that outline the procedures that are to be followed to maintain quality control and assurance. Two with special significance to reinforcement steel are the inspection of black and epoxy-coated reinforcing bars, and the reinforcement bar and/or dowel bar plant certification procedure. (26,27)

Test Frequency

Testing of material is identified in the previously mentioned memorandums. The frequency and location of sample collection depends on the type of material and plant that produced it, and subject to the authority of the resident engineer. The responsibility of the contractor on the job site is to notify the resident engineer when the material arrives onsite. This is so that the engineer may select samples and notify the District Materials Office so material may be tested.

As stated in the materials inspection manual, the frequency of sampling for tests is to be based on random field tests and random Bureau of Materials and Physical Research (BMPR) tests. (23) Also, the materials inspection manual indicates that the frequency is determined by Article 1030.05D2E and any ASTM or AASHTO Manual that is appropriate for that specific material.

As stated in the memorandum for inspection of black and epoxy-coated reinforcement bars, IDOT employees are to conduct annual inspections of material at each production plant and to randomly sample 6 samples. (27)

Test Methods

Testing of material is completed by the District Materials Office. The specifics for testing are determined by the materials inspection manual as well as the "Standard Specification for Road and Bridge Construction." (23,24) These manuals require that testing of reinforcement bars has to conform to the standards set forth in the ASTM standards A 706 (A 706M) and E 190, as well as AASHTO M 32, M 284 (M 284M), M 55, M 203, and M 221. (4)

Appendix E
Indiana DOT Quality Assurance Practices

Background

The Indiana Department of Transportation (INDOT) uses several publications to ensure quality assurance and control, most notably the "Manual for Frequency of Sampling and Testing and Basis for use of Materials." (28) In addition, a state certification program provides listings of approved methods for sample selection, testing, and quality assurance. INDOT has the final authority in determining whether to accept and make a material available for use on a job site. If a supplier has consistently been conforming to standards, the frequency of material testing from that manufacturer may be diminished at the discretion of the engineer. However, to maintain quality standards, the material is still subject to testing at any time, and may be rejected if found to be non-conforming to predetermined standards.

State Requirements and Standards

As stated in section 106.02 of the INDOT "Standard and Specifications Manual," and in accordance with IC 5-16-8 and the 23 CFR 635.410 all steel, except for pig iron and reduced iron ore, will be made in the United States using open hearth, basic oxygen, electric furnace, Bessemer, or other steel manufacturing processes. (29)

As per the department standard specifications, contractors will supply information on the material to the INDOT engineer within five days prior to the delivery of the material. This allows for INDOT inspectors to examine the material source, if necessary.

Standards between manufacturers, established by the INDOT Office of Materials Management, show that variations should be limited to set values. The tolerances for differences in test samples should be at maximum 1% for unit weight, 10% for yield strength, 10% for tensile strength, and 4% for elongation. It is also stated that if 90% of the material conforms to these standards, then its manufacture will have passed the laboratory requirements. Fabricator requirements are the same as the manufacturer, except that the variation in unit weight and wire diameter is 5% only. (30)

As per section 106 of the INDOT "Standard and Specifications Manual," if a material supplied from a source has been approved for use five or more consecutive times, then it may be used on an immediate basis prior to receipt of test results. (29) If any material from that same source fails a test, then that source may no longer be considered for immediate usage and will have to produce passing material another five or more consecutive times to be reinstated to the immediate use status. If material that was used for immediate use does not conform to standards, then at the discretion of the engineer, that material may remain in place at a reduced cost.

Quality Assurance Guidelines and Practices

Control of material is determined by the testing procedures and certification program, random sampling, and certification forms outlined by INDOT, (Indiana Department of Transportation Office of Materials Management, 2014), (Indiana Department of Transportation Office of Materials Management, 2013), (Indiana Department of Transportation, Office of Materials Management, 2015). [31,30,32] The Department of Standard Specifications, section 106 outlines the usage of the material and the supply methods. This shows that the material is subject to inspection at any time throughout the work process. Also, as indicated by the standard specifications, there is a potential for a supplier of material to obtain a status of immediate usage. This allows for material obtained from that supplier to be used immediately even before test results are returned. The method of quality control in this case is to determine a pattern of frequency for compliant material from a supplier. If a supplier habitually conforms to the standards of INDOT, then the INDOT engineer may reduce the amount of testing required, adjusting test frequency should any lapse in quality occur.

Material testing and frequency for INDOT is dictated by the manual for frequency of sampling, testing, and basis for use of materials. This manual outlines each material that may be used in construction and the frequency of methods used to test such material. To maintain quality, the manual conforms to the requirements listed in 23 Code of Federal Regulations (CFR) 637, subpart B.

Test Frequency

The INDOT Office of Material Management publishes the manual for "Frequency of Sampling and Testing as Basis for use of Materials." [28] The test frequency for each material is separated by the type of material. For uncoated reinforcing bars, straight or spiral, one 5ft random verification sample is required per year per manufacturer. For coated reinforcing bars, straight, bent or spiral, a 5ft random verification sample is required per year per manufacturer. For dowel rods, one random verification sample is required per year per manufacturer. For welded wire, one 3ft by 3ft sample per wire size for each 20 tons from each source. Threaded tie bar assemblies less than 10 units require a visual inspection, but for assemblies greater than 10 units, two complete assemblies are required when less than 8ft and one complete assembly is required otherwise for each 4000 assemblies. A splicing system for reinforcement bar consists of two 3ft bars and a coupler for random verification sample per year per manufacturer. For bent tie bars, as stated in the INDOT Frequency Manual, "One random verification sample required per year per manufacturer as directed. The manual requires two complete bar samples when less than 8 ft., otherwise one complete bar sample." (Indiana Department of Transportation, Office of Materials Management, 2015.) [28]

Test Methods

Testing will conform to the random sampling method outlined in the INDOT publication 802-13P. This publication identifies the sampling methods to ensure that testing is done without bias and to ensure that it is in fact random. The methods outlined are in accordance with the department's standard specifications and with ASTM D 16. Sampling and testing will also conform to the standards outlined in the Manual for Frequency of Sampling and Testing. This manual dictates the methods for testing, along with a reference, sub reference, and specific reference for each material. As per the publication on testing, 804-14P, testing will conform to the ASTM standards A 775, and A 615. [32]

Appendix F
Kentucky DOT Quality Assurance Practices

Background

The Kentucky Transportation Cabinet (KNTC), has established a method of sampling and testing of reinforcement steel that applies ASTM standards. These standards are outlined in the Kentucky standards and specifications, as well as in the publications of the division of materials. KNTC uses these publications to determine methods of sampling, testing, and certification for approved materials suppliers. The publications include the "Materials Field Sampling and Testing," and the "Kentucky Methods and Standards Manual." (33,34)

State Requirements and Standards

Kentucky's method of testing and acceptance of steel reinforcement requires that all material be identified by heat, project sampling, and test. The certification of reinforcement bars must be complete prior to application of any epoxy coating. Also, the documentation supplied by producer of the material must conform to the standards outlined in the "Kentucky Methods and Standards Manual" (Commonwealth of Kentucky Transportation Cabinet Department of Highways, 2014). (34)

As per the "Kentucky Methods and Standards Manual," section 811, all reinforcement will be Grade 60 unless otherwise stated. (34) The acceptance of material will only be from manufacturers that are listed on the state's approved materials list. The shipment of material will also come with proper identification of manufacturer's heat or test identification numbers.

As per the materials field sampling methods, uncoated reinforcing steel does not need a qualified inspector or sample for testing. The method is a visual inspection, with proper identification of the fabricator's heat number and mill test reports. Visual inspection is to determine major defects, or rust, as well as proper grade and markings. However, epoxy-coated steel reinforcement must be sampled by the section engineer, and a quantity of two 60-inch bars for each heat of 10,000lbs. As per the materials field sampling methods, for heat numbers that are less than 10,000lbs, the material may be accepted on the certification of the manufacturer.

The KNTC adheres to requirements and guidelines for the sampling, testing, and acceptance of material is provided in the "Kentucky Methods and Standards Manual." (34)

Quality Assurance Guidelines and Practices

Quality assurance of reinforcement steel is determined by the materials division of the KNTC. The materials division provides publications for "Materials Field Sampling and Testing," as well as the "Kentucky Methods and Standards Manual." (33,34) The former specifies responsibilities for the materials engineer in regards to the reinforcement material. It also indicates that the acceptance and testing will be done by qualified personnel.

The KNTC has also established a quality control plan. This plan ensures that the methods of inspection, verification, testing, quality control, acceptance, and independent assurance all meet the parameters outlined in the Code of Federal Regulations 23 CFR 637.

Test Frequency

The "Materials Field Sampling and Testing: states that the material used on a construction site will be sampled at a frequency unique to the individual project and specified by the site manager. Also, to reduce redundant testing, the sample may be applied to multiple projects. The "Kentucky Methods and Standards Manual" sets the frequency of testing. (34) This manual lists each material with requirements for the inspecting authority, the sample frequency, and the sample methods.

The frequency for uncoated steel reinforcement is for each shipment to be visually inspected. For the epoxy coated steel reinforcement, the frequency is to be determined by the quantity of material delivered. Therefore, if the total amount delivered is over 10,000lbs, then a sample must be obtained and tested. For material less than 10,000lbs, only a visual inspection and verification of manufacturer's certification are required.

Test Methods

Testing of steel reinforcement is outlined in section 2.3 of the "Kentucky Methods and Standards Manual." (33) This section states that the parameters tested will be for yield and tensile strengths, elongation, 180° bend, deformations and phosphorus content. Test results will be in pounds per square inch for yield and tensile strength, percent for elongation, and weight in pounds per foot. The strength results are to be rounded to the nearest 1kip.

Testing will be performed in accordance with AASHTO and ASTM standard that is associated with properties being tested of the material. As per the "Kentucky Standards and Specifications Manual" section 811, the ASTM standards used will be ASTM A615 for billeted steel, A617 for axel, A706 for weld-able steel, A775 for flexibility of bar coating, and A996 for rail steel. The use of welded steel wire fabric will conform to AASHTO M55, and AASHTO M221 for deformed wire fabric.

The "Kentucky Methods and Standards Manual" also provides test procedures. (34) Tolerance requirements for steel reinforcement such as holidays in epoxy-coatings, and bending tests are identified in this manual.

Appendix G
Maryland DOT Quality Assurance Practices

Background

To guide quality assurance practices, Maryland adheres to all standards established in the applicable AASHTO Manuals and ASTM standards for steel reinforcement and has its own "Standards and Specifications for Construction and Materials" manual as well as a "Maryland State Highway Administration Structural Standards and Details Specifications" to address steel reinforcement. The state also has a certification program. [35,36]

State Requirements and Standards

State requirements are outlined in its "Standards and Specifications for Construction and Materials" manual, section 908, Page 703. [35] Epoxy coated reinforcement, when specified, will conform to section 917.02 of the "Standards and Specifications for Construction and Materials". [35] Dowel bars used for traverse joints will have a maximum pullout strength as per the AASHTO Manual M 254. The use of stainless steel bars must conform to ASTM standards A276, Type SM-29, and ASTM A615. For the use of sleeves for dowel bars in expansion joints, the sheet metal shall be capable of sliding over 2.25 inches of the dowel (Maryland Department of Transportation, Office of Materials Technology, 2011). Stainless steel bars may be used in place of epoxy coated plain bars.

For steel reinforcement, the state of Maryland's Department of Transportation published the structural standards and details specifications. [36] Chapter 7 in this document specifically identifies parameters for steel reinforcement with details for every type and size of reinforcement outlined for construction. The chapter also covers the design strength and epoxy coating requirements for each type of reinforcement.

Certification Program

To screen manufacturers supplying material to construction sites, the state of Maryland uses a certification program. This program establishes standards that the manufacturers must conform to in order for the state to be able to use their products. The certification program allows for uniformity of material from various manufacturers and enables the state to set standardized test frequencies and methods to verify conformity of the manufacturers to the standards. Test frequencies and methods are identified in a manual as well as in the risk assessment report. [37] Special requirements for the placement and use of the steel reinforcement are outlined in the reinforcing details guide in the Maryland State Highway Administration Structural Standards and Details Specifications" manual, chapter 07 (Maryland Department of Transportation, Office of Materials Technology, 2015). [36] Section TC 1.03 of the Standard Specifications for Construction and Materials outlines the random process of sampling and testing needed for manufacturers to adhere to in order to maintain certification. Also, the verification of the material certifications is determined by the Quality Assurance Manual (Maryland Department of Transportation, Office of Materials Technology, 2011).

Quality Assurance Guidelines and Practices

Maryland's Department of Transportation outlines the Quality Assurance Program in section 647.2-07 of the risk assessment report. [38] Quality assurance for the state of Maryland follow the guidelines established in the Code of Federal Regulations CFR 23-637. Stated in the risk assessment report, the process for acceptance of material will consist of the verification of material conformity to standards through systematic sampling and frequency.

Maryland's quality assurance components are outlined as storage and handling, roller protection, method of transportation, touch-up procedures and material storage, material inspection for pre- and post-fabrication, certification review, and certification retention. The established parameters for quality assurance are outlined in the risk assessment report. To meet the requirements listed for certification of reinforcing steel, the risk assessment report references the ASTM A615, and A706, as well as the TC-1.03. The quality conformance of epoxy coatings is determined by the AASHTO Manual M284, and ASTM 775 (Maryland Department of Transportation, Office of Materials Technology, 2008). [35]

Material used for construction will be obtained from manufacturers that are listed on the list of qualified producers/manufacturers, as per the state certification program. This list is maintained by the Maryland Department of transportation; it can be found on their website.

Test Frequency

The Maryland Transportation department determines test frequency based on the Maryland "Quality Assurance Processes, Details and Frequencies" report. This report is published by the Maryland State Highway Administration, Office of Materials Technology and available on the Maryland Transportation department website.

Material testing frequencies are outlined in appendices C and D of the "Quality Assurance Processes, Details and Frequencies" Manual. The manual identifies each material for use in individual construction phases or all phases and lists the material along with the frequency at which the Transportation department must test material. The implications of the frequency publication are that the testing be done systematically, without deviation. Projects that require large quantities of material need to follow the "Material Testing Frequencies Manual." Projects using only small quantities of material may perform only one test for acceptance except unless otherwise specified in the small quantity exceptions table.

Test Methods

Testing requirements for reinforcement steel is outlined in section 908 of the "Standards and Specifications for Construction and Materials". [35] The testing for deformed reinforcement is to be done in accordance with the ASTM A615 or A706 Grade 60. Plain, rounded steel reinforcement will conform to testing requirements outlined in ASTM A615 Grade 60, or ASTM A36. Welded steel wire fabric testing must conform to the AASHTO Manual M55, while deformed wire must conform to AASHTO M221. The Steel Bar Mats shall conform to ASTM A184 (Maryland Department of Transportation, Office of Materials Technology, 2011). [37]

Appendix H
Massachusetts DOT Quality Assurance Practices

Background

The Massachusetts Bay Transportation Authority (MBTA), maintains quality assurance through the use of testing, certification, clearly establishing responsibilities for the inspecting authority, and by tracking material throughout the work process. These key points are identified through the Quality Assurance Plan, as well as the "Construction Manual of Guidelines and Standards." [39,40] Both manuals establish that project work contract requirements in turn guide quality assurance testing requirements. A qualified individual from MBTA will conduct testing and inspection, with results reported and documented as per the Quality Assurance Plan, section 8.1 (Massachusetts Bay Transportation Authority, 2009). [39]

State Requirements and Standards

Since no other supplemental state information was provided, state practice can be assumed to follow standards outlined in the Code of Federal Regulations, the AASHTO manuals and ASTM standards listed for testing requirements. Reinforcement must comply with recommendations outlined in the concrete reinforcing steel institute's "Manual of Standard Practice" for reinforcement (Massachusetts Bay Transportation Authority, 2007). [41]

As per the Massachusetts Quality Assurance Plan, in the case that material is not properly identifiable, such that the markings are missing or other means of identification are not possible, use of that material is prohibited.

Quality Assurance Guidelines and Practices

The Quality Assurance Plan documents the state quality assurance process. An important aspect of quality control described is the traceability of material. This includes being able to identify material by the heat number, lot, batch, and laboratory analysis. Traceability allows for the physical identification of material as a means to determine the material conformity to standards.

Detailed within the Quality Assurance Plan are the responsibilities of any party involved in the handling, inspection, or control of material, with Section 1.0 outlining for management all roles and responsibilities. Sections 8.0 and 9.0 describe material inspection and testing. These sections outline a qualitative viewpoint on how to maintain quality. (Massachusetts Bay Transportation Authority, 2009). [33]

The "Construction Manual of Guidelines and Standards" part II section VII specifically describes the standards for approved materials (Massachusetts Bay Transportation Authority, 1977). [40] This section describes in detail the need for material to conform to safety regulations, maintain long life, serviceability, and low risk of failure.

Test Frequency

No specific data was found on frequency of testing. The frequency of testing can be assumed to follow the standards outlined in the Code of Federal Regulations, the AASHTO manuals, and ASTM standards listed for testing requirements.

Test Methods

Testing requirements for steel reinforcement are outlined in the plant-precast structural concrete report. Testing on steel reinforcement by the MBTA will conform to AASHTO and ASTM standards.

The MBTA will test reinforcement bars in accordance with ASTM A615/A615M Grade 60. Loy alloy steel will conform to standards established in ASTM A706/A706M. Galvanized bars will conform to ASTM A767/A767M. Plain wire steel will be tested in accordance with ASTM A28, galvanized steel. Deformed steel wire will conform to ASTM A496. Testing of plain steel welded wire will conform to ASTM A185.

Reinforcement that is to be used in cast in place concrete will conform to standards outlined in ASTM A615 Grade 60 and will be bent cold.

Appendix I
Michigan DOT Quality Assurance Practices

Background

To ensure that reinforcement steel meets quality standards, the Michigan Department of Transportation (MDOT) produces a "Materials Quality Assurance Procedures Manual" that provides guidelines and procedures for MDOT engineers to document, sample, test, and accept material. (42) In addition, Michigan uses a manufacturer certification program to allow manufacturers to pre-qualify, thus enabling inspectors to reduce quality assurance at job sites to visual inspection only. This of course minimizes cost and time. The "Materials Quality Assurance Procedures Manual" provides manufacturers with information about production requirements to meet certification. It provides inspectors with the visual inspection parameters in section 6.01 (Michigan Department of Transportation, Construction Field Services Division, 2015). (42)

State Requirements and Standards

MDOT requires proper documentation by tagging and labeling of all material that passes visual, lab, or filed tests. This is required as per section 1.08 of "Materials Quality Assurance Procedures Manual." Further, the material that is to be used on the project Worksite must conform to *Buy America* certification requirements. To verify this certification, the contractor submits a compliance certification to MDOT engineers. Any material that does not conform to the Buy America standards will be documented and submitted for approval with exact percentages and cost. As per the "Materials Quality Assurance Procedures Manual," section 4.12.03, the contractor must supply certification of material compliance in accordance with Title 23 of the Code of Federal Regulations (CFR), Section 635.410. (42)

Outlined in division 905 of the MDOT specification book are special requirements for steel reinforcement. These include size, yield strength, epoxy-coating requirements, and tolerances in manufacturing. The Michigan Department of Transportation uses several methods to obtain uniformity in reinforcement steel. These methods include an initial visual inspection on all material entering the job site, regardless of previous testing approval.

Testing and acceptance of material is determined by the "Materials Quality Assurance Procedures Manual." Its Chapter 7 lists the parameters for selecting samples and for testing, with section 905.03 beginning the reinforcement steel requirements for acceptance, sample size, and any special remarks for each material.

Parameters for MDOT testing and acceptance are outlined in the "Standards Specifications for Construction," division 9, section 905. (43) These parameters identify the types of tests, and the frequency at which the tests will be completed. In addition to the ASTM standards, minimum bend diameters are identified in its Table 905-1. MDOT adheres to construction standards provided in the "Materials Quality Assurance Procedures Manual." [42]

Quality Assurance Guidelines and Practices

As noted, MDOT maintains quality assurance parameters in its "Materials Quality Assurance Procedures Manual." This manual states that MDOT quality assurance is in accordance with Title 23, of The Code of Federal Regulations, Part 637. In addition, the "Materials Quality Assurance Procedures Manual" identifies other publications that MDOT uses to ensure conformance to quality standards. These include the "MDOT Construction Manual," "MDOT Materials Source Guide," the "Michigan Test Methods," and the "MDOT Quality System Manual."

MDOT performs visual inspection on all materials used in the construction. This is to ensure that damaged or non-uniform materials that may have initially been approved through its certification program are not inadvertently used in the construction work.

Procedures to establish a list of manufacturers that comply with the specifications and performance criteria set by MDOT are outlined in the "Materials Quality Assurance Procedures Manual," section 6.01. Section 6.18.01 lists the parameters to qualify epoxy-coated reinforcement steel and ensure it meets standards. Acceptance criteria for material is established in a tabular format in the" Materials Quality Assurance Procedures Manual." This table lists the responsible party for inspection, the sample size, and the potential of acceptance without testing based on approved manufacturer lists.

Test Frequency

As per the "Materials Quality Assurance Procedures Manual," testing and sampling will be conducted in accordance with the construction contract documents, and section 1.01.01 of the manual. Section 1.05.01 specifies that random sampling may be done by the cube root method. This method establishes a number of items within a container to be sampled by taking the cube root of the total number of items. Also, section 1.06 of this manual provides more details about the random sampling method. A key point is that the contractor is not to know the random numbers used to determine sampling to ensure the contractor does not influence the sample.

In addition, MDOT personnel can identify the sampling method from the MDOT "Materials Source Guide" by referencing the Materials Acceptance Requirements table on page 8.

If a manufacturer obtains a quality certification, the material may still be subject to inspection by the resident engineer to ensure quality. This verification may determine the rejection of material or delay in work, if test results conclude the material does not conform to standards.

Section 3.03 of the "Materials Quality Assurance Procedures Manual" also provides a schedule table for testing. The table shows at what intervals the material must be tested for use. For example, the specification number 905.03 for Uncoated Steel Reinforcement specifies that the first sample for testing will be at 20,000 pounds, and every subsequent sample will be at 100,000 pounds.

Test Methods

Testing requirements for reinforcement steel are outlined in division 905 of the MDOT specification book. Testing is required to meet standards established by ASTM and AASHTO methods for the corresponding material.

For reinforcement bars, deformed bars must meet requirements outlined in ASTM A706, A615, A616, 96a, or A617-96a for Grade 60. Spiral reinforcement will conform to Grade 40 steel bars of ASTM A615, A617-96a, or A82. Dowel rods will conform to ASTM A706, Grade 40, Grade 50, or Grade 60 of ASTM A615, A616-96a, or 617-96a. Epoxy coated steel reinforcement must conform to standards established in AASHTO M284, and additionally, must conform to any quality assurance listing that describes epoxy-coated steel such as section 706.03.E.8 of the specification manual.

Appendix J
Minnesota DOT Quality Assurance Practices

Background

The Minnesota Department of Transportation (MnDOT), establishes the procedures and methods for material selection, testing, and acceptance through publications made readily available on the Minnesota Department of Transportation website. This website also lists a risk analysis for engineers and quality assurance publications to assist in the material selection process (Minnesota Department of Transportation, 2016). [44] The state of Minnesota follows the standards outlined in AASHTO Manuals as the predominant methods for sampling, testing, and accepting reinforcement steel for project use.

State Requirements and Standards

Outlined in the MnDOT materials lab supplemental section 3301, are special requirements needed for each type of reinforcement. [45] These requirements outline the specific AASHTO standards to which any reinforcement steel used must conform.

For acceptance of any reinforcement materials, the minimum inspection will be visual in accordance with the materials control schedule. Any further testing required will be determined by the control schedule and AASHTO standards. Upon inspection of an epoxy-coated steel reinforcement, the material is properly tagged and identified as either “Inspected,” or “Sampled.” This form of material process tracking prevents redundant testing and ensures quality control.

Practices of the state of Minnesota’s Department of Transportation are in compliance with AASHTO standards. These standards are supplemented through the identified publications listed above. Testing sampling and frequency are determined based on type of material, the materials control schedule, and the materials lab supplemental publication.

Quality Assurance Guidelines and Practices

MnDOT’s website lists the publications that identify quality control in alphabetical order. There are two major publications that identify qualified product uses and describe quality control processes, a qualified products list, and the “Materials Lab Supplemental Specifications for Construction.” [45]

The first is the qualified products list. This list identifies information about the use of approved MnDOT material and the process to obtain approval for material. The second publication is the quality management process for design-bid-build, which provides guidance for quality management and the process to maintain quality assurance. To ensure MnDOT construction adheres to standards of quality, a Quality Management Process will be implemented prior to construction. The process is described in the “Quality Management Process Manual.” This process is to be used for the several methods of checks and balances by senior management, design squads, and the approved staff.

To further the adherence to quality assurance, methods are outlined in the procedures for sampling and testing. MnDOT establishes parameters for material testing and selection through the use of the publication "Materials Lab Supplemental Specifications for Construction". [(45)] This publication outlines the methods for testing of material in accordance with AASHTO and ASTM standards. Outlined in this publication are the special requirements that may be associated with the use of steel reinforcement (Minnesota Department of Transportation, 2014).

To aid quality assurance, MnDOT has a publication for the determination of risk estimation for engineers. This publication outlines the methods and practices for MnDOT in making risk based estimates for construction. This method assists the materials engineer in determining quality standards for materials used in construction (Jennifer S. Shane, 2015). [(46)]

Test Frequency

The methods of sampling and testing to ensure quality are explained in the "Schedule of Material Control". [(47)] This publication establishes the timeframe and frequency of testing for any given material. The frequency of testing is variable dependent upon the type of material and whether the manufacturer has obtained a quality control certification. Every type of reinforcement is inspected, at a minimum visually (Minnesota Department of Transportation, 2014). [(47)]

Test Methods

Testing of reinforcement steel is done in accordance with the materials lab supplement publication. This publication outlines which AASHTO or ASTM standard is to be used for any given type of construction material used by MnDOT.

For billet steel bars, rail steel bars, and axle steel bars, the specifications requirements are AASHTO M31, M322, and M322 respectively. Dowel bars are to meet standards outlined in AASHTO M31, and for epoxy coated dowel bars AASHTO M254.

Appendix K
Montana DOT Quality Assurance Practices

Background

The Montana Department of Transportation (MDT), lists the various publications on the use of reinforcement steel on the Montana official state website. This listing includes the "Methods of Sampling and Testing," which identifies specific MDT quality assurance practices for reinforcement steel. [48,49] Also, chapter 16 of the "Montana Structures Manual" establishes the parameters required for reinforced concrete, which specifies the use of reinforcing steel.

State Requirements and Standards

As per chapter 16 of the "Montana Structures Manual," the maximum size of reinforcing bar for reinforced concrete shall be #36. [50] As per MT 414-09, the reinforcement sampling will be done by the contractor, and in accordance with MT-601, table 1. Testing and acceptance of material will be done in accordance with table MT-601, and the use of the miscellaneous materials and "Methods of Sampling and Testing," material acceptance methods. [49] Any conflict in testing requirements that occur, table MT-601 will govern.

The state of Montana uses several publications to determine the frequency and testing of reinforcement steel. These publications are used in conjunction with AASHTO and ASTM standards. As per the publication MT 414-09, the method of acceptance for reinforcing steel is set by obtaining certification documents, and random sampling.

Project managers hold the responsibility of determining the quantity of samples that will be collected from a shipment of material. The quantity of the samples, if any, collected will be documented as when, where, and which shipment. Listed in the MT 414-09 is the locations that each sample will be collected from given a type of reinforcement. For example, for a Footing, the outermost bar in the mat may be sampled. Project managers may accept small lots of reinforcing steel bars which pass bending tests in accordance to AASHTO M31.

Quality Assurance Guidelines and Practices

The Montana Department of Transportation provides the parameters for quality assurance through the "Methods of Sampling and Testing Manual," section 602–13, with guidance on how to select samples for testing in section 601. [48,49] The MDT will select random samples in accordance with guidance in the MT 606 Random Sampling Techniques section.

Also, the MDT "Materials Manual" lists the assurance stages needed in testing reinforcement steel such as acceptance sampling, testing, and independent assurance. Independent assurance is stated as being necessary to spot check acceptance sampling and testing results. This check is not specifically used to ensure compliance with specifications.

Section 601 of the "Miscellaneous Materials and Testing Methods Manual" outlines the material acceptance methods. [49] Stated within section 601, if there is ever any conflict between sample and test frequencies, the table listed in MT 601 will govern. Further, this section outlines the separate types of acceptance methods that may occur given the determined frequency from table MT 601. These types of methods include sample and test results, certification, qualified products, visual inspection, final record, and pre-inspection. Each acceptance method has a requirement that must be met to be able to use that acceptance method, otherwise samples and tests must be complete as per the materials Manual.

Test Frequency

Minimum frequency of testing reinforcement steel is listed in the Montana "Miscellaneous Materials and Test Methods Manual," section 601, page 126. This section provides a table that identifies each type of reinforcement and the sample frequency associated with that sample. Special requirements that might be associated with the acceptance of the material is also listed in the table, in a Notes section.

In addition to the minimum frequency table, the project manager may decide how many samples may be selected for random sampling. This is to be done in accordance with the "Miscellaneous Materials and Test Methods Manual," section 601, which also identifies acceptance criteria for material, used to determine the rate at which the MDT collects samples for testing.

Test Methods

The "Montana Standard Specifications for Road and Bridge Construction Manual," section 711 lists test requirements for examining reinforcing steel. [51] For reinforcing bars, testing is done in accordance with AASHTO M31 standards. Epoxy coated reinforcing bars must conform to the ASTM standards A615 for furnishing, ASTM A775 or A934 for epoxy coating applications. For testing wire and wire mesh, furnishing the wire reinforcement will conform to AASHTO M32, and wire mesh in accordance with AASHTO M55. Bar mats will conform to AASHTO M54. Guidelines for further testing of specialized reinforcement steel, such as pins, rollers, structural steel, and high ensile strength bolts are all provided in the standards and specifications manual, section 711.

Appendix L
Nebraska DOT Quality Assurance Practices

Background

The Nebraska Department of Roads (NDOR), has published several documents that outline the methods of quality assurance in steel reinforcement acceptance and testing. These publications are the “Standard Specifications for Highway Construction,” and the “Materials Sampling Guide.” [52,53] The NDOR uses both publications to determine the criteria to certify material suppliers, inspection personnel, and methods of sampling and acceptance.

State Requirements and Standards

As per the minimum requirements for quality control outlined in the materials sampling guide, the contractor will supply personnel qualified for sample collection. Also, the contractor will submit all sample collection information and test results to the engineer.

Section 1020 of the “Standard Specifications for Highway Construction” states that the steel tie bars will be epoxy coated and deformed Grade 40 or 60. Manufacturers will apply coating so that the flexibility of the bars allows for a bend up to 120 degrees around the mandrel of the size identified in section 1021.02 of the “Standard Specifications for Highway Construction” manual. [52]

As per the “Materials Sampling Guide,” all reinforcement will be sampled and tested. Also, the steel reinforcement may be furnished to a project without the testing being completed by the central laboratory. In this case, the samples and certificates are submitted to the laboratory and material is not used until certification has been approved. The sampling and testing is done in accordance with the previously mentioned publications, and is also done on every lot, heat number, size and type of reinforcement used in the project work.

Quality Assurance Guidelines and Practices

As stated in the “Materials Sampling Guide,” the term *quality assurance* is defined as the “planned and systematic actions necessary to provide sufficient service and products that will conform to the specified requirements of quality.” [53] NDOR advances this goal by using an acceptance program, described in the same “Materials Sampling Guide.” The acceptance program identifies the verification sampling and testing parameters needed to ensure that quality standards are being met (State of Nebraska Department of Roads Materials and Research Division, 2016).

Also stated in the material sampling guide appendix C, is the quality control program. This program is designed to establish minimum requirements for a contractor to obtain approval of material to be used in work.

As stated in the "Standard Specifications for Highway Construction" manual, for each type of steel reinforcement used in NDOR construction, testing will be done on each lot, heat number, size, and type before use in work.

Test Frequency

The frequency at which the samples will be taken to ensure quality are determined by the "Materials Sampling Guide," section 3.3. This section states that the samples will be taken for quality control by the contractor, and will be done in accordance with the quality control program. This guide also provides minimum material certificate test and inspection requirements, and specifies that reinforcement bars are required to be tested. The guide indicates that samples will consist of two six-foot-long samples from every bar designation and heat number. For epoxy coating on steel bars, the engineer may obtain from the applicator 7 ounces of sample resin for each lot used. For the acceptance sampling of dowel bars, two 6ft. sample coated, of each bar size and heat number will be provided to the NDR Materials and Research laboratory.

Test Methods

As per the "Standard Specifications for Highway Construction" manual, section 1020, steel bar reinforcement testing will conform to AASHTO and ASTM standards. Testing for the steel bars will conform to the ASTM standard A615/A. Coating of epoxy resin will be in accordance with the Manual AASHTO M284, and the testing conducted by the National Bureau of Standards (NBS). Bending tests shall be done at room temperature. The temperature for testing shall be between 68°F and 86°F. Dowel bars will adhere to AASHTO M254, ASTM A615 Grade 40 or 60.

Appendix M
Nevada DOT Quality Assurance Practices

Background

The state of Nevada Department of Transportation (NDOT), adheres to quality control as outlined in several publications. Quality control is specifically addressed in the NDOT "Standard Specifications for Road and Bridge Construction." (54) Methods for sampling testing and selection are provided in the "NDOT Construction Manual" and the "Materials Testing Manual." (55,56) The latter specified how to conduct a test in accordance with the appropriate AASHTO or ASTM standards.

State Requirements and Standards

For test sample selection, the state of Nevada requires that the supplier furnish two samples of each bar size. This is in addition to any random sample that NDOT may obtain throughout the construction process. The sample size for reinforcing steel must be 0.75m (30 inches).

The state requirement is to use domestically produced steel and iron in federal aid projects, regardless of comprised percentage in the manufactured form. The use of steel or iron that has foreign steel materials will not be more than 0.1% of foreign material, or the total contract cost will not exceed $2,500.00. These parameters are in accordance with the Code of Federal Regulations title 23 CFR 635.410.

As per the NDOT "Standard Specifications for Road and Bridge Construction" manual, any steel reinforcing material that fails to meet test parameters specified in AASHTO M31 or ASTM A706 may still be used in construction if the material passes the section area test method outlined in Test Method No. Nev. T484 (State of Nevada Department of Transportation, 2014). (54) Section 505 of the manual identifies that the use of Grade 420 reinforcement steel will be permitted on projects unless otherwise stated in job plans. Also, samples taken will be from a furnished extra bar that is one in 100 tons. This bar is to be selected from the longest bar of each size.

Quality Assurance Guidelines and Practices

The "NDOT Construction Manual" states that the determination of quality is defined in conjunction with the Nevada Alliance for Quality Transportation Construction (NAQTC), as well as the Western Alliance of Quality Transportation Construction (WAQTC). To determine if a person is qualified to administer sampling and testing for the state of Nevada's Department of Transportation, the person must be either WAQTC and American Concrete institute (ACI) certified, or NAQTC certified. These certifications ensure a qualified individual completes the testing, and in compliance with standards.

Quality is discussed in section 106, control of material of the Standards and Specifications Manual. This section states that reinforcement steel used must be new material from a supplier that is listed on the qualified products list. The qualified products list is a list that has been evaluated and determined to be suitable for use.

Section 505 of the “Standard Specifications for Road and Bridge Construction” describes the practices used for the placement and furnishing of reinforcing steel. This section also lists the appropriate AASHTO or ASTM standards to be followed to ensure quality control.

Test Frequency

Section 106.04 of the “Standard Specifications for Road and Bridge Construction” manual states that all material will be inspected or tested prior to use. If material is used that has not been inspected or tested, it will be considered unauthorized and could be rejected. Table 5.1 in the “NDOT Construction Manual” specifies the minimum frequency of testing for steel reinforcement and the minimum number of samples that must be obtained for reinforcing steel, along with specific remarks to sampling and testing methods. For reinforcing steel, the samples must be for each bar size from each manufacturer, as well as two bar size for every 100 tons thereafter.

Test Methods

As per the “NDOT Construction Manual,” section 5-406, testing for the NDOT is completed by the structural labs located in either Carson City or Las Vegas. [55] Also, in accordance with Test Method T484B, of the materials and testing division of the Nevada Department of Highways states the methods used for reinforcement steel testing. This test method conforms to the ASTM standard A370. Also, the ASTM standard used for tensile strength tests will be A615 (State of Nevada Department of Highways Materials and Testing Division, 2016).

The “NDOT Construction Manual” table for sampling and testing specifies that tests for steel reinforcement must conform to the AASHTO and ASTM standards in the remarks section. This section lists the standards ASTM A706, as well as AASHTO M31 for grade 300 or 420 steel.

The “Standard Specifications for Road and Bridge Construction” manual specifies that the testing for welded wire reinforcement must conform to the ASTM standard A1064. For pre-stressing steel, NDOT uses AASHTO Manuals M204, M203, and M275.

For fabrication and handling of reinforcement steel, the “Standard Specifications for Road and Bridge Construction” manual requires conformance to AASHTO M284, M317, and ASTM D3963 and A775.

Appendix N
New York DOT Quality Assurance Practices

Background

The requirements for the use of reinforcing steel by the state of New York State Department of Transportation (NYSDOT), are outlined in its "Standards and Specifications Manual," section 709. (57) This section outlines the type of material to be used, along with required testing parameters such as the ASTM standards, and various state of New York requirements. The NYSDOT uses a certification program to identify reliable manufacturers.

State Requirements and Standards

Procurement of steel reinforcement is to be done through a certified manufacturer that is identified on the department's Approved List of materials. Also, the material must conform to the state's *Buy America* standards, unless otherwise stated.

Epoxy coating on steel reinforcement must be of an organic compound: powdered-epoxy resin applied through electrostatic methods. The epoxy coating must be inert with concrete, and a type that is capable of being used in shop or field repairs. Specifications on epoxy coatings are provided in the NYSDOT "Standards and Specifications Manual," section 709-04. This section identifies the coating application methods, surface preparation, and coating thickness as well as test parameters for the rebar.

The requirements for sample selection of steel bar reinforcement Grades 420, and 520 are provided in section B1 of Appendix B in the "Materials Inspection Procedures Manual." (58) These requirements provide specifics such as sample quantities given heat numbers, sample length, and the ASTM standards to which the tests must conform.

Further, New York requires that NYSDOT personnel adhere to testing and inspection methods in the "Standards and Specifications Manual and the "Materials Inspection Procedures Manual." (57,58)

The New York Department of Transportation Department's approved list and material certification specifications determine acceptance of steel reinforcement. Also, material used is to conform to the requirements of *Buy America* as per Code of Federal Regulations 23 CFR 637.

For sampling and testing, the quantity of samples is stated in the NYSDOT "Standard and Specifications Manual," section 709-04. This section defines the term "Lot" and the minimum amount of sample to obtain from each lot.

Quality Assurance Guidelines and Practices

The state of New York's Department of Transportation materials bureau has established standards and specifications to ensure materials quality in construction and manufacturing. It describes risk assessment, as well as verification and qualification parameters for manufacturers along with guidance for inspection and acceptance of material.

The qualitative risk assessment parameters used to determine the potential risk of material selection are outlined in Appendix A of the materials inspection procedures. These parameters establish guidelines to which the selection of material will have to follow to ensure that the acceptance of material will not produce unacceptable risk (New York State Department of Transportation, 2005). (58)

Quality assurance practices are specified in the NYSDOT "Standard Specifications Manual," section 556-3, construction details. This section describes the processes for ordering, handling and storage, placing and fastening, field repair of coatings, and field bending. All processes in this section conform to the material testing, acceptance, and inspection standards for reinforcement steel outlined in section 709 of the same manual.

Test Frequency

The NYSDOT "Materials Inspection Methods Manual" describes testing. The frequency for testing material is dependent upon the material type and grade. (58) As stated in the NYSDOT "Standards and Specifications Manual," the frequency of testing will be defined by the verification sampling and testing requirements. (57) This is further described in the Department's Acceptance Program, section A. The manual also states that the Department holds the authority to obtain and inspect any sample at any time during the construction process to ensure that materials conform to project standards and specifications.

Test Methods

Testing for reinforcing steel is determined by the New York "Standards and Specifications Manual," section 709. The testing for bar reinforcement, Grade 420 is to conform to the ASTM standards A615, and A996M for deformed bars. For Grade 520, the ASTM standard A615 will be used. Stainless steel reinforcement, both Grades 420, and 520 are to conform to the ASTM standards A955M and A276. Epoxy coating on steel reinforcement will conform to ASTM standards B499 as well as being approved for use and listed on the Department Approved List of materials.

For straight reinforcement bar, the sampling is to consist of two heats of bars, ten bars per heat. All ten of the bars will be tested to ensure that they conform to required dimensions. To test for ultimate strength, yield strength, and percent elongation, five of the samples will be used. For the bend test, the remaining five samples will be used. For coiled reinforcement bars, sampling will be of two heats of bars, twenty bars per heat. Testing will consist of conformity of dimensions on ten bars, and the remaining ten will be tested for yield strength, ultimate strength, and percent elongation. Five of the samples that were used for dimensional testing will be used for the bend test.

Appendix O
North Dakota DOT Quality Assurance Practices

Background

The state of North Dakota Department of Transportation (NDDOT), establishes quality assurance through publications such as the “Standard Specifications for Road and Bridge Construction,” and the “Field Sampling and Testing Manual.” [59,60] These publications specify the methods of inspection, sampling, and acceptance for reinforcement steel, along with other material. NDDOT testing conforms to AASHTO and ASTM standards, as described in the standard specification and testing manuals. North Dakota also has a certification program.

State Requirements and Standards

As per section 836 of the “Field Sampling and Testing Manual,” any steel reinforcement not covered by a certification, may not be used in work, and must be replaced by a material that has sufficient certification. Proper identification is also determined by the “Standard Specifications for Road and Bridge Construction” section 836.01. This section states that the material will be properly identified and tagged with the heat numbers as either embossed numbers, printed on paper with waterproof ink, and or engraved numbers (North Dakota Department of Transportation, 2015). [60]

As per section 836 of the “Field Sampling and Testing Manual,” inspectors must identify the material used and document the heat numbers, quantity of bars, size, length, shape, and any other pertinent information. This includes rust that may have formed on outer surface of bars. If there are not visible markings, or the marking are illegible, then the reinforcement may not be used in the construction (North Dakota Department of Transportation, 2015). [60]

Quality Assurance Guidelines and Practices

Quality assurance practices are addressed as the control of material in the “Standard Specifications for Road and Bridge Construction” section 106. [60] This section states that the determining factor for sampling testing inspection and certification of compliance is the contractual agreement for the work. This is also supplemented with the statement that if the value of the material is less than $5,000 and the material is not directly applied to a structure or roadway, then the inspecting authority may accept the material as is without inspection.

The engineer can obtain a sample and test the material, and use the results of the test to determine acceptance of the material. If a contractor performs the sampling and testing, then the contractor will supply the NDDOT engineer with documentation showing the results of the tests.

To further quality assurance, NDDOT established a certification program. Proper identification is the responsibility of the contractor on the certification of compliance. This documentation includes a description of the material, the quantity, supplier, lot number, bin number, heat number or other engineer-approved identification, and identification of the project for which the material will be used.

Also, as per section 836 of the "Field Sampling and Testing Manual," all reinforcing steel will be accepted by the engineer or manager by at minimum of a visual inspection (North Dakota Department of Transportation, 2015).

Test Frequency

The NDOT "Frequency Guide of Sampling and Testing" states that the acceptance samples obtained for testing of steel reinforcement must adhere to guide section 824. All steel reinforcement is accepted based in the certification verification established by the engineer, or manager, and upon completion of a visual inspection.

Test Methods

The "Standards and Specifications Manual," section 836, provides test methods. It identifies that deformed reinforcement steel bars will conform to the standards of AASTHO M31, Grade 40 or Grade 60, and that if there is an epoxy coating, then the steel bars will conform to ASTM A775. The testing of welded deformed steel bars will conform to AASHTO M54, Grade 40 or 60. Testing of steel welded wire will conform to AASHTO M221, and plain welded wire to AASHTO M55. The deformed steel wire testing will be in accordance to AASHTO M 225, and for plain steel wire testing will conform to AASHTO M32. Dowel bar testing will conform AASHTO M31, M322, and for epoxy coatings ASTM A775 (North Dakota Department of Transportation, 2014). [(59)]

Appendix P
Oregon DOT Quality Assurance Practices

Background

The state of Oregon Department of Transportation (ODOT) sets testing and acceptance requirements for reinforcing steel in its “Standard Specifications for Construction” manual and “Construction Manual,” and relies on corresponding AASHTO and ASTM standards. [61,62]

Oregon has a large coastal region, making it important that ODOT control for steel reinforcement corrosion and material deterioration in material acceptance and use choices. To ensure material quality, the construction manual outlines parameters for use of material from qualified manufacturers.

Section 00151 of the “Standard Specifications for Construction” manual establishes that the authority of the engineer is the final determination on all construction matters. [61] This includes the sampling, inspection, testing, and acceptance of all construction materials. The quality of the construction materials is inspected by qualified personnel; however, they are not authorized to complete the final acceptance of material.

State Requirements and Standards

When contractors supply material, they must conform to the statistical sampling methods outlined in the “Standard Specifications for Construction” manual, section 00165.40. This section outlines the statistical requirements for sample size and required quality level. Section 00165.40 subsection C lists the parameters needed to determine when test results are accepted. These parameters include the percentage of each constituent of the materials meeting specifications and the cost for the material. Contained within the same section is a table that lists the percent within limits for the pay factor, and which uses the standard deviation method given a quantity of samples collected (Oregon Department of Transportation, 2015). [61]

The acceptance of material will be dependent upon the authority of the resident engineer, who will ensure that the material will conform to standards provided by either AASHTO, ASTM, ODOT standards and specifications, or the “Non-Field Tested Materials Guide.” ODOT will only accept material from approved manufacturers that conform to the *Buy America* provisions in the “Standard Specifications for Construction” manual section 00160.20. [61]

Contractors will limit the use of materials to contain no more than one-tenth of one percent, (0.1%) of material that is from a foreign source, or no more than $2,500. If any material that is used exceeds either of these amounts it will be replaced with material that is produced locally. As per the “Standard Specifications for Construction” manual, section 00160.01 and the construction manual chapter 22, the contractor will provide a list of material sources to the project manager within 15 days before use. [61,62]

Oregon uses a system of mandatory and prospective sources to obtain materials for construction. Also, if needed, there is a potential to use a material list not included on the approved *Buy America* list. These methods of material acquisition are accomplished through the use of quality compliance certificates. The certificates, and the format in which they need to be completed, are outlined in the construction manual, chapter 12B. This allows for the acceptance of material and testing of material either in the field or laboratory from sources that may not have been previously approved by the resident engineer.

The test frequency and methods are accomplished through statistical methods outlined in section 02510.11 part (e) of the "Standard Specifications for Construction" manual. This section states that the material will conform to AASHTO M284 and ASTM A775 standards. The amount of testing will be sufficient enough to ensure that the quality of the reinforcement is such that the risk of acceptance of faulty material is minimal. All sampling, testing, and acceptance of material will be determined based on AASHTO and ASTM standards (Oregon Department of Transportation, 2015). [61]

Quality Assurance Guidelines and Practices

Oregon has identified the importance of quality on the Oregon Department of Transportation website. The quality assurance team has several links on the quality webpage. However, each link when clicked on opens a web file error 404. This is an indication that the Oregon Department of Transportation considers quality to be important, however their searchable material is not available to the general public.

The material used for construction is regulated by the ODOT "Standard Specifications for Construction" manual, in section 00150 and 00165. Section 00165.00 identifies that the contractor will only use material that meets the requirements outlined by the engineer and the standards needed for the work. Testing and acceptance is a requirement to determine whether the material conforms to standards. Upon testing, if any of the material is found to be not within standards, the engineer has the authority to reject that material at his or her discretion, with the contractor having to incur any resulting added cost.

Quality certification needs to be documented as per the "Standard Specifications for Construction" manual, section 00165.35. The certification requirement is to verify that all material conforms to regulations identified in any test method used such as ODOT, AASHTO, ASTM, or other methods.

Test Frequency

Frequency of testing is identified in section 02510.11 part (e) of the "Standard Specifications for Construction" manual. This section states that the material will conform to AASHTO M284 and ASTM A775. The testing will also be done by the ODOT materials laboratory to ensure that the material meets the pre-qualification requirements.

Acceptance sampling of material is identified in "Standard Specifications for Construction" manual, section 00165.50. This section outlines that the engineer will perform a statistical analysis to determine acceptance of material in accordance with section 00165.40 of the same manual. This allows for a sampling of a material based on pre-determined statistical methods, to reduce the amount of testing without significant risk of accepting faulty material (Oregon Department of Transportation, 2015). (61)

Test Methods

As per the "Standard Specifications for Construction" manual, section 00165.03, when testing materials, the resident engineer may allow for testing to occur at a location of his or her choice, such as the field, laboratory, or other testing facility. Even though certain AASHTO, ASTM, and other materials specifications may require testing at the place of manufacture. Also, testing of material will conform to any standard or specification that outlines the required methods of testing for said material. ODOT identifies in the "Standard Specifications for Construction" manual that if any publications have conflicting information on how to test the material, the materials must meet the requirements in the "Field-Tested Materials Guide," and/or the "Non-Field Tested Materials Guide." (61)

Testing of seven-wire strand will be done in accordance with AASHTO M203 and ASTM A416, grade 270 supplement 1, with an ultimate strength of 270000 psi. High tensile strength wire will be tested to the standards of AASHTO M204 and ASTM A421. High tensile strength bars will be tested in accordance with AASHTO M275 and ASTM A722. Welded wire reinforcement will conform to the AASHTO M55 and M221 standards, as well as the ASTM A185 and A497 standards. Dowel rods will meet requirements outlined in the AASHTO M31 and M227 as well as the ASTM A615 for Grades 40 and 60, and ASTM A663 for Grades 70, 75, and 80. Wire reinforcement will conform to standards of AASHTO M32 and M225, as well as the ASTM standards A82 and A496 (Oregon Department of Transportation, 2015).

Appendix Q
South Dakota DOT Quality Assurance Practices

Background

The South Dakota Department of Transportation (SDDOT), has established a material testing process, documented in the “Standard Specifications for Roads and Bridges,” “SDDOT Construction Manual,” “SDDOT Materials Testing and Inspection Certification Program Manual,” and “SDDOT Minimum Sample and Test Requirements.” [63,64,65,66] These publications describe the methods for control of work, material testing, the frequency of sample collection, and the qualified personnel responsible for sample collection. South Dakota also uses a tiered certification system to identify quality assurance requirements based on material, and has a certification process in place for those performing inspection, acceptance, and testing.

State Requirements and Standards

The minimum standards for testing states that reinforcing steel will not be used until certification records have been received, or tests have been completed. Also, sample bars are not to be larger than #8 size for testing. Further, the reinforcement steel must conform to parameters outlined in section 1010 of the SDDOT “Standard Specifications for Roads and Bridges.” [63] As per section 6, the source of the material will be supplied by the contractor to the engineer before delivering the material to the Worksite.

Testing will be done in accordance with contract requirements. If discrepancy exists in sample collection methods, the order sample method precedence sequence is to first look to the “SDDOT Materials Testing and Inspection Certification Program Manual,” then AASHOT guidelines, and lastly the ASTM standards. To measure the reinforcement steel, the theoretical weight will be used. The weights identified for each bar size are located in the “Standard Specifications for Roads and Bridges” manual, section 480, page 358. Also, epoxy coatings on dowel bars will conform to AASHTO M254 Type B with the exception that the film thickness will be from 5 to 13 mils after the cure. All other epoxy coated steel will conform to ASTM A775 (South Dakota Department of Transportation, 2015). [65]

Acceptance of the material is dictated by the discretion of the engineer, and the tier level at which the material is classified. The engineer may accept material that is conditionally approved prior to inspection based off of supply source (South Dakota Department of Transportation, 2015). [66]

The state of South Dakota uses the 23 CFR 637 to determine the requirements needed for individuals to become certified in performing duties of inspection, acceptance, and testing of reinforcement steel. The materials testing and inspection program dictates the certification of the individuals who perform inspection duties. Steel reinforcement is tested and accepted based off the certification program, along with the guidelines established in the previously mentioned publications such as the "Standard Specifications for Roads and Bridges" and "SDDOT Construction Manual." [63,64]

Quality Assurance Guidelines and Practices

As per the "SDDOT Construction Manual," all material is associated with a tiered system. Establishing the tier level, (1, 2, or 3), is a risk mitigation mechanism to identify the potential severity of impact that a material would have on construction should the material fail. Tier 1 material is critical material, not placed in work unless materials has been certified by engineer. Tier 2 material is not as severe as Tier 1 material, but must still be obtained from an approved material suppliers list, or certified by engineer. Tier 3 material has no requirements under certification, and may be accepted after only visual inspection. Reinforcing steel bars are identified as per the minimum testing requirements as Tier 2 (South Dakota Department of Transportation, 2008). [64]

The "Standard Specifications for Roads and Bridges," identifies the methods to ensure quality of material. It states that the requirements to obtain material from approved sources that are to be inspected by the resident engineer. The engineer will obtain samples in accordance with the most recent approved standards established in the "SDDOT Materials Testing and Inspection Certification Program Manual," as well as the AASHTO and ASTM standards.

Further, to ensure that the quality of material is uniform and locally produced, SDDOT adheres to *Buy America* requirements. These requirements state that the amount of foreign material in steel or iron products must be less than 0.1% or less than $2500, whichever is greater.

Test Frequency

South Dakota provides only general information regarding test frequency guidelines, and looks to methods established in the 23 CFR, AASHTO Manual, and ASTM standards to determine frequencies. As stated in the "SDDOT Construction Manual," the resident engineer is responsible for determining sampling, inspection, and testing all material prior to its use.

Test Methods

Testing of reinforcement steel is done in accordance with the standards listed in section 1010.1 of the "Standard Specifications for Roads and Bridges" manual. This section specifies that testing for bar reinforcement will conform to AASHTO M31, or ASTM A615 Grade 60. Also, welded wire will conform to ASTM A1064. Tie bar testing will conform to AASHTO M31, Grade 40. Testing of Dowel bars will conform to the AASHTO M31, or ASTM A615 Grade 40 or Grade 60. Or if applicable ASTM A663 for Grade 70 minimum or AASHTO M255. Epoxy coatings on bars will conform to AASHTO M254 Type B, or ASTM A775 (South Dakota Department of Transportation, 2015). [65]

Appendix R
Utah DOT Quality Assurance Practices

Background

The Utah Department of Transportation (UDOT) establishes the control of material through several publications. The Utah 2012 "Standard and Specifications Manual," section 03211, identifies the use of reinforcing steel and welded wire in construction projects. (67) The manual also identifies required AASHTO and ASTM standards, and the specific requirements to maintain material quality.

State Requirements and Standards

Section 01455 of the Standards and Specifications Manual identifies the requirements for material quality and for adherence to *Buy America* practices. Any projects that are completed with federal aid will conform to Title 23 CFR part 634.410. This title requires that the steel or iron used is 100% made from a domestic supply. The department will award the contract for the project to the lowest bidder who supplies the lowest percentage of foreign steel, or if the contractor provides foreign steel bid that is more than 25% less than that of the domestic steel bid. Further, the practices of UDOT are to use Grade 60 deformed or plain carbon steel bars unless otherwise stated. Also, when using epoxy-coated steel, the coating thickness must be between 8 and 12 mils.

UDOT adheres to the previously stated AASHTO and ASTM standards for implementing quality assurance practices in steel reinforcement. It has also put in place a certification program that conforms to predetermined standards set by the UDOT Materials Division and Quality Division. This certification program establishes qualified reinforcement steel manufacturers, so as to reduce testing requirements to random sampling and other more simplified testing methods described more fully in the Test Frequency information below. The frequency is then determined based on the need for verification of quality from manufacturers, and the "Minimum Sampling and Testing Requirements," and the "Materials Manual of Instruction." (68) The material supplies are then listed on a qualified suppliers list located on the UDOT website.

Quality Assurance Guidelines and Practices

To maintain quality standards during construction UDOT identifies the control of work in its "Standards and Specifications Manual," section 00727. UDOT also published the "Quality Control Quality Assurance Guidelines" to establish practices for uniformity of material and work. (68) These guidelines serve as a general reference material to those who are operating as the inspecting authority or the resident engineer (Utah Department of Transportation, 2014).

Section 01455 of the "Standards and Specifications Manual" also identifies the methods to ensure quality control. They describe methods for documentation of certifications and compliance, supply source requirements, methods of testing, the certification of compliance for manufacturers, methods to handle and store material to ensure that the quality of the material is not reduced, and the method of rejection for material that does not conform to the standards of the construction. Also listed are the requirements for the UDOT's *Buy America* practice.

Test Frequency

As stated in the UDOT "Standards and Specifications Manual", the department may use random sampling by heat number and manufacturer at any given time or location throughout the construction process to verify material quality. Also, as per section 01455 of the "Standards and Specifications Manual" and the AASHTO and ASTM guidelines, the frequency of sampling and testing is stated to be done in accordance with the publications "Minimum Sampling and Testing Requirements," and the "Materials Manual of Instruction." (67)

Test Methods

UDOT completes testing of reinforcement steel in accordance with the AASHTO and ASTM standards listed in the UDOT "Standards and Specifications Manual," section 03211. Testing of deformed and plain carbon-steel bars will conform to AASHTO M31. Testing of steel welded wire will conform to AASHTO M55. For Zinc coating on iron and steel the AASHTO M111 will be used. AASHTO M235 for epoxy resin adhesives and AASHTO M284 for epoxy coated reinforcing bars will be used. For cold finish steel bars, the ASTM standard A108 will be used. Testing of low-alloy deformed bars will conform to ASTM A706. Testing of zinc-coated bars will conform to ASTM A767. Testing of Headed steel bars will conform to ASTM A970 (Utah Department of Transportation, 2012). Testing of bond performance will conform to ASTM E1512.

Other standards and testing will comply with the American Welding Society (AWS), Concrete Reinforcing Steel Institute (CRSI) Manual of standard practice, and the UDOT Quality Management Plans (QMP).

Appendix S
Washington DOT Quality Assurance Practices

Background

The Washington State Department of Transportation (WSDOT), establishes quality control through several materials and construction standards. Specifically, the "WSDOT Materials Risk Analysis Manual," chapter 9, and the "Standard Specifications for Road, Bridge, and Municipal Construction," division 9 describe materials use. [69,70] Section 9-07 of the latter manual addresses the use of reinforcing steel. As stated in the "WSDOT Standard Specifications for Road, Bridge, and Municipal Construction," WSDOT will test reinforcing steel in accordance with AASHTO and ASTM standards. For further manage quality control outcomes, WSDOT has put certification processes in place for materials manufacturers and for materials testers.

State Requirements and Standards

State requirements are wide ranging, from particular material coating and reinforcement degree to certification programs and sampling based on statistical analysis of potential risk.

Thickness of epoxy-coating will be within 10 mils, plus or minus 2 mils. Damage to the coating will not exceed 0.25% of the surface area of each bar. In addition, reinforcement will conform to ASTM A706, and AASHTO Seismic Section 8.8.4 and 8.8.8. These requirements help ensure that steel reinforcement in WSDOT construction will sustain should earthquakes or various other natural loadings common throughout the state of Washington affect the completed construction work.

Certification Programs

As per the WSDOT Quality Assurance Program, materials testers must become certified. The "WSDOT Test Methods/Field Operating Procedures" describes frequency and scope of the tests. Testers must adhere to information in this publication along with information provided in the "Standard Specifications for Road, Bridge, and Municipal Construction" and the Construction Manual. [70,71]

In addition, WSDOT has also put in place a manufacturer certification program to maintain quality control over the production of materials. It enables WSDOT to establish standards and requirements for the manufacturer and to conduct testing at the manufacturing production site. The practice minimizes the risk of obtaining materials from a source that produces materials of inconsistent quality.

Acceptance of reinforcing steel by the engineer will be done based on the compliance of the manufacturer's certification. Compliance will conform to AASHTO R 53 and the NTPEP program.

Sampling Based on Statistical Analysis of Potential Risk

A significant WSDOT quality assurance tool is a risk analysis method the department has put in place to set risk ratings for individual construction materials. It is associated with the department's "Documentation and Exchange of Lively and Pure Homeopathic Information," which they identify as the ***Delphi Method*** (Washington State Department of Transportation, 2010) and (Abbreviations.com, 2016). [63,5] The ratings they set consider outcomes should a material not conform to standards and fail, as severity of consequences will vary. Therefore, WSDOT adjusts the frequency and degree of quality assurance procedures based on a material's risk level, applying more resources to high-risk materials necessitating a higher frequency of testing over low-risk material that WSDOT may accept with minimal testing.

To ensure maximum conformity to standards, a state would have to test every material at each construction job site. However, with proper risk analysis, the state minimizes resource expenditures while maintaining the likelihood of safe outcomes.

The Delphi Method approach is that of an expert review. The transportation office gathers the input of a group of persons who are considered resident experts on the subject material, and establishes a ranking system based on their input. To gather their opinions, WSDOT uses a survey with two questions, "what is the risk of failure?", and "what is the consequence of that risk?" (Washington State Department of Transportation, 2014) and (Washington State Department of Transportation, 2010). [72,69] The transportation department posed these questions to a group of engineers with specialties in structural design, hydraulics, pavement design, and electrical, as well as project inspectors and other department employees who might be familiar with the material.

WSDOT conforms to several previously listed AASHTO and ASTM standards to ensure the quality of the reinforcement steel and also to provide further guidance on setting sample selection and test frequency. These parameters also list the need to conform to seismic design specifications in both the AASHTO Seismic Section, and the ASTM A706, Grade 60 as an additional requirement for construction.

Quality Assurance Guidelines and Practices

To ensure the standards for construction are being met, WSDOT put in place a "Project Risk Management Guide" and the "Materials Risk Analysis Report." [72,69] These guide management oversight and risk assessment. Together, the documents help ensure that effective management identifies and mitigates risk taken during construction, taking into account potential risk should materials fail.

The "Materials Risk Analysis Report" identifies several methods to accept a material for construction use, specifying material and recommended test frequency and type. [69] Recommendations vary by material levels, set through the Delphi Method analysis described earlier. The "Materials Risk Analysis Form" articulates analysis outcomes by identifying parameters needed to determine test frequency. Page 11 of this form includes a table of risk averages and standard deviations (Washington State Department of Transportation, 2010). [69]

Test Frequency

WSDOT uses several methods to set acceptance for materials. Chapter 9 of the "WSDOT Construction Manual" establishes guidelines for sampling small quantities of material and helps testers to identify conditions when they can reduce the test frequency of material. In both cases, WSDOT relies on the resident project engineer as the authority to determine whether a test frequency reduction is feasible and appropriate. As a result, the resident engineer may request that the Region Materials Engineer make a 10% deviation from the testing frequency schedule (Washington State Department of Transportation, 2014) (Washington State Department of Transportation, 2010). (72,69)

Test Methods

As per section 9-07.2 of the "WSDOT "Standard Specifications for Road, Bridge, and Municipal Construction," testing will conform to ASTM and AASHTO standards. For deformed steel bars, testing will be done in accordance with AASHTO M31 or ASTM A706 Grade 60. For headed steel reinforcing bars, testing will conform to section 9-07.2 of the standard specifications manual and the ASTM A970. For epoxy-coated steel reinforcing bars, testing will be done in accordance with ASTM A775 and A706. Plain steel bars will be tested in accordance with AASHTO M31, Grade 60. Epoxy-coated dowel bars will conform to AASHTO M31, Grade 60, ASTM A615, Grade 60, and ASTM A1078 Type 2. Corrosion Resistant dowel bars and Tie bars will conform to AASHTO M255, Grade 60 and AASHTO M31, Grade 60, as well as ASTM A276, Type 316L and ASTM A1035. Wire mesh will be tested in accordance with AASHTO M55, AASHTO M221, and AASHTO M225 (Washington State Department of Transportation, 2016). (71)

Appendix T
Wyoming DOT Quality Assurance Practices

Background

To establish the methods for quality assurance in material selection, sampling, testing, and implementation in work, the Wyoming Department of Transportation (WYDOT) uses several publications. These include the WYDOT "Construction Manual," "Materials Testing Manual," and a "Standards and Specifications Manual." [73,74,75] Each establishes specific requirements for each type of reinforcing steel to be used in WYDOT construction. In addition, WYDOT has a certification program in place for manufacturers.

State Requirements and Standards

The Wyoming Department of Transportation requires steel reinforcement to conform to AASHTO and ASTM standards. WYDOT will oversee sample selection in accordance with the "Materials Testing Manual, and the "Construction Manual" and engineers will adhere to the standards these manuals set. [68,67]

Also, as per the WYDOT "Materials Testing Manual," the minimum yield strength will be associated with Grade 40, Grade 60, Grade 75, or Grade 80. [74] The minimum tensile strength will conform to 60,000 lb/in^2 for Grade 40, 90,000 lb/in^2 for Grade 60, 100,000 lb/in^2 for Grade 75, or 105,000 lb/in^2 for Grade 80.

Section 130.0 of the WYDOT "Materials Testing Manual" identifies sample size specification requirements for reinforcement steel. Deformed bar requirements elongation and bending test provisions are listed in the WYDOT "Materials Testing Manual," section 880.0. [74] Deformation requirements for maximum average spacing, minimum average height, and maximum gap are listed in a table in this same manual in section 880.0.

Certification Program

WYDOT has a certification program in place for manufacturers to ensure compliance with state "Manufactured Product Certifications" requirements. The program enables WYDOT to conduct testing at the manufacturing production site. The practice minimizes the risk of obtaining materials from a source that produces materials of inconsistent quality. The engineer will use material that has been certified from inspection and testing at its source. Further, WYDOT may accept material from manufacturers that are not on the certification list, as long as the material is stated as being equivalent to the specified material, and the engineer approves this in writing.

Quality Assurance Guidelines and Practices

Section 106 of the WYDOT "Standard Specifications Manual" establishes the methods for control of material and the corresponding quality assurance requirements. [(75)] This section states that the engineer will use the "Materials Testing Manual" to determine if a material being considered for use in the construction project will conform to the standards established in the contract. The engineer will use material that is from a certified manufacturer who is in compliance with the "Manufactured Product Certifications" requirements (Wyoming Department of Transportation, 2010). [(75)]

The WYDOT method of material approval is to test in accordance with AASHTO-accredited laboratories. The approval of a source of material does not constitute the approval of the material for work. Further testing may need to be completed before WYDOT accepts the material for use at the construction site.

The WYDOT "Construction Manual" establishes quality assurance methods for using reinforcement steel in construction. [(73)] Section 514 states that all samples collected will be in accordance with the materials program for testing and sets guidelines for inspection and testing.

Test Frequency

WYDOT sets test frequency in accordance with AASHTO, ASTM standards, as well as the WYDOT "Standards and Specifications Manual," section 514.4.1.

Test Methods

WYDOT also applies AASHTO and ASTM standards to set test methods as well as the "Standards and Specifications Manual," which states that the engineer will test all reinforcement steel before use. This is done by sampling two 4.5ft. long samples from each manufacturer, heat number, and size (Wyoming Department of Transportation, 2010).

As per the "Materials Testing Manual," testing of reinforcement steel will conform to AASHTO M31, ASTM A615, WYDOT 811.1.2, WYDOT 130.0, and WYDOT T-128 Manuals. Test parameters in the WYDOT "Standard Specifications Manual," section 811 are as follows; testing of steel reinforcement bars will be done in accordance with ASTM A615 for grade 46 or 60. [(75)] For testing of epoxy coating, the ASTM standard A775 will be used. For testing of galvanized bars, the ASTM standard A767 will be used. And for spiral reinforcement the ASTM standard A82 will be used.

Testing of steel bar mats will conform to AASHTO M54. Welded wire fabric will be tested in accordance to AASHTO M55. Dowel bars and tie bars will be tested in accordance to AASHTO M245 type B, and AASHTO M31.