Office of the Inspector General
Audit Report

California Bridge Seismic Retrofit Program

Federal Highway Administration
Region 9

Report Number: R9-FH-7-002

Date Issued: November 7, 1996

Memorandum

U.S. Department of Transportation
Office of the Secretary of Transportation
Office of Inspector General

Subject: ACTION: Report on Audit of California Bridge Seismic Retrofit Program Report Number R9-FH-7-002

Date: November 7, 1996

Reply to Attn of: JRA-9

From: Robin K. Dorn-Hunt
Regional Audit Manager, Region IX

To: Regional Administrator
Federal Highway Administration, Region 9

We are providing this report for your information and use. Your August 26, 1996, comments on our June 26, 1996, draft report were considered in preparing this report. A synopsis of the report follows this memorandum.

In your comments to our draft report, you concurred with all the recommendations. The actions taken to resolve the recommendations are considered responsive to our finding and recommendations. We are concerned, however, with corrective actions pertaining to field tests of shotcrete. The lack of uniform quality control testing procedures applies to projects with written authorization to use shotcrete, as well as those with oral authorization. The California Department of Transportation (Caltrans) should consider investigating any bridge project where shotcrete tests were insufficient or inconclusive. Please reconsider Caltrans' proposed field testing criteria, and provide us your written comments within 60 days of this report.

The audit recommendations, except Recommendation 2 pertaining to field tests of shotcrete, are considered resolved, subject to the followup provisions of Department of Transportation Order 8000.1C.

We appreciate the cooperation and assistance provided by your staff and State of California officials. If you have any questions, or require additional information, please contact me at (415) 744-3090.

#

U.S. Department of Transportation

Office of the Inspector General

California Bridge Seismic Retrofit Program

Federal Highway Administration
Region 9

Report No. R9-FH-7-002 **November 7, 1996**

SYNOPSIS

Objective

The objective of the audit was to evaluate the effectiveness of California's program to seismic retrofit bridges at risk from earthquakes.

Conclusion

The California Department of Transportation (Caltrans) has given bridge seismic retrofit projects (retrofit projects) the highest funding priority. The actions taken by Caltrans in bridge seismic design and retrofitting should contribute significantly to reducing the risks to life, property, and economic hardship from bridge failures during earthquakes.

However, Caltrans did not apply uniform quality control specifications and testing procedures when using shotcrete (pneumatically placed concrete) for bridge seismic retrofit construction. This occurred because Caltrans approved change orders to substitute shotcrete for castinplace concrete in retrofit projects before establishing uniform quality control specifications and testing procedures for shotcrete. The Federal Highway Administration (FHWA) was not aware Caltrans was using shotcrete without uniform quality control specifications and testing procedures. As a result, Caltrans and FHWA do not have adequate assurance bridges retrofitted with shotcrete will withstand the seismic forces of major earthquakes as designed.

Monetary Impact

The report did not identify any monetary recoveries.

Recommendations

We recommended the FHWA Regional Administrator require Caltrans to: (1)develop uniform quality control specifications and testing procedures for shotcrete used in retrofit projects, (2)conduct laboratory and field testing of shotcrete retrofit components, and (3)repair or replace any shotcrete components which do not meet standards.

Management Position

FHWA concurred with all three recommendations and corrective actions are being implemented. A copy of FHWA's complete response is included as an appendix to this report.

Office of Inspector General Comments

The actions taken to resolve the recommendations are considered responsive to our finding and recommendations. We are concerned, however, with corrective actions pertaining to field tests of shotcrete. The lack of uniform quality control testing procedures applies to projects with written authorization to use shotcrete, as well as those with oral authorization. Caltrans should consider investigating any bridge project where shotcrete tests were insufficient or inconclusive. Please reconsider Caltrans' proposed field testing criteria and provide us your written comments within 60Êdays of this report.

The audit recommendations, except for Recommendation 2 pertaining to field tests of shotcrete, are considered resolved. However, all recommendations are subject to the followup provisions of Department of Transportation Order 8000.1C.

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I. INTRODUCTION

Earthquakes in California over the last 25 years have damaged or collapsed highway bridges resulting in injuries and deaths to motorists, property loss, and economic hardship to urban areas. The October 17, 1989, Loma Prieta earthquake collapsed the upper and lower closure spans of the San Francisco-Oakland Bay Bridge, killing 1 motorist and injuring 12 others. This heavily traveled bridge was closed for repairs for 4 weeks.

San Francisco-Oakland Bay Bridge

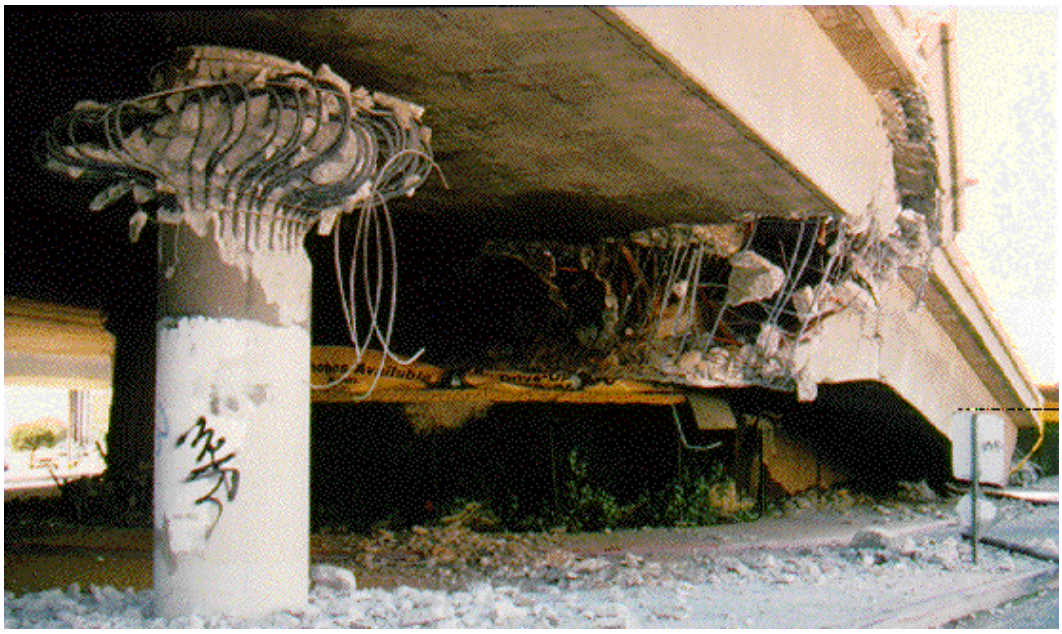
The Loma Prieta earthquake also collapsed the upper roadway of the Cypress Viaduct in Oakland, California, causing 42 deaths and 108 serious injuries. The Cypress Viaduct was subsequently dismantled in its entirety, and is being reconstructed with Federal funds at a cost of about $1 billion. It is not scheduled to open until 1998, which is 9 years after the earthquake.

The January 17, 1994, Northridge earthquake in the San Fernando Valley

Cypress Viaduct

caused major damage to nine bridges. Economic losses from closure of

the Santa Monica freeway ramps and overpasses were estimated at over $1 million per day.



Santa Monica Freeway at La Cienega Boulevard

Background

The California Bridge Seismic Retrofit Program (retrofit program) began after the San Fernando Valley (Sylmar) earthquake in 1971. This earthquake collapsed one bridge and buckled several others, resulting in two bridge-related fatalities. Prior to this disaster, California bridges were designed with minimal consideration of seismic forces.

The California retrofit program, in its early years, was not given high priority. Between 1971 and 1987, Caltrans spent only $54 million for bridge seismic retrofit projects (retrofit projects). The Whittier Narrows earthquake in Los Angeles County in October 1987 added to Caltrans awareness of the importance of the retrofit program. This earthquake nearly collapsed an Interstate freeway structure during commute traffic.

Two months after the 1989 Loma Prieta earthquake, the California Legislature mandated Caltrans either repair or replace all state bridges not meeting current seismic safety standards. The enactment of Senate Bill 36 provided $80 million for an accelerated retrofit program. Caltrans screened the 12,000 state bridges, and identified 2,200 bridges needing retrofitting. Caltrans estimates it will cost $1.8 billion ($1.6 billion in Federal funds) to retrofit these 2,200 bridges, excluding toll bridges. The work is being done in two phases and is scheduled to be completed by the end of 1997. As of

March 1, 1996, Caltrans had completed retrofit construction for 1,057 bridges. Caltrans is considered nationally and internationally to be a leader in bridge seismic design and retrofitting.

Federal Highway Administration's (FHWA) bridge seismic retrofit policy has been one of encouraging states to identify deficient bridges, evaluate the consequences of seismic damage, and initiate a program for reducing seismic risk. FHWA issued Seismic Design Guidelines for Highway Bridges in 1981, Seismic Retrofitting Guidelines for Highway Bridges in 1983, and Seismic Retrofitting Manual for Highway Bridges in 1995. FHWA is involved with Caltrans in developing technologies for the use of advance composites and seismic isolation devices for retrofitting bridges.

Objective, Scope, and Methodology

The objective of the audit was to evaluate the effectiveness of California's program to seismic retrofit bridges at risk from earthquakes. The audit was conducted between June 6, 1995, and January 31, 1996, and included a review of Caltrans retrofit policies and practices from 1989 through 1995.

We interviewed FHWA and Caltrans officials, and bridge design and construction experts from industry and academia. We visited retrofit project sites and reviewed project documents. We evaluated Caltrans process for: screening and prioritizing bridges to be retrofitted, selecting preferred seismic design, and approving construction contract standards and specifications. We also reviewed FHWA's program oversight. The audit was performed in accordance with Government Auditing Standards prescribed by the Comptroller General of the United States, and included such tests of records as deemed necessary in the circumstances.

Management Controls

We assessed controls for identifying, selecting, and prioritizing retrofit projects. We also reviewed design and construction strategies. We assessed FHWA's program monitoring system, which consisted primarily of process reviews. FHWA performs one or two process reviews of structures per year, but does not specifically sample retrofit projects.

Prior Audit Coverage

No prior audits of California's Bridge Seismic Retrofit Program have been performed by the Office of Inspector General (OIG).

The General Accounting Office (GAO) issued a report, dated June 19, 1990, on the effects of the Loma Prieta earthquake on the Bay Bridge and Cypress Viaduct. GAO criticized Caltrans for not moving

faster to complete seismic retrofitting, but made no recommendations. The GAO also issued a report, dated January 23, 1992, on states with highway bridges at risk from earthquakes. GAO recommended FHWA require states to identify bridges vulnerable to earthquake damage in conjunction with their routine bridge inspections, and include earthquake vulnerability information as part of data reported in the National Bridge Inventory. FHWA did not agree with the recommendation.

II. FINDING AND RECOMMENDATIONS

Finding. Shotcrete in Bridge Seismic Retrofit Construction

Caltrans has given bridge retrofit projects the highest funding priority. Caltrans used a scientific model to screen, evaluate, and prioritize state-owned bridges for seismic retrofitting. This model enables Caltrans to efficiently select bridges for retrofitting. Caltrans actions should significantly reduce the risks to life, property, and economic hardship from bridge failures during earthquakes.

However, we found Caltrans did not apply uniform quality control specifications and testing procedures when using shotcrete as a bridge retrofit material. This occurred because Caltrans approved change orders to substitute shotcrete for cast-in-place concrete in retrofit projects without first establishing uniform quality control specifications and testing procedures for shotcrete. Further, FHWA was not aware Caltrans was using shotcrete without uniform quality control specifications and testing procedures. As a result, Caltrans and FHWA do not have adequate assurance bridges retrofitted with shotcrete will withstand the seismic forces of major earthquakes as designed. Caltrans used shotcrete in 53 of 292 bridge seismic retrofit projects as of September 1995.

Discussion

The American Association of State Highway Transportation Officials (AASHTO), in its publication Seismic Design of Highway Bridges, emphasizes that adherence to good quality controls during construction is critical to obtaining a product which meets design criteria. According to the publication, "Structural failures which have occurred during earthquakes and are directly traceable to poor quality control during construction are innumerable." Also, according to AASHTO, quality construction is dependent on sound specifications, and trained inspectors implementing approved testing procedures. According to Caltrans officials, poor construction practices were not discussed as a cause of structural failures in the Loma Prieta or Northridge earthquake reports.

Caltrans relies on the American Concrete Institute (ACI) for guidance on shotcrete quality control in bridge construction. Shotcrete is concrete pneumatically projected onto bridge structural components at a high velocity, and is an acceptable retrofit process when uniformly controlled and tested. The ACI Manual of Concrete Practice discusses shotcrete processes, applications, materials, and equipment. The Manual states:

> . . . there is presently a scarcity of useful engineering data [for shotcrete] and the information available shows a wide range of values. This is attributable, in part, to a lack of standard testing procedures, variations in constituent material quality and gradation, non-uniformity of application techniques, the absence of testing standards, and difficulty in correlating factors between test specimens and in-place shotcrete cores.
>
> It should be stressed that the properties and performance of shotcrete are largely dependent on the conditions under which it is placed. They may also be dependent on the characteristics of the particular equipment selected, and ultimately on the competence and experience of the application crew.

Experts in structural engineering, contacted at the December 1995 International Seismic Conference on Bridges and Highways in San Diego, California, were not aware of any transportation engineering organization in the world, other than Caltrans, using shotcrete in bridge retrofit projects. Further, the National Center for Earthquake Engineering Research, which collects and compiles engineering research worldwide, had no record of seismic research on shotcrete similar to its use by Caltrans in bridge seismic retrofit projects.

The experts identified possible serious problems with using shotcrete in structural construction. For example, Frieder Seible, Ph.D., Professional Engineer, and Professor of Structural Engineering, at the University of California at San Diego told us the more intricate the reinforcing, the more difficult it is to properly encase steel reinforcing bars with shotcrete. Some bridge components have elaborate steel hooks and closely spaced steel bars that can cause voids during shotcrete application. Professor Seible also explained, that as standard protocol, Caltrans tests new technologies or material applications in the laboratory before use in the field. However, Caltrans did not test the seismic behavior of shotcrete column casings before using this technique in the Mission Valley retrofit project in San Diego.

Also, the Deputy Director of the National Center for Earthquake Engineering Research in Buffalo, New York, told us shotcrete construction should be supported with laboratory tests as evidence the materials will perform satisfactorily when subjected to seismic forces. Caltrans has tested shotcrete for compression forces, however these tests are not conclusive for shotcrete column casings where the completed work will be subjected to significant tensile forces as well as compression forces.

The Chief Materials Engineer for AGRA Earth and Environmental Limited, advised us that the quality of reinforced shotcrete, in new construction or

retrofit projects, is directly related to the training and experience of the nozzleman applying the shotcrete, and the inspector overseeing the nozzleman's work. This expert provided us with examples of qualification requirements for shotcrete nozzleman and inspectors, and sampling and testing standards in contracts awarded by various Government transportation agencies. For example, the Hawaii Department of Transportation includes the following requirements in contracts with structural shotcrete:

> Application Qualifications: The work shall be performed under the immediate supervision of a foreman with at least 3 years experience in shotcrete placement of the type selected by the contractor. Qualified nozzleman shall be employed who have had previous training or experience in the application of shotcrete on at least two similar projects.

The city of Seattle, Department of Construction, includes the following minimum inspection and testing requirements in contracts using structural shotcrete:

> Approval of the shotcrete procedure by the [City] Engineer . . . is required prior to application of structural shotcrete on any project. Approvals are required for the design mix, slump, lift height, nozzleman, nozzleman's assistant (blow pipe operator), equipment, method of taking compression test samples, and pre-construction testing.

Since 1992, Caltrans has issued contract change orders, or given contractors verbal authorization, to substitute shotcrete for cast-in-place concrete in reinforced bridge components; including diaphragm bolsters, bent caps, abutment bolsters, infill walls and bridge column casings. Caltrans used shotcrete in 154 bridges, on 53 seismic retrofit projects, under contract as of September 1995. FHWA provided $169 million for these retrofit projects. However, Caltrans had not established quality control specifications, or approved sampling and testing procedures, for reinforced shotcrete in bridge construction. The only shotcrete quality control specifications published by Caltrans applied to nonstructural construction, such as ditch and channel linings, and slope paving.

Nozzleman Applying Shotcrete

Caltrans used shotcrete instead of cast-in-place concrete, in part, to reduce project costs and save time. However, the cost and time savings have not materialized to date. For example, in the Mission Valley Viaduct Project, Caltrans received a $19,838 credit from the contractor for substituting shotcrete for cast-in-place concrete which cost $5.7 million. Also, on most projects, time savings were offset by shotcrete pre-construction setup requirements. According to FHWA engineers, shotcrete was also used to reduce construction problems, especially in pouring infill walls or placing diaphragm bolsters. However, research by the OIG engineer indicates technology is available for pumping cast-in-place concrete in difficult locations.

During the audit, we reviewed 29 projects where shotcrete was substituted for cast-in-place concrete. Quality control specifications for these shotcrete projects were not consistent, and did not provide quality control measures to ensure the end-product met design criteria. For example, two of the projects required the shotcrete nozzleman to have 3,000 hours experience, three projects required 300 hours, and the other 24 projects had no requirements for nozzleman experience. In those cases where nozzleman experience was specified, Caltrans structure representatives could not verify the requirements had been met.

The frequency of shotcrete testing varied widely. For example, four of the projects required three test cores be furnished for each 50 cubic yards of shotcrete placed, three projects required three test cores for each 300 cubic yards, and the other 22 projects had no requirements for test cores.

As discussed above, the ACI and structural engineering experts consider nozzleman qualifications and testing procedures to be critical elements in successful shotcrete jobs. A qualified nozzleman provides the best warranty against voids, sand pockets, and accumulated rebound material, intrinsic to shotcrete. Core testing is vital in assessing uniform density and compressive strength of shotcrete components.

Also, shotcrete sampling and testing were insufficient or non-existent. For one project we visited, the Caltrans engineer tested the shotcrete for compressive strength by casting cylinders from the back of the delivery truck. A preferred method for testing shotcrete is to use test panels and extract production cores adjacent to steel bars. On another project we reviewed, the Caltrans engineer waived all pre-construction and production testing because he had been satisfied with the work of the contractor on a previous project. However, this engineer did not have formal training in inspecting shotcrete work.

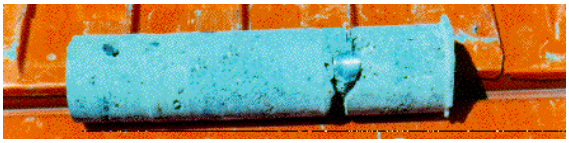
Further, for two other projects reviewed the shotcrete applications were defective, and the contractors were required to repair or replace the shotcrete. Voids in shotcrete work at the Los Angeles River Bridge were repaired with pressurized grouting methods. For one span of the Petaluma bridge, the Caltrans engineer rejected shotcrete in all 16 bolsters because the materials did not bond to the reinforcing steel bars in the bolsters. On another span of the Petaluma bridge, the Caltrans representative rejected 1 of 2 bolsters because of poor bonding to the reinforcing steel bars. For both spans, Caltrans required the contractor to replace the shotcrete bolsters with bolsters constructed with cast-in-place concrete. For one of the bridges, the Caltrans engineer stated:

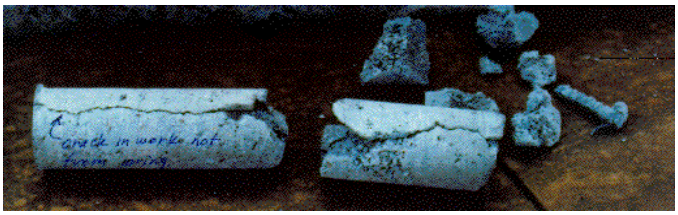
> In my judgment as a registered [civil] engineer, this [shotcrete] was not acceptable, and further use of this material would not have been an efficient and sound engineering use of project funds. I feel that the Contractor could not produce a sound product with any sort of consistency, which from volumes of documentation, can be achieved with Cast-in-Place Concrete.

During our audit, the Caltrans' Chief, Office of Structure Construction dispatched a Caltrans headquarters senior bridge engineer to evaluate shotcrete projects in various parts of the state. The engineer visited six projects and found shotcrete had inconsistent and unpredictable results, including areas of non-homogeneous concrete behind reinforcing steel bars, widely varying compressive test results, and large voids in abutment diaphragms that could mean poor workmanship. The engineer recommended shotcrete be used only for hinge diaphragm bolsters, and only at certain locations. Caltrans' Chief, Office of Structure Construction, notified engineers in the field to limit shotcrete work to bolsters, and to require sufficient testing to verify proper bonding.

The Caltrans Director of Engineering Services, at the exit conference on January 17, 1996, told us Caltrans would work with FHWA to test the performance of shotcrete column casings, and develop standard specifications and testing procedures for shotcrete. Caltrans, in early January, provided FHWA with a draft shotcrete guide that included quality

Below are examples of defective shotcrete





Shotcrete Cores Showing Shadows and Cracks

control specifications, and guidance to structure representatives for sampling and testing shotcrete in bridge structural work.

FHWA Construction Monitoring

FHWA was not aware Caltrans did not have quality control specifications or testing procedures for shotcrete until we brought the matter to their attention at a meeting on September 18, 1995. However, the Code of Federal Regulations (Title 23, Part 637) states:

> Each State highway agency shall develop a sampling and testing program which will provide assurance that the materials and workmanship incorporated in each Federal-aid highway construction project are in reasonably close conformity with the requirements of the approved plans and specifications, including approved changes.

FHWA California Division officials stated FHWA does not review Caltrans plans, specifications, and estimates for retrofit projects except for projects costing $5 million or more per structure. As of September 1995, one project using shotcrete exceeded $5 million (Mission Valley, San Diego). Division officials told us they considered Caltrans the expert on retrofit construction, and assumed Caltrans had quality control specifications and testing procedures for shotcrete. The officials told us

they did, however, review Caltrans sampling and testing procedures for cast-in-place concrete in 1993.

To enhance the Federal role in bridge seismic retrofit programs, FHWA needs to raise the awareness of bridge engineers to shotcrete quality control issues. In our opinion, FHWA should develop guidance and instructional information for use by bridge design and construction engineers at the local, state, and Federal levels. This guidance will assist engineers in providing more meaningful oversight of shotcrete applications by contractors, and ensure an acceptable end product.

Subsequent to our discussions on shotcrete with the FHWA Chief, Bridge Division, Office of Engineering in December 1995, and our audit briefing with the FHWA Regional Administrator in early 1996, FHWA announced a nationwide Seismic Bridge Design Training Program starting in June 1996. The objective of the program is to ensure uniform application of seismic design principles by bridge engineers. The training will consists of three components: seismic design examples, national seminars, and a help desk service.

Recommendations

We recommend the FHWA Regional Administrator require Caltrans to:

1. Develop uniform quality control specifications and testing procedures for shotcrete used in bridge retrofit projects.

2. Conduct laboratory and field tests for shotcrete.

3. Repair or replace bridge components which do not meet test requirements.

Management Response

In the August 26, 1996 response to our June 26, 1996, draft report, FHWA, Region 9 (Region) concurred with all three recommendations.

Region officials stated that Caltrans has developed uniform specifications which govern the use of shotcrete on construction projects. Further, Caltrans agreed to investigate projects where the use of shotcrete was allowed by verbal authorization and complete any necessary repairs by June 1997. Also, FHWA is currently working with Caltrans to establish laboratory tests of shotcrete. Testing the seismic behavior of shotcrete should be well under way by March 1997.

The Region's complete response is included as the appendix to this report.

Office of Inspector General Comments

The Region's planned actions are considered responsive to the audit recommendations. We are concerned, however, with corrective actions regarding field tests for shotcrete. We request FHWA reconsider accepting Caltrans proposal to field test only those projects where use of shotcrete was verbally authorized. During the audit, we reviewed two projects where Caltrans verbally authorized the use of shotcrete for bridge retrofit work. We also reviewed 27 projects where Caltrans provided written authorization to contractors to use shotcrete for bridge retrofit work. We found that the written authorizations did not consistently provide for quality control tests to assure the shotcrete bonded to reinforcing steel bars, and was free of shadows and voids adjacent to the steel bars. For the bridge retrofit projects we reviewed, we cannot conclude that there is a relationship between the manner of authorization to use shotcrete, and the sufficiency of test evidence available to judge the acceptability of the shotcrete work. Therefore, it would be prudent for FHWA to require Caltrans to field test shotcrete projects, regardless of method of authorization. Selection criteria for field testing shotcrete should be directed toward projects where existing evidence is insufficient to judge shotcrete bonding, or the presence of shadows or voids adjacent to the reinforcing steel bars.

Exhibit A

AUDIT TEAM MEMBERS

The following audit team members participated in the audit of the California Bridge Seismic Retrofit Program:

Larry E. Arata	Project Manager
Gary W. Kirk	Auditor-in-Charge
Gerald L. Blumenthal	Auditor
Susan M. Lier	Auditor
Fred Oshalim	Auditor
Steven R. Townsend	Auditor
Rodolfo E. Perez	Engineer
Joyce K. Mayeda	Administrative Assistant

Appendix
(5 pages)

RECEIVED
AUG 26 1996

Memorandum

U.S. Department of Transportation
Federal Highway Administration

Subject Draft Report: Audit of California Bridge Seismic Retrofit Program Project No. 595-005-9000

Date August 26, 1996

From Regional Administrator
San Francisco, California

Reply to Attn.of HTP-09
407.50

TO Ms. Robin K. Dorn
Regional Audit Manager, Region IX
Office of Inspector General (JRA-9)
San Francisco, California

In response to your June 26, 1996, memorandum which transmitted the subject draft report, we have been working closely with the California Department of Transportation (Caltrans) in resolving the review findings. We concur with the three recommendations contained in the report which are now being implemented. The following is the status of each recommendation:

1. Caltrans have developed uniform specifications which governs the use of shotcrete on construction projects. Copies of Caltrans' Special Provisions 10-1 "Shotcrete" and 10-1 "Diaphragm Bolster" are attached.

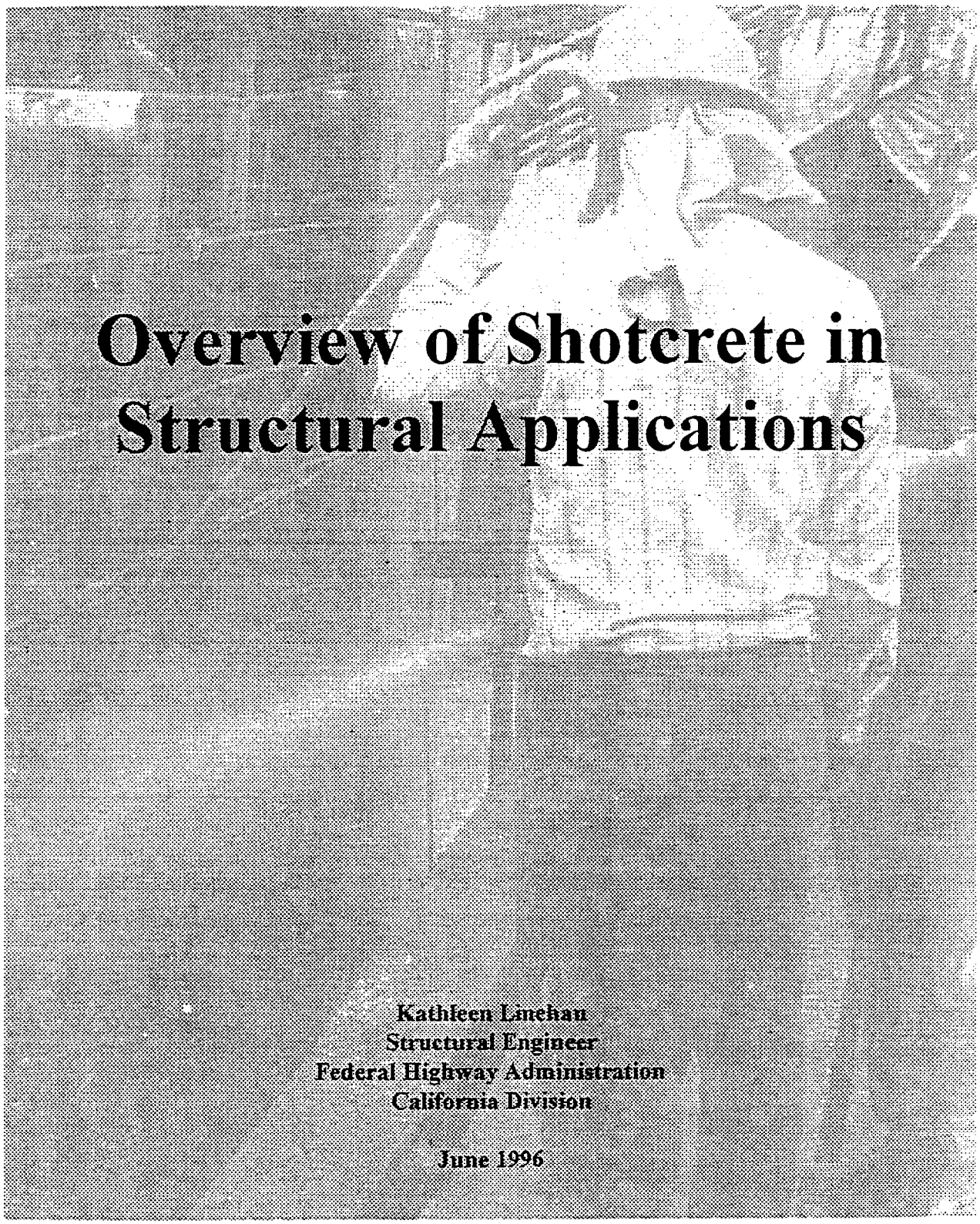
2. We are working with Caltrans to implement a research project to test the seismic behavior of shotcrete. The testing should be well underway by March 1997.

3. Caltrans have agreed to investigate projects where the use of shotcrete was allowed by verbal authorization. The target date for completion of this investigation and any necessary repairs is June 1997.

In addition, our California Division office has prepared the attached report "Overview of Shotcrete in Structural Applications" which we plan to distribute to the Headquarters and the other FHWA Regional offices. Caltrans is also in the process of preparing a formal response which will be provided to you.

for Julie Anna Cirillo

2 Attachments



Overview of Shotcrete in Structural Applications

Kathleen Linehan
Structural Engineer
Federal Highway Administration
California Division

June 1996

Introduction

In 1995 the Office of the Inspector General conducted an audit of California's Seismic Retrofit program with the finding that shotcrete use in structural applications was lacking standard procedures and specifications. The concern was that the use of this material on highway projects was growing rapidly, with very little formal guidance for its use. In response to that criticism, Caltrans has put together a field manual for shotcrete use, including a standard special provision.

In addition to Caltrans' effort, AASHTO is currently working on a shotcrete construction practices manual. AASHTO is tying into the work already done by the Canadian Strategic Highway Research Program in developing the "C-SHRP Recommended Practice for Shotcrete Repair of Highway Bridges". However, neither of these manuals specifically addresses the use of shotcrete in structural applications on bridges, which is the focus of the Caltrans manual.

Since the inception of Caltrans' Seismic Retrofit program, shotcrete use has been steadily increasing in California., Currently, the standard special provision allows the use of shotcrete as an option in locations designated in the plans. It has been widely used for adding diaphragm bolsters in locations where conventional cast-in-place concrete construction would be impossible due to space and access constraints. It has also been utilized in strengthening bent caps, abutment bolsters, and infill walls. Most recently, it has even been used as an expedient method of encasing bridge columns in concrete jackets.

Besides being effective for locations where access is difficult, shotcrete repair is easily made " during construction, allowing inspectors to have sections removed that are questionable without impacting production significantly.

Caltrans Guidelines

Caltrans has set these guidelines for the appropriate use of shotcrete as a substitute for ClP reinforced concrete:

- In vertical sections, 8-12 inches is best for shotcrete thickness
- Steel reinforcement bars should be placed in a single mat
- Double mats can be used if bars are no larger than ##6 and spacing no closer than 12 inches

Applications with more steel or greater thickness will cause the success of the method to be more dependent upon skilled construction and proper inspection.

There are two methods by which shotcrete can be placed:

- The wet method, in which all the shotcrete ingredients, including mix water, are mixed prior to entering the delivery system

- The dry method, which utilizes the nozzle to add most of the water at the point of application. A smoother finish can be attained using the dry method.

Caltrans allows only wet method shotcrete to be used for the structural applications, since its mixing and delivery methods are closer to those of cast-in-place concrete. Shotcrete mix designs are handled in the same manner as any concrete mix. It needs to go through the same testing and approval process to insure adequate strength. Sampling and testing are conducted according to the requirements of ASTM C42, which describes the procedures for obtaining and testing drilled cores and sawed beams of concrete.

Test panels are constructed prior to the actual construction to represent the most heavily reinforced section in the design. Cores can be taken from a non-reinforced test panel or from the reinforced panels to test that the compressive strength meets the minimum of 3250 psi. The reinforced test. panel is then demolished after 7 days to inspect for homogeneous concrete and rebar encasement. Additionally, the special provision requires that three production cores be taken for every 300 square feet of surface area (or one per bolster, for abutment bolsters), In addition to ensuring that design strength is met, the production cores should be located adjacent to the rebar, so they can show whether or not there is shadowing behind the rebars.

Dry method shotcrete maybe used as a 1/2 inch thick finish coat, but is not included in the design calculations or the dimensions shown in the plans. .

Prequalification

Because the quality of the product is so dependent upon the skill of the workers and the coordination between the nozzleman and, blowpipe operator, Caltrans requires prequalification of contractors to place structural shotcrete. They have established a four part prequalification process. Contractors must prove that 1) the concrete mix is workable, 2) that the mix meets design strength, 3) that the nozzleman and blowpipe operator are competent, and 4) that the required finish can be achieved. The nozzleman must have written proof of 3000 hours of experience (18 months) and the entire production crew must be used to construct any test panels. Inspectors are encouraged to be closely involved in the construction process and even rake out sections of concrete just to get a feel for the quality of the product and learn what good and not so good sections look like.

Construction and Inspection

There are no unique requirements for curing. Shotcrete curing is to comply with the current Caltrans specification for structural concrete, which requires a water cure on surfaces visible to the public and allows curing compound on hidden surfaces.

One of the most important things to look for in inspection of shotcrete construction is a proper water cement ratio. Strength is generally not a concern, since shotcrete mixes use more cement and a lower water/cement ratio than ordinary structural concrete, but the homogeneity and consolidation are dependent upon the consistency of the mix. Sloughing off of wet concrete indicates too much moisture in the mix, and a mix that is too dry will not be workable. Also, the underneath lift must be wet enough to allow consolidation with the next lift.

A simple rule is provided for the inspectors, to encourage thorough inspection and learning of the process of shotcrete construction WHEN IN DOUBT, RAKE IT OUT! Because of the ease of replacing removed sections of wet shotcrete, raking sections out to check for quality can be done without impacting the progress much.

Closing

Two years of Caltrans cost data shows an average cost of $272/CY. Experience has shown that in general, the more difficult the access to the work is, the more expensive the shotcrete work will" be.

With skilled contractors and close inspection, shotcrete can be a very cost effective alternative to CIP concrete construction in some situations. As it's utilization grows in highway construction, the knowledge and comfort level will grow as well, giving us reduced costs and increased quality.