Conventional pile footings have often been treated as a support fixed against translation and rotation for the purpose of seismic analysis and design. The proposed ATC-32 draft design specifications require that foundation stiffnesses be accounted for in the dynamic response analysis. In addition, pile footings must be capable of resisting lateral loads imposed by the safety evaluation earthquake. It is generally acceptable to consider all possible mechanisms of resistance such as passive soil resistance, lateral pile capacity and, when appropriate, friction between the pile cap and the surrounding soil.

In general, the current Caltrans' BDS does not allow the number of piles in a foundation to be governed by the calculated or assumed ultimate lateral capacity of individual piles subjected to earthquake loading. This practice has been questioned by some. As part of the ATC-32 project, methods are being developed to determine how bridge pile foundations should be designed for lateral capacity.

Design provisions for spread footings are also included in the ATC-32 draft design specifications. An important issue in spread footing design for lateral loads is the amount of footing uplift that will be allowed. It has been recommended that load eccentricity during the Safety Evaluation earthquake be limited to 25 percent of the spread footing dimension for single column bents, and 33 percent for multiple column bents. The ATC-32 Project Engineering Panel is currently considering these recommendations.

Concrete Design

Several aspects of concrete design are being considered in the ATC-32 project. These include the design of ductile elements, the design of non-ductile elements using a capacity design approach, and the detailing of reinforced concrete for seismic resistance.

In order to design a ductile column, the designer requires methods to: 1) determine the flexural strength of compression members; 2) determine the shear strength of these members; and 3) prevent excessive degradation of flexural and shear strength during an earthquake. The current Caltrans' BDS provides reasonably good methods in each of these three areas, but the ATC-32 project seeks to improve them. At the present time new methods have been proposed by ATC-32 subcontractors which attempt to make column design more consistent with recent laboratory testing results for bridge columns. These new methods are currently being reviewed by the ATC-32 project panel. It is not known at this time whether these methods will be recommended as replacements for current BDS methods, whether they will be modified and then recommended for BDS, or whether they will be offered as potential improvements that require further verification and peer review.

Although the final form of the ATC-32 concrete design recommendations is still under review, it is generally agreed that the subcontractor's proposals result in many desirable trends for design. Although the proposed "Q" factors will result in higher seismic design forces, the requirement for more longitudinal column reinforcement will be mitigated somewhat by the use of probable rather than nominal material strengths in column flexural design. Confinement requirements are increased, however. Column shear design forces and foundation design forces will also be increased through the use of higher multiplication factors for determining probable plastic hinging moments to be used in capacity design.

A method for determining shear capacity that is based on contributions from concrete, reinforcing steel and axial load has been proposed. In addition to direct consideration of axial load, this method considers the degrading effect of plastic hinging on the concrete contribution to shear strength and assumes a steeper shear crack angle which mobilizes more transverse reinforcement. Although laboratory test results and post-earthquake observations tend to support this method of determining shear strength, the form of this approach is novel and may require further trial use and peer review before it is adopted for widespread use in design.

Another subject area of major concern with respect to reinforced concrete design is the development of reinforcing steel. Prior to the 1989 earthquake, Caltrans was using reinforcement development provisions from the 1983 American Association of State Highway and Transportation Officials (AASHTO) Standard Specifications for Highway Bridges which were felt by some to be unconservative. After the earthquake the provisions of the American Concrete Institute (ACI) were adopted as an interim measure. However, the current ACI design specifications were written primarily with buildings in mind and are very restrictive with respect to large diameter bars which are common in many bridges. Based on recent research, the ATC-32 guidelines are attempting to develop new provisions which overcome the problems with both the AASHTO and ACI methods.

In addition to reviewing and modifying provisions currently used by Caltrans for concrete design, ATC-32 will also add new provisions in subject areas related to ductile design for which the current BDS is silent. This includes design procedures for shear and bending within footing and superstructure joints, flexural yielding of bent caps and superstructures near columns, and torsion within columns, knee joints, and bent caps. Caltrans has been using interim measures for these areas of design on a project-by-project basis since the 1989 earthquake, but a comprehensive guideline that can be universally applied is badly needed.

General

It is expected that the draft BDS, which also includes provisions for the design of steel bridges, will be expanded and modified as the project progresses. The draft BDS will be used by Caltrans, ATC and two project subcontractors for trial designs. The trial design process should reveal flaws in the draft code that can be corrected before final recommendations for changes are made to Caltrans.

Possible future phases of the project are contingent on additional funding, but may deal with design issues not addressed by the current project as well as the issue of seismic retrofitting.

CONCLUSION

The ATC-32 project seeks to develop a comprehensive seismic design criteria for bridges that reflects input from many highly qualified people. The goal is to achieve a consensus among these people and thus provide the design community with a stable criteria that can be applied uniformly to all bridges in California.

In recent months the project has experienced some administrative delays and the final completion date of the project has also been delayed. Coincidentally, the Northridge earthquake occurred during this time period resulting in several highway bridge failures including partially retrofitted bridges and two bridges designed after 1971. It is likely that this earthquake will rival both the San Fernando and Loma Prieta earthquakes for its impact on bridge design. It is therefore appropriate that the current ATC-32 recommendations be reevaluated in light of experience gained during this earthquake. This reevaluation will undoubtedly affect the final outcome and timing of the ATC-32 project.

TABLE 1—SEISMIC PERFORMANCE CRITERIA

Ground Motion at Site	***Ordinary Bridge Category***	***Important Bridge Category***
Functional Evaluation	*Service Level-Immediate 'Repairable' Damage*	*Service Level-Immediate 'Minimal' Damage*
Safety Evaluation	*Service Level-Limited 'Significant' Damage*	*Service Level-Immediate 'Repairable' Damage*

DEFINITIONS

Service Level

Immediate: Full access to normal traffic available almost immediately.
Limited: Limited access possible within days (i.e. reduced lanes, light emergency traffic). Full service restorable within months.

Damage

Minimal: Essentially elastic performance.
Repairable: Damage that can be repaired without closure.
Significant: No collapse, but damage that may require closure to repair.

Important Bridge

One or more of the following:

- Bridge required to provide secondary life safety. (Example: access to emergency facility)
- Loss of bridge creates major economic impact
- Bridge formally identified by a local emergency plan as critical

TABLE 2—MINIMUM REQUIRED ANALYSIS

Bridge Category	Configuration Type	Functional Evaluation	Safety Evaluation
Ordinary	Type I	None Required	A
	Type II	None Required	B
Important	Type I	A	A
	Type II	B	B and C

A = Equivalent Static Analysis
B = Elastic Dynamic Analysis
C = Inelastic Static Analysis

Type I Configuration: Bridge with continuous superstructure, well balanced spans and supporting bents with approximately equal stiffness.

Type II Configuration: Bridge with intermediate superstructure hinges, irregular configuration, bents of nonuniform stiffness, or significant skew.

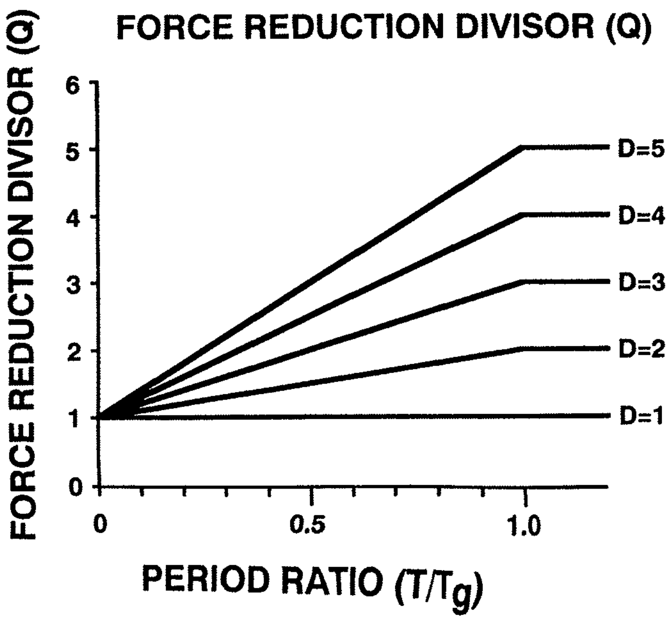

Fig. 1—Force reduction divisor Q

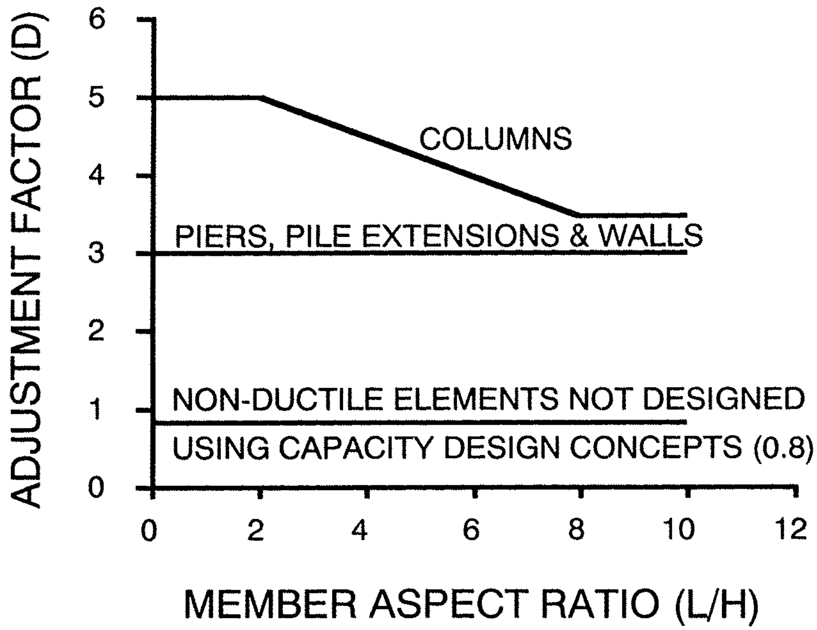

Fig. 2—Allowable values for *D*

SP 160-8

Column Seismic Retrofitting Using High-Strength Fiber Jackets

by Edward R. Fyfe

Synopsis: In 1987, testing began on a concept to use High Strength Fibers to retrofit columns to increase strength and ductility. The tests were completed on fourteen columns at the University of California, San Diego. Columns were tested for confining the lap-splice flexural areas for circular and rectangular columns with increased strength and ductilities in testing of 8 or more. Columns were tested for shear-flexural performance (with no lap-splice) with tested increased strength and ductilities of 8 or more. The rectangular columns were wrapped in the shape of the rectangle successfully. The University of British Columbia in Vancouver used the wrap system for columns and pier cap retrofit and obtained a ductility of 12. Thirty-two field installations as of October, 1994, have now been completed. Design recommendations and durability testing has been completed.

Keywords: Ductility; earthquake-resistant structures; fibers; field tests; glass; reinforcing materials; stiffness; strength; tests

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INTRODUCTION

This paper summarizes testing carried out on the High Strength Fibrwrap System, repair technics developed, and installations in the field.

The High Strength Fiber System is a method of wrapping a high strength fiber composite with an epoxy matrix to field fit the composite to columns on bridges, buildings and many other structures. The system was conceived and testing started in 1987 to meet the initial need by the Department of Transportation, California to improve the strength and ductility of the California bridge columns.

Fourteen large scale columns, 2-3 feet in section and 8-10 feet high were tested at the Powell Engineering Laboratory at the University of California, San Diego.

Three circular and two rectangular columns were tested for confining the lap splices in the vertical reinforcing steel at the bottom flexural area of the columns (prior to 1973, single column bents on bridges in California had these lapsplice conditions). The glass-polyaramide-epoxy composite was wrapped around bladders (thin elastomeric bag wrapped around the column) and stressed by injecting cement grout into the bladders. The rectangular columns were made elliptical. The testing result was increased strength and tested ductilities of over 8 with no increase in stiffness.

Two circular and two rectangular columns were tested in double bending for shear-flexural (no lap) splice conditions. The columns were simply wrapped with no stressing. Significantly, the rectangular columns were wrapped in the rectangular shape with the corners only bevelled 3/8" by 3/8" (steel jackets need to be elliptical to be effective). The test results were increased strength and ductilities of over 8 with no increase in stiffness. A rectangular column with 6% vertical reinforcing steel was also tested with, again, excellent results (1).

A circular column that had been tested without a jacket and was severely cracked and spalled at 0.5 inch displacement, was repaired and wrapped with the Fibrwrap System. On retest, the column was displaced to 5.0 inches and a displacement ductility of 10. No column failure occured at ductility 10, and when the Fibrwrap jacket was removed, no cracking or spalling was observed. This test showed that damaged columns can be repaired and retrofitted to increased strength and obtain ductilities of 10 or more. The actual test ductilities with Fibrwrap are in appendix 1.

Additional testing of a three column bent with a pier cap at the top of the column was carried out in 1994 at the University of British Columbia in Vancouver (2). The test was a half scale of the actual Oak Street Bridge in Vancouver, British Columbia, Canada. The columns and pier caps are inadequate in strength and ductility. The columns and the pier caps were wrapped. The areas at the bearing seats and pier cap ends were not wrapped. The test was a success with ductility of 12 achieved without failure.

Testing of the Hexcel Fyfe Co. pre-fabricated system, where the composite is manufactured in two halves, and bonded in the field with cement grout to fill the void between the system and the column, were completed at Penn State University in 1992 (3). The system increases strength and ductility but is not as effective as wrapping. Long term testing on the joint connections need to be done before the system should be considered a candidate solution for field projects.

Testing has now been carried out on wall systems. Provided the walls are reinforced concrete block, the testing has demonstrated that with the proper fiber configuration, strength and ductility can be achieved. A five story building was tested to a 2.0 percent drift angle after Fibrwrap was applied to the lower 2 floors. A recent miniwall test showed that application of the fiber to one side of the wall can be effective. The fiber selection must provide for coefficient of expansion effects because the wall system depends on bond. Anchorage at wall ends, window, and other areas, depending on the materials, is necessary with the wall system.

Tests have been completed to demonstrate ability of the Fibrwrap System to expand when steel corrosion causes expansion of the columns. The system is used in applications where corrosion has caused cracking and spalling.

Testing is underway on concrete and wooden beams, beam column connections, and unreinforced masonry and brick walls.

The testing has developed a new engineering tool to use a composite to increase strength and ductility of columns without increasing stiffness. The system has many advantages over steel or concrete jackets, such as speed and ease of installation. The system, if field fitted, can be used in tight spaces between columns, drains, or walls.

The durability of the exact Fibrwrap System has been confirmed by tests. One thousand hour testing for ozone, 140^{o}F., water, salt water, alkaline soil and ultra violet showed no significant loss of strength. Effervescence, cold temperature, and freeze thaw testing have also been completed showing durable properties. Temperatures to -40^{o} showed no failure modes.

In 1991, the first installation was on 15 columns on three bridge ramps, at Highway 2 and 5 for the Department of Transportation, California. The columns are six feet in diameter and ranged from 18 to 55 feet high. The site was fifteen miles from Northridge and showed no adverse effects to the 1994 Northridge earthquake. Some early problems with the bladder concept were resolved during the project.

In late 1991 - early 1992, ninety-six columns were retrofitted on a I-80 bridge at Sparks, Nevada. The Nugget Hotel casino was built under half the bridge and fourty-eight columns were wrapped in the casino (two columns were in the bar fish aquarium). The feature of wrapping in the small gap between the columns and roof saved the contractor from cutting into the roof.

In November 1993, the Fibrwrap System was used to retrofit fourty-two columns in the lower parking of the Nikko Hotel in Los Angeles which were damaged in the June 1992 Landers earthquake. In the January 1994 Northridge earthquake, the system was tested and