ened. This 7200-ft (2195-m) bridge will carry five lanes of northbound traffic and the older, widened bridge will carry the southbound lanes. Design alternative studies were completed by four separate consulting firms to determine the two most competitive. Studies were conducted for a structural steel truss, similar to the existing bridge, a structural steel box girder, a concrete and steel cable stayed bridge, and a structural lightweight concrete segmental box girder bridge. The structural steel truss and the structural lightweight concrete segmental box girder bridge were the two most competitive designs. Confirming cost estimates were conducted by a fifth, cost estimating specialty consulting firm to remove any doubt from the comparisons.

Caltrans had planned to have two alternatives designed and bids taken for both, with the lowest bid accepted. Each bridge is composed of a series of 528 spans supported on normal weight piers ranging up to 250 ft (76.2 m) from bedrock to deck. Structural lightweight concrete will be used for the decks and superstructure on both alternatives, with polyester concrete overlay wearing surfaces. In 1996 the decision was made to complete design of only the structural lightweight concrete alternative, after bids on some nearby structural steel bridges showed that material not to be competitive with concrete in this region.

Structural Lightweight Concrete Research

Concerns over the shear strength and ductile performance of structural lightweight concrete in a seismic event prompted the Department to initiate a research project at the University of California at San Diego. The project is being conducted at the Charles Lee Powell Structures Laboratory under the supervision of Professor Nigel M. J. Priestley, who has conducted much of the Caltrans' seismic research for concrete members. This lightweight concrete testing program is being conducted in three phases; first to determine the shear strength of structural lightweight concrete, second to investigate the flexural strength and ductility, and third to investigate the dynamic behavior of structural lightweight concrete. Only the results of the fist two phases are available now.

The importance of assessing the shear strength of structural lightweight concrete lies in the undesirable characteristics of a shear failure. Since structural engineers try to provide adequate protection against shear failure in the design of any reinforced concrete member, it is important to accurately evaluate the shear strength of the material. Two structural lightweight concrete bridge column test specimens were built and tested.

While Caltrans has not used structural lightweight concrete in bridge columns or other supporting elements it was important to determine the flexural strength and ductility of columns designed with the concrete. This second series of tests was completed in late 1996. Three columns were constructed and tested, two with lightweight concrete and one with normal weight concrete for comparison.

Based on this work it is suggested that the initial cracked section stiffness of a lightweight concrete member can be conservatively reduced by 15% from the stiffness of a normal weight concrete column. This would result in an increase in elastic displacements in a moderate earthquake. For design for the ultimate limit state the reduced stiffness would not play a role. However, the use of force-based design would likely result in an inaccurate estimate of displacement. Therefore, the use of direct displacement-based design is recommended.

Based on these tests it can be concluded that the hysteretic damping of structural lightweight concrete is essentially the same as for normal weight concrete. For direct displacement-based design, damping relations for normal weight concrete can be applied without modification for lightweight concrete. Analysis of these test results indicate that the ultimate concrete compression strain is not affected by the type of concrete, and that estimates of displacement capacity with the same degree of conservatism as for normal weight concrete can be obtained for lightweight concrete.

Closing Remarks

The results to date indicate that structural lightweight concrete using expanded shale aggregate is a viable alternative, especially where dead load is a design consideration. It can be used in columns with dependable, predictable behavior in seismic zones.

Caltrans intends to continue the use of structural lightweight concrete in whatever applications prove to be cost effective. Research will continue on material performance in high seismic zones. Current policy will be updated to encourage the expanded use of the aggregate.

Tests performed at UCSD on structural lightweight concrete bridge columns indicate that the non-ductile shear strength of the concrete is not significantly altered. However, ductile shear strength appears to be lower based on strain levels in the transverse steel as well as observations on aggregate cracking. More detailed analyses are underway to develop design recommendations for structural lightweight concrete. Until this work is completed Caltrans will continue to use structural lightweight concrete only in the superstructures, and normal weight concrete in the substructures because of the need to design for ductile performance in the columns during a seismic event.

Reinforcing Bar Specifications — 1911 through 1968

by Gustav G. Erlemann, Consultant, Jeffersonville, NY

Investigating the feasibility of rehabilitating a reinforced concrete building constructed 60, 70 or more years ago requires a complete structural analysis in order to determine the present day load capacity of the structure. That capacity is determined by the strength of two materials, concrete and steel. Random drilled cores taken from the old building will give the present strength of the concrete with a great deal of accuracy, but how to determine the strength of the imbedded reinforcing bars?

It would be extremely expensive and destructive to obtain sufficient samples of different bar sizes in order to test the bars. The original architectural and engineering plans, if available, could provide data pertaining to bar sizes, spacings, cover and typical details, but would not necessarily specify the grade of steel. The question thus is what type and grade of steel was typically manufactured and furnished during the period the building was constructed.

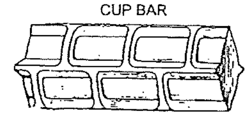
During the period 1900 to 1930, steel was produced mainly by the open hearth furnace process, using a combination of pig iron, iron ore and steel scrap as the raw material. Some steel was produced using the Bessemer process, and a small percentage by electric furnace. In comparison, today's reinforcing bars are produced almost exclusively by electric furnace with steel scrap as the raw material.

The first *Standard Specification for Billet Steel Concrete Reinforcement Bars* was adopted by ASTM in 1911, revised in 1914, designated A 15. The A 15 specification had three classes of bars: plain, deformed, and cold-twisted. The plain and deformed bars were specified in three grades: structural, intermediate and hard. Cold-twisted bars conformed to structural grade only. Section 2 (a) of A 15 stated "the basis of purchase shall be *structural grade* unless otherwise noted."

COLD TWISTED SQUARE BARS

DEFORMED BARS

CUP BAR



The tensile properties conformed to the following:

	Structural	Intermediate	Hard	Cold-twisted
Yield min., psi (MPa)	33,000 (228)	40,000 (276)	50,000 (345)	55,000 (379)
Tensile, psi (MPa)	55,000 (379) to 70,000 (483)	70,000 (483) to 85,000 (586)	55,000 (379) min.	n/a

Deformations were not standard, and in fact very dissimilar compared to present markings. Most were patented and particular to the producing mill, and were labeled *cup*, *corrugated*, *lug*, *herringbone*, or by the name of the inventor, such as *Havemeyer*, *Elcannes*, *Scofield*, or *Thacher*. Bar sizes were also not standard, with each manufacturer publishing a list of sizes available from that mill. Shapes were round, square, oval, flat with either raised *lugs* or depressed *dimples*. A conservative estimate of the steel grade of the reinforcing bars furnished for a concrete structure built between 1910 and the mid 1920's would be *structural grade*.

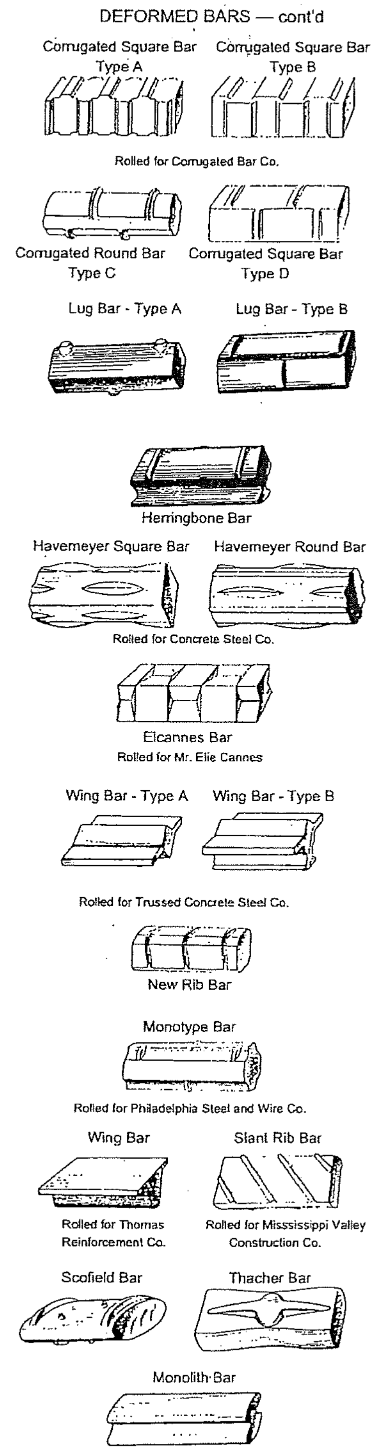
Effective January 1, 1928, the U.S. Department of Commerce recommended that the "Standard" for new billet reinforcing bars be *intermediate grade*. In effect, this suggested not specifying structural grade reinforcing bar. It is interesting to note that in 1928, A 15-14 was still in effect. During the decade of the 1920's, the producing mills standardized reinforcing bar to: 1/4 in. (6 mm) rd; 1/2 in. (13 mm) rd; 1/2 in. (13 mm) sq; 5/8 in. (16 mm) rd; 3/4 in. (19 mm) rd; 7/8 in. (22 mm) rd; 1 in. (25 mm) sq; 1-1/8 in. (29 mm) sq; 1-1/4 in. (32 mm) sq; 1-1/2 in. (38 mm) sq; and 2 in. (51 mm) sq. During the same decade, each mill developed its own deformation or brand pattern with a quality mark "N" for new billet, plus a letter or symbol designating the producing mill. Thus, intermediate grade new billet reinforcing bar became typical into the 1930's through the 1940's As a historical note, the 1/2 in. (13 mm) sq size was eliminated in 1942 as a war emergency measure.

In 1950, ASTM revised the specifications pertaining to new billet reinforcing bars. ASTM A 15-50T changed all reinforcing bars to round, designated #3 (10 mm diameter) through #11 (35 mm diameter), replacing 3/8 in. (10 mm) rd through 1-1/4 in. (32 mm) sq. #2 or 1/4 in. (6 mm) rd was not classified as deformed, and was available only as plain round. However, A 15-50T still listed plain and deformed reinforcing bar with the same three grades: structural, intermediate and hard. At the same time, ASTM issued *Tentative Specifications for the Deformations of Deformed Steel Bars for Concrete Reinforcement*, designated A 305-50T. A 305 required minimum deformation heights, a maximum angle of the deformations with respect to the bar axis, deformation spacings per foot, and the overall length of the deformations.

It was not until 1964 that ASTM A 408, *Special Deformed Round Bars*, namely #14S (44 mm diameter) and #18S (57 mm diameter), originally 1-1/2 in. (38 mm) sq and 2 in. (51 mm) sq, now round with the same cross-sectional area, became available in the same grades as A 15. In the same year (1964), ASTM adopted two higher strength grades of reinforcing steel: A 432-64, yield 60,000 psi (414 MPa) min., tensile 90,000 psi (621 MPa) min., and A 431-64, yield 75,000 psi (517 MPa) min., tensile 100,000 psi (690 MPa) min., for sizes #3 (10 mm diameter) through #18S (57 mm diameter).

Finally, in 1968, ASTM adopted A 615-68 titled *Standard Specifications for Deformed Billet Steel Bars for Concrete Reinforcement*. A 615 incorporated previous A 15, A 305, A 408, A 431, and A 432 into one specification, and also eliminated structural grade steel and plain round reinforcing bar, listing three grades: Gr 40 (276 MPa yield strength) and Gr 60 (414 MPa yield strength) in sizes #3 (10 mm diameter) through #18 (57 mm diameter) and Gr 75 (517 MPa yield strength) in sizes #11 (35 mm diameter), #14 (44 mm diameter), and #18 (57 mm diameter) only.

In conclusion, it is reasonable to assume that a reinforced concrete structure built in the period 1910 through 1927 was reinforced with structural grade (Gr 33 or 228 MPa yield strength) deformed reinforcing bars, and from 1928 through 1963 with intermediate grade (Gr 40 or 276 MPa yield strength) deformed reinforcing bars. Of course, during these same periods higher strength steel reinforcing bars were available and may have been used or specified for a particular project; however, unless specific data are available regarding the grade of the material supplied to that project, conservative judgment would use the foregoing values of the grade of steel when evaluating an "elderly" structure.



Publisher's Note

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Our purpose is to disseminate information related to the uses of concrete in engineered structures. If there are topics or ideas you would like to have discussed in future issues, please let us know. Items from this newsletter may be reprinted without prior permission.

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