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EVALUATION OF REINFORCING BARS IN OLD REINFORCED CONCRETE STRUCTURES

A SERVICE OF THE CONCRETE REINFORCING STEEL INSTITUTE

INTRODUCTION

Most practicing structural engineers sooner or later face the task of evaluating old structures. This task is always an interesting challenge, because it is never a routine application of the current practice in design. Owners commonly require re-evaluation when planning a change in building usage, restoration, additional stories, or lateral additions in any combination. Frequently, the original contract documents, the "as-built" revisions, and so on, cannot be found.

The structural engineering challenge is two-fold. First, the material properties must be determined for the concrete. The concrete can and usually does gain 25 percent or more strength than it had at 28 days, but the concrete can also have deteriorated under fire or chemical exposures. The second challenge concerns the reinforcing bars — determining the yield strength, the bar sizes and their cross-sectional areas, the locations of the bars, effective depths of structural members, the bending and cut-off details of the bars, and development lengths (bond and anchorage).

Where documentation is lacking for the existing structure, the following abbreviated history of reinforcing bars may be a useful starting point.

Reference 1 is an excellent presentation on the history of reinforced concrete. Included in the article are illustrations of a variety of patented reinforcing bars, and an extensive list of references regarding codes, design and construction, and reports on landmark tests.

REINFORCING BARS — SPECIFICATIONS, BAR SIZES AND ALLOWABLE STRESSES

Specifications. Reinforcing bars, as we know them today, came about in 1900. Specifications were first developed by the Association of American Steel Manufacturers in 1910. The American Society for Testing and Materials (ASTM) adopted standard specification A15 for billet-steel concrete reinforcing bars in 1911. Reinforcing bars were plain and deformed in structural, intermediate and hard grades (minimum yield strengths), or deformed, cold-twisted. Structural grade (minimum f_y = 33,000 psi) was normally used, unless otherwise specified. The specified minimum yield strengths of structural, intermediate, and hard grades were 33,000, 40,000, and 50,000 psi, respectively. The minimum yield strength of cold twisted bars was specified at 55,000 psi.

ASTM also issued similar specifications for rail-steel (A16) and axle-steel (A160) reinforcing bars. The minimum yield strength for rail-steel bars was 50,000 psi, and for axle-steel bars the same as for billet steel bars.

Table 1 summarizes the ASTM specifications for reinforcing bars from 1911 to the present.

Bar Sizes. Table 2 shows the standard reinforcing bar sizes recommended by the Joint Committee on Standard Specifications for Concrete and Reinforced Concrete in its 1924 Report (Reference 2).

Allowable Stresses. Some early authorities stated that allowable stresses in tension in the reinforcement higher than 12,000 psi show "very little to be gained in economy" and recommended a maximum of 14,000 psi (Reference 3). Recommended allowable stresses in tension in the 1924 Joint Committee Report (Reference 2) were:

- 16,000 psi for structural grade and rail-steel bars
- 18,000 psi for intermediate and hard grade bars and twisted bars.

In its 1940 Report, the Joint Committee increased its recommended allowable stresses to:

Tension

- 18,000 psi for structural grade bars
- 20,000 psi for intermediate and hard grades or rail-steel bars
- 16,000 psi for all web reinforcement

Compression

- 16,000 psi for intermediate grade bars
- 20,000 psi for hard grade or rail-steel bars

Table 1—Reinforcing Bars 1911 to Present; ASTM Specifications; Minimum Yield and Tensile Strengths in psi

ASTM Spec	Years		Steel Type	Grade 33 (Structural)		Grade 40 (Intermediate)		Grade 50 (Hard)		Grade 60		Grade 75	
	Start	End		Min. Yield	Min. Tensile	Min. Yield	Min. Tensile	Min. Yield	Min. Tensile	Min. Yield	Min. Tensile	Min. Yield	Min. Tensile
A15	1911	1966	Billet	33,000	55,000	40,000	70,000	50,000	80,000				
A408	1957	1966	Billet	33,000	55,000	40,000	70,000	50,000	80,000				
A432	1959	1966	Billet							60,000	90,000		
A431	1959	1966	Billet									75,000	100,000
A615	1968	1972	Billet			40,000	70,000			60,000	90,000	75,000	100,000
A615	1974	1986	Billet			40,000	70,000			60,000	90,000		
A615	1987	Present	Billet			40,000	70,000			60,000	90,000	75,000	100,000
A16	1913	1966	Rail					50,000	80,000				
A61	1963	1966	Rail							60,000	90,000		
A616	1968	1999	Rail					50,000	80,000	60,000	90,000		
A160	1936	1964	Axle	33,000	55,000	40,000	70,000	50,000	80,000				
A160	1965	1966	Axle	33,000	55,000	40,000	70,000	50,000	80,000	60,000	90,000		
A617	1968	1999	Axle			40,000	70,000			60,000	90,000		
A996	2000	Present	Rail, Axle			40,000	70,000	50,000	80,000	60,000	90,000		
A706	1974	Present	Low-Alloy							60,000	80,000		
A955M	1996	Present	Stainless			40,000	70,000			60,000	90,000	75,000	100,000

BOND AND ANCHORAGE

After establishing the yield strength of the reinforcing bars, the next important property required for evaluation of old structures concerns bond and anchorage. Steel mills in the USA completed conversion of their production to "high-bond" deformations about 1947, which continue virtually unchanged to the present day. In 1947, ASTM issued a specification, designated as A305, which prescribed requirements for deformations on reinforcing bars. The A305 specification existed from 1947 to 1968. In 1968, the requirements for deformations were merged into the specifications for reinforcing bars—A615 (billet-steel), A616 (rail-steel), and A617 (axle-steel).

For older structures, it is prudent to consider all varieties of reinforcing bars—plain round, old-style deformed, twisted square, and so on—conservatively and simply as 50 percent as effective in bond and anchorage as current bars. In other words, the tension development lengths, ℓ_d, for the old bars would be twice (double) the ℓ_d required for modern reinforcing bars. Since most strength design reviews for flexure will be based on a yield strength, f_y = 33,000 psi instead of today's 60,000 psi, the tension development lengths for the old bars can be determined by adding 10 percent to any current table of tension development lengths, ℓ_d, for modern reinforcing bars. The main deficiencies encountered in old structures will be in tension lap splice lengths provided for bars larger than #6, and typical details with top bars larger than #6 cut off at 0.25 times clear span.

Standard end hooks, 90° or usually 180°, on old-style bars in earlier codes were considered to develop half the allowable tension stress. Under today's strength design method, this value would approximate $\phi f_y/2$ = (0.90)(33,000 psi)/2 ≈ 15,000 psi.

DETAILS OF REINFORCING BARS

Flexural Members. For structures built during the period 1900 to 1940, design standards and accompanying typical details of reinforcing bars evolved gradually, beginning with a bewildering variety of patented systems. Where design drawings or project specifications are not available, and no clue remains to the system used, caution is particularly prudent. Many of the older patented systems would be considered much less effective today—some were theoretically sound and went out of style because of high costs, but others were based upon theory not acceptable today. In two-way slabs, do ***not*** assume that there was only two-way reinforcement. Especially, if the topmost layer is disappointingly light, it may be part of a *four-way* system, with four layers instead of two. Look for diagonal bands of bars.

Where original design drawings are not available, typical details for reinforcing bars as shown in ACI Detailing Manuals (Reference 4) were commonly used since 1947. These typical details can be assumed and used for initial calculations if original service loads are known. In any case, these calculations should be confirmed or modified as soon as data on bar sizes, bar spacings, and effective depths of structural members can be checked in the field.

Particularly for flexural members, load tests are especially convincing when used to check calculated capacity based upon material tests and reconstituted placing drawings. In particular, even non-destructive load tests can thus be used to validate calculated deflections before and after cracking. (Reference 5).

Columns. Non-destructive surface tests should be employed at numerous locations to evaluate the concrete. If it is necessary, column concrete cover can be removed to observe vertical bar sizes, splice details, ties or spirals, etc., and replaced with little or no impairment of the structural capacity. Load tests on columns are generally not feasible, and so evaluation of column strength must be analytical. Even cutting out sample test cores to determine concrete strength is not generally advisable, since vertical reinforcing bars may be damaged and replacing removed concrete is not likely to be effective.

Under present codes, the contribution of spiral reinforcement to column capacity is considerably less than under old codes. In a present day evaluation, therefore, spiral columns, especially square or rectangular, are more likely to limit the total capacity than tied columns.

Locating Reinforcing Bars. Instruments now available permit the user to locate and follow individual reinforcing bars inside concrete slabs or beams. Some give accurate indications for the depth of concrete cover and even relative size of bar. Again, it is desirable to calibrate such readings by exposing the bars at some non-critical locations. These readings are particularly valuable in re-constructing the design details—bend points, cut-off points, and bar spacings—at least for the outside layers of bars.

CONCRETE PROPERTIES

The present day concrete properties in place should be determined by tests. Even if original project specifications are available, the specified concrete compressive strength, f'_c, is not a reliable value years later. Evaluation of present in-place concrete strength may be demonstrated by several more or less non-destructive methods. The ASTM standard test methods are:

(a) Test of cast-in-place cylinders, ASTM C873 (limited to use in slabs)

(b) Pulse velocity testing, ASTM C597

(c) Rebound number, ASTM C805

(d) Penetration resistance, ASTM C803

(e) Pullout strength, ASTM C900

It should be noted that all these methods require correlation with strength tests on drilled cores. The measurements of these various properties of concrete are ***related*** to compressive strength, tensile strength, or modulus of elasticity which can be converted to compressive strength of standard cylinders for design strength. Even instruments purporting to read "psi" or with "conversions provided" must be calibrated with the tests on cores from the actual concrete in question.

Table 2—Standard* Reinforcing Bar Sizes (1924)

Size, in.	Area, in.[2]	
	Round	Square
	**	†
3/8	0.11	–
1/2	0.20	0.25
5/8	0.31	–
3/4	0.44	–
7/8	0.60	–
1	0.79	1.00
1-1/8	–	1.27
1-1/4	–	1.56

* Recommended by the Joint Committee on Standard Specifications for Concrete and Reinforced Concrete in its 1924 Report.

** Most suppliers offered a ¼-inch round bar, as well as the recommended standard sizes.

† The ¼-inch square bar was used, but to a lesser extent. Square bars were usually deformed, or if plain in structural grade, twisted to enhance bond and yield strength properties.

1. Round bars were plain or deformed.

2. A number of producers offered additional sizes, in 1/16-inch increments, prior to adoption of this reduced list of standard sizes.

SELECTED REFERENCES

1. "Reinforced Concrete at the Turn of the Century", by Robert E. Loov, *ACI Concrete International*, December 1991, pp. 67-73.

2. "Recommended Practice and Standard Specifications for Concrete and Reinforced Concrete" by Joint Committee on Standard Specifications for Concrete and Reinforced Concrete; the committee was composed of representatives of ACI, AIA, AREA, ASCE, ASTM and PCA. Reports were published in 1916, 1924 and 1940.

3. *Principles of Reinforced Concrete Construction*, by F. E. Turneaure and E. R. Maurer, John Wiley & Sons, New York, 1908.

4. ACI Detailing Manual for Buildings, 1947, ACI Committee 315, and Detailing Manual, 1957, 1965, 1974, 1980 . . .

5. "Full-Scale Load Testing of Structures", STP-702, ASTM, 1980 (Symposium Collection).

OTHER RESOURCES

ACI Building Codes, 1928, 1936, 1941, 1947, 1951, 1956, 1963, 1971, 1977 . . .

"Strength Evaluation of Existing Structures", Chapter 20, ACI 318-77, ACI 318-83, ACI 318-89 . . .

"Application of ACI 318 Load Test Requirements", by R. C. Elstner, D. P. Gustafson, J. M. Hanson and P. F. Rice, CRSI *Professional Members' Bulletin*, No. 16, 1987, CRSI, 11 pp.

"Strength Evaluation of Existing Concrete Buildings (ACI 437R-91)", by ACI Committee 437, 24 pp.

This report No. 48 replaces EDR No. 11.

SOFT METRIC REINFORCING BARS

While the focus of this report is on the past, it is important for readers of this document to be aware of current industry practice regarding soft metric reinforcing bars. The term "soft metric" is used in the context of bar sizes and bar size designations. "Soft metric conversion" means describing the nominal dimensions of inch-pound reinforcing bars in terms of metric units, but not physically changing the bar sizes. In 1997, producers of reinforcing bars (the steel mills) began to phase in the production of soft metric bars. Within a few years, the shift to exclusive production of soft metric reinforcing bars was essentially achieved. Virtually all reinforcing bars currently produced in the USA are soft metric. The steel mills' initiative of soft metric conversion enables the industry to furnish the same reinforcing bars to inch-pound construction projects as well as to metric construction projects, and eliminates the need for the steel mills and fabricators to maintain a dual inventory. Thus, USA-produced reinforcing bars furnished to any construction project most likely will be soft metric.

Designations of Bar Sizes. The sizes of soft metric reinforcing bars are physically the same as the corresponding sizes of inch-pound bars. Soft metric bar sizes, which are designated #10, #13, #16, and so on, correspond to inch-pound bar sizes #3, #4, #5, and so on. The metric bar designations are simply a re-labeling of the inch-pound bar designations. The following table shows the one-to-one correspondence of the soft metric bar sizes to the inch-pound bar sizes.

Soft Metric Bar Sizes vs. Inch-Pound Bar Sizes

Soft Metric Bar Size Designation	Inch-Pound Bar Size Designation
#10	#3
#13	#4
#16	#5
#19	#6
#22	#7
#25	#8
#29	#9
#32	#10
#36	#11
#43	#14
#57	#18

Minimum Yield Strengths or Grades. Virtually all steel mills in the USA are currently producing reinforcing bars to meet the metric requirements for tensile properties in the ASTM specifications. Minimum yield strengths in metric units are 300, 350, 420 and 520 MPa (megapascals), which are equivalent to 40,000, 50,000, 60,000 and 75,000 psi, respectively. Metric Grade 420 is the counterpart of standard Grade 60.

Bar Marking. Soft metric reinforcing bars are required to be identified with the Producer's mill designation, bar size, type of steel, and minimum yield strength or grade. For example, consider the marking requirements for a #25, Grade 420 metric bar, which is the counterpart of an inch-pound #8, Grade 60 bar. Regarding the bar size and grade, the ASTM specifications require the number "25" to be rolled onto the surface of the metric bar to indicate its size. For identifying or designating the yield strength or grade, the ASTM specifications provide an option. A mill can choose to roll a "4" (the first digit in the grade number) onto the bar, or roll an additional longitudinal rib or grade line to indicate Grade 420.

The 27th Edition of the CRSI *Manual of Standard Practice* was published in March 2001. Chapter 1 in the Manual includes a detailed presentation of the inch-pound and metric requirements in the ASTM specifications for reinforcing bars. Appendix A in the Manual shows the bar marks used by USA producers to identify Grade 420 soft metric bars.

More information about soft metric reinforcing bars is also provided in Engineering Data Report No. 42, "Using Soft Metric Reinforcing Bars in Non-Metric Construction Projects". EDR No. 42 can be found on CRSI's Website at **www.crsi.org**.

Readers of this report are also encouraged to visit the CRSI Website for:

- Descriptions of CRSI publications and software, and ordering information
- Institute documents available for downloading
- Technical information on epoxy-coated reinforcing bars
- Technical information on continuously reinforced concrete pavement
- Membership in CRSI and member web links
- General information on the CRSI Foundation
- Information on the CRSI Design Awards competition

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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.

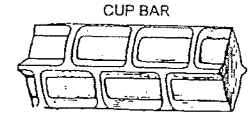
During the period 1900 to 1930, steel was produced mainly by the open hearth furnace process, using a combination of pig iron, iron ore and steel scrap as the raw material. Some steel was produced using the Bessemer process, and a small percentage by electric furnace. In comparison, today's reinforcing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

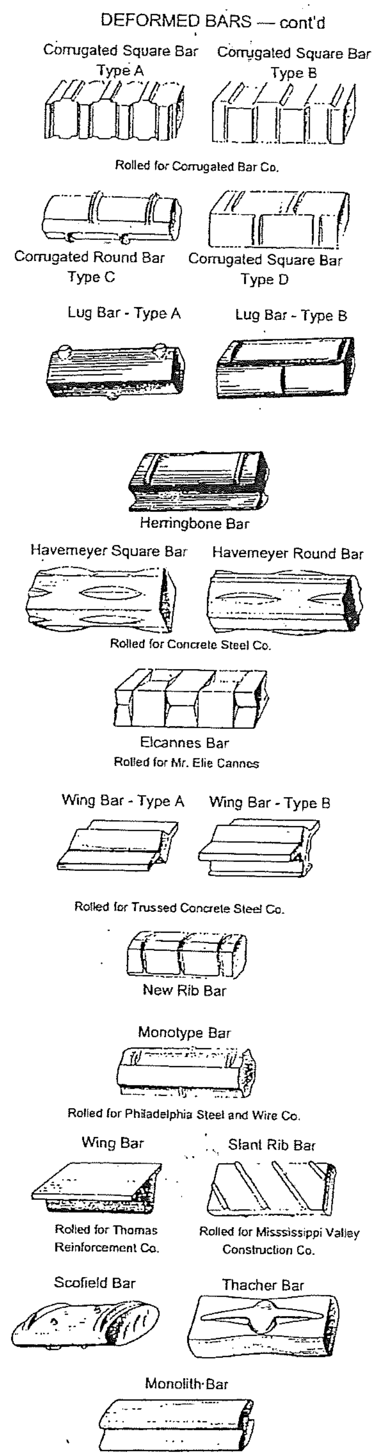
Effective January 1, 1928, the U.S. Department of Commerce recommended that the "Standard" for new billet reinforcing bars be *intermediate grade*. In effect, this suggested not specifying structural grade reinforcing bar. It is interesting to note that in 1928, A 15-14 was still in effect. During the 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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