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# Compression Testing of Concrete: Cylinders vs. Cubes

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# COMPRESSION TESTING OF CONCRETE: CYLINDERS VS. CUBES

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## ABSTRACT

Concrete cylinder and cube specimens for compression testing were compared through a survey of past research, including testing procedures, factors affecting the cylinder/cube strength ratio, and conversion factors and equations. The main difference between cylinder and cube testing procedures is capping. Cylinder ends are usually not plane or parallel enough to mate properly with platens of compression testing machines, and thus must be capped with sulphur, neoprene, or other suitable material for proper distribution of the applied load. Cubes, however, are not capped but cast in rigid molds with sides that are plane and parallel. When tested, they are flipped on their sides so that machine platens mate properly with cube surfaces. Factors affecting the cylinder/cube strength ratio are 1) casting, curing, and testing procedure; 2) specimen geometry; 3) level of strength; 4) direction of loading and machine characteristics; and 5) aggregate grading. Past efforts to determine empirical conversion relationships and conversion factors have shown that it is difficult (if not impossible) to predict relationships between cylinder and cube strengths. Past research has also shown the cylinder/cube strength ratio to be between about 0.65 and 0.90, although ratios outside that range have also been observed. Based on this survey of past research, replacing cylinder testing with cube testing is not recommended.

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# I. INTRODUCTION

## A. Background

Concrete strength in structures is typically estimated by casting smaller specimens from the same concrete and crushing them in the laboratory. Most countries have their own standards for concrete compression testing, which differ in many ways but probably most significantly in type of specimen used. Cylindrical specimens — 150 mm (6-in.) in diameter by 300 mm (12-in.) in height — are used in Australia, Canada, France, New Zealand and the United States. Cube specimens (150 or 100 mm) are used throughout much of Europe, including Great Britain and Germany (*1*).

The two specimen types differ in several respects, both in testing procedure and results. One of the most significant differences is the process of capping. When cast, ends of cylinder specimens are seldom sufficiently plane and parallel to mate properly with testing machine platens. To counteract this problem, they must be capped. Cubes, however, are cast in rigid molds with opposite walls that are plane and parallel. When tested, cubes are flipped on their sides, and do not require capping.

This difference in capping requirements for cylinders and cubes initiated an investigation concerning the two specimen types. This report surveys the literature and past research on the relationship between cylinders and cube-shaped specimens, covering three areas of comparison:

1. Testing standards and procedures,

2. Factors affecting the cylinder strength/cube strength ratio,

3. Conversion factors and equations.

Following discussion on these areas, important advantages and disadvantages of using cubes and cylinders are summarized, and a recommendation is made regarding testing of cubes versus cylinders. First, standards from the United States and Britain used in this investigation will be reviewed.

## B. Compression Test Specifications

### 1. The U.S. Cylinder Test

Standards for concrete compression tests in the United States relevant to transportation structures are provided by AASHTO (*2*) and ASTM (*3*). Standards for making, capping, curing, and testing cylinders are provided in the following specifications:

*AASHTO*

M 205 Molds for Forming Concrete Test Cylinders Vertically
T 22 Compressive Strength of Cylindrical Concrete Specimens
T 23 Making and Curing Concrete Test Specimens in the Field
T 126 Making and Curing Concrete Test Specimens in the Laboratory
T 231 Capping Cylindrical Concrete Specimens

*ASTM*

C 31 Practice for Making and Curing Concrete Test Specimens in the Field
C 39 Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens
C 192 Practice for Making and Curing Concrete Test Specimens in the Laboratory
C 470 Standard Specification for Molds for Forming Concrete Test Cylinders Vertically
C 617 Practice for Capping Cylindrical Concrete Specimens
C 1231 Practice for Use of Unbonded Caps in Determination of Compressive Strength of Hardened Concrete Cylinders

Cylinder specimens are cast in individual molds, which can be either multi-use or single-use. Typical multi-use molds are made of steel or cast iron, with separate bases clamped to the mold walls. Typical single-use molds are made of sheet metal, cardboard, paper, or plastic. Specimens are cast and compacted in multiple layers [three layers for a 300 mm (12-in.) cylinder]. Compaction is achieved by rodding or by vibration of each layer.

Curing occurs in a controlled environment. Initially, cylinders must be held in a moist environment between 16 and 27° C (60 and 80° F). After shipment to the laboratory within 48 hours of casting, molds are removed. Specimens are then placed in a moist environment at a temperature of 23 ± 1.3° C (73.4 ± 3° F). Additional conditions and options for curing are given in AASHTO T 23. Specimens are typically tested after 28 days, though tests are often performed at 24 hours, 3 days, 7 days, and 90 days.

AASHTO standards require the surfaces of compression test specimens to be plane within 0.050 mm (0.002 in.), and perpendicular to the axis within 0.5°. Because most specimens do not meet this requirement, the ends are usually capped before any load is applied. Examples of capping materials are sulphur mortar and cement paste. More recently, neoprene pads with steel extrusion controllers have been used in lieu of bonded capping materials.

Specimens are loaded between two bearing blocks, the lower of which is fixed. The upper block is spherically seated, and rotates to mate with the surface of the specimen. Specimens are loaded to failure at a specified rate. Compressive strength is then calculated as the maximum applied load divided by the measured cross-sectional area of the specimen. Failure mode is also recorded.

2. <u>The British Cube Test</u>

Standards for concrete compression tests in Britain are published by the British Standards Institution. Standards for molding, curing, and testing cube specimens are found in various parts of *BS 1881: Methods of Testing Concrete* (*4*) as follows:

Part 108: Method for Making Test Cubes from Fresh Concrete
Part 111: Method of Normal Curing of Test Specimens (20 Degrees Celsius Method)
Part 112: Methods of Accelerated Curing of Test Cubes
Part 116: Method for Determination of Compressive Strength of Concrete Cubes

The standard casting and curing procedure for cube specimens is similar to that for cylinder specimens. Concrete is sampled on site; placed in a clean, dry container; and, if necessary, transported to the location where cubes will be cast. The concrete is re-mixed by hand, and cubes are cast in rigid multi-use molds as soon as possible after sampling. Cube molds are usually steel or cast iron, with the base rigidly clamped or bolted to the mold walls. Single-use molds are not permitted. Specimens are cast and compacted in layers 50 mm (2-in.) thick. Rodding and vibration are acceptable means of compaction. Cubes are cured in a moist environment under well controlled conditions. Curing temperatures are 20 ± 2°C (68 ± 4° F) for specimens tested at less than seven days, and 20 ± 5° C (68 ± 9° F) for specimens tested at seven days or more.

Unlike cylinders, cubes need not be capped. When tested, cubes are flipped on their sides. Opposite faces of rigid cube molds are assumed parallel and plane. The platens of the testing machine thus will mate evenly with the specimen surfaces without need for a capping system to distribute the load. Molds must be checked often for intended geometry to ensure that specified tolerances are met, or strength test results could be misleading.

Testing machines are set up similarly for cubes and cylinders. The lower platen is fixed, and the upper platen is free to rotate to ensure that the platen aligns with the cube surface. The upper platen is then fixed after mating with the cube surface. Specimens are loaded to failure at a specified rate, and compressive strength is calculated as the maximum applied load divided by the measured cross-sectional area of the specimen. Mode of failure is also noted.

## II. FACTORS INFLUENCING THE CYLINDER/CUBE STRENGTH RATIO

The relationship between compressive strength of concrete cylinder and cube specimens is complex. The effects of numerous factors, combined with inherent variations associated with concrete, complicate comparisons between the two types of tests. Past research has identified effects of several factors on the cylinder/cube strength ratio:

1. Casting and testing procedures

2. Specimen geometry

3. Level of strength ($f_c'$)

4. Direction of loading and machine characteristics

5. Aggregate grading

### A. Effects of Casting, Curing, and Testing Procedures

Two main factors are associated with the compression testing process: 1) type of mold, and 2) capping and surface planeness. The cylinder/cube strength ratio can be affected by the type of mold used to cast cylinder specimens. Cubes are always cast in rigid molds (i.e., made of steel or cast iron), but cylinders can be cast in either rigid or non-rigid molds. Cylinders cast in cardboard molds have shown a slight reduction in strength (up to 3.5 percent) from those cast in steel or cast iron (*5*).

Method of capping and out-of-plane surfaces can affect the cylinder/cube strength ratio. Method of capping is known to have some effect on cylinder strength (*6,7,8*), thus affecting the cylinder/cube strength ratio. Planeness of cube specimens is as important as capping of cylinder specimens. Out-of-plane mold surfaces have been shown to reduce the strength of concrete cubes by as much as 15 percent (*9*). Care must be taken to ensure that mold and specimen tolerances are met, or the cube strength and cylinder/cube strength ratio could be misleading.

### B. Effects of Specimen Geometry

Various aspects of specimen geometry are recognized to affect compressive strength test results. The most significant factor is the specimen's height-to-maximum lateral dimension (*h/d*) ratio. Other

Figure 1. Approximate effects of multiaxial stresses in cylinder and cube specimens

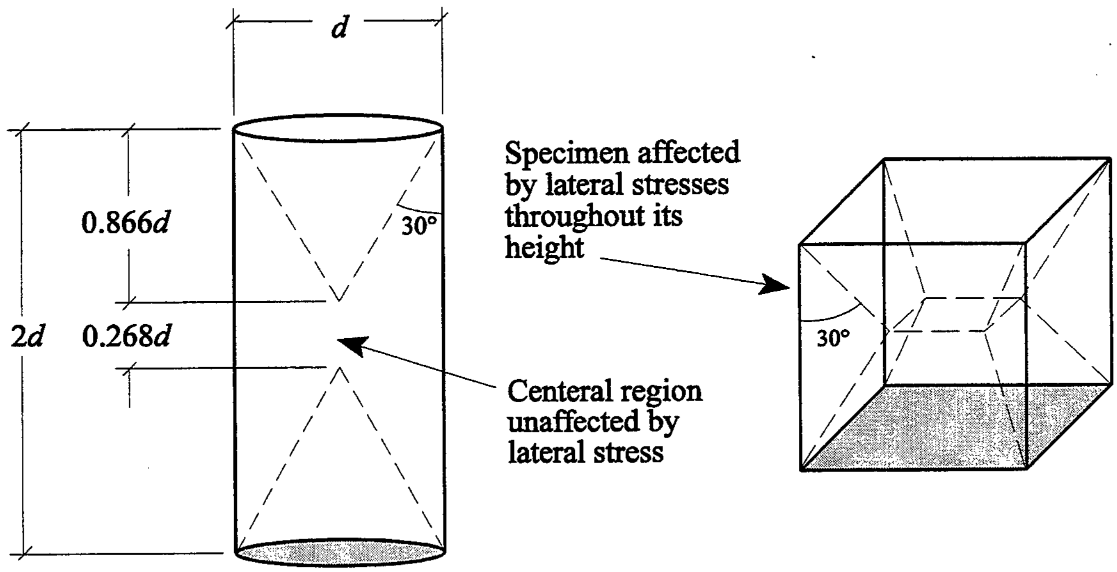
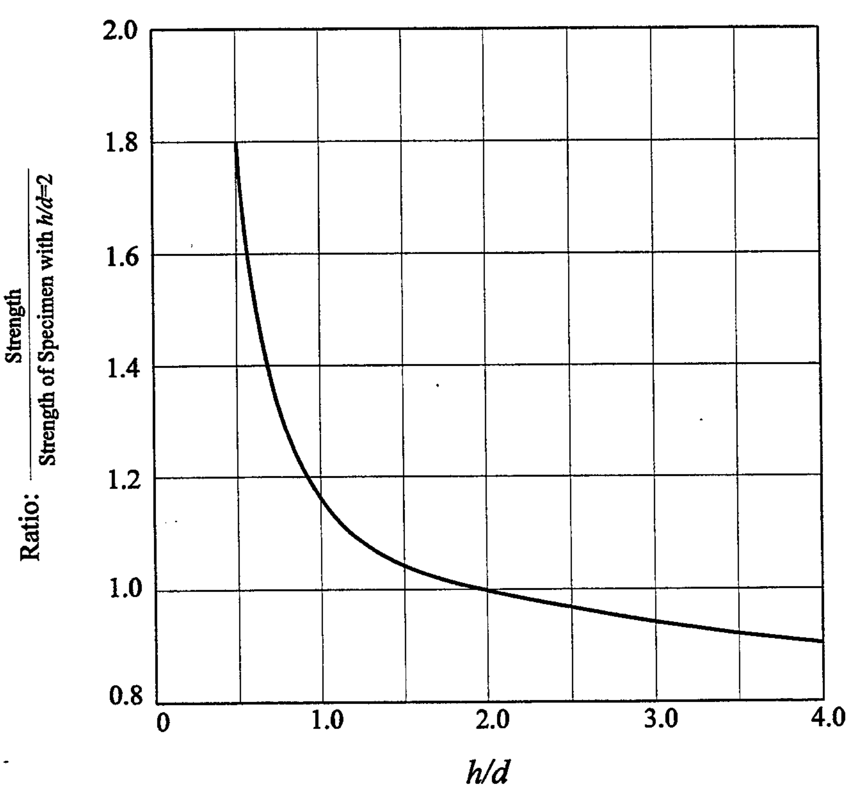



Figure 2. General relationship between height/diameter ratio and strength ratio.



geometrical factors are *d* alone, and overall specimen volume (*V*). These three factors, along with cross-sectional shape, will now be discussed.

Although desirable, true uniaxial stress throughout a specimen is not possible in practice. Frictional effects between the specimen and machine platens produce lateral stresses in specimens. This results in a multiaxial state of stress that tends to increase the strength exhibited by test specimens. Lateral stresses affect specimen stress state in a cone-shaped or pyramid-shaped region to a depth of about $(\sqrt{3}/2)d = 0.866d$ at each end (*1*). Such specimens as 150 × 300 mm (6 × 12 in.) cylinders with $h \geq 1.7d$ will have a region not usually experiencing these multiaxial stresses. Cubes are affected by multiaxial stresses throughout the specimen. Both are shown in Figure 1. It can be expected that cubes will exhibit greater strengths than cylinders for otherwise identical concretes. Past research has shown this to be the case (*10,11*).

The general relationship observed between *h/d* and strength is shown in Figure 2 (*1,10*). It is evident from Figure 2 that the strength ratio is more sensitive to *h/d* for *h/d* < 1.5 than for *h/d* > 1.5. Cubes thus are more susceptible than cylinders to variations resulting from slight differences in *h/d.*

The effect of *d* is based on the probability of having a weak unit of concrete in any cross-section. The larger a specimen's *d*, the more likely it contains a cross-section with an element of low strength that governs failure of the specimen. Neville (*12*) suggests that the relationship between strength P and lateral dimension *d* is $P \propto 1/d^2$. Because 150 × 300 mm (6 × 12 in.) cylinders and 150 mm cubes have identical *d*, lateral dimension is not an issue when comparing these specimens. However, variations in dimensions, such as the 100 mm cube allowed by BS 1881, make *d* an influencing factor in the cylinder/cube strength ratio. Neville (*1*) has also observed that the effect of *d* becomes insignificant as *d* is increased beyond 600 mm (24-in.), indicating that such reductions in strength need not be extrapolated to real pavements and structures with much larger dimensions.

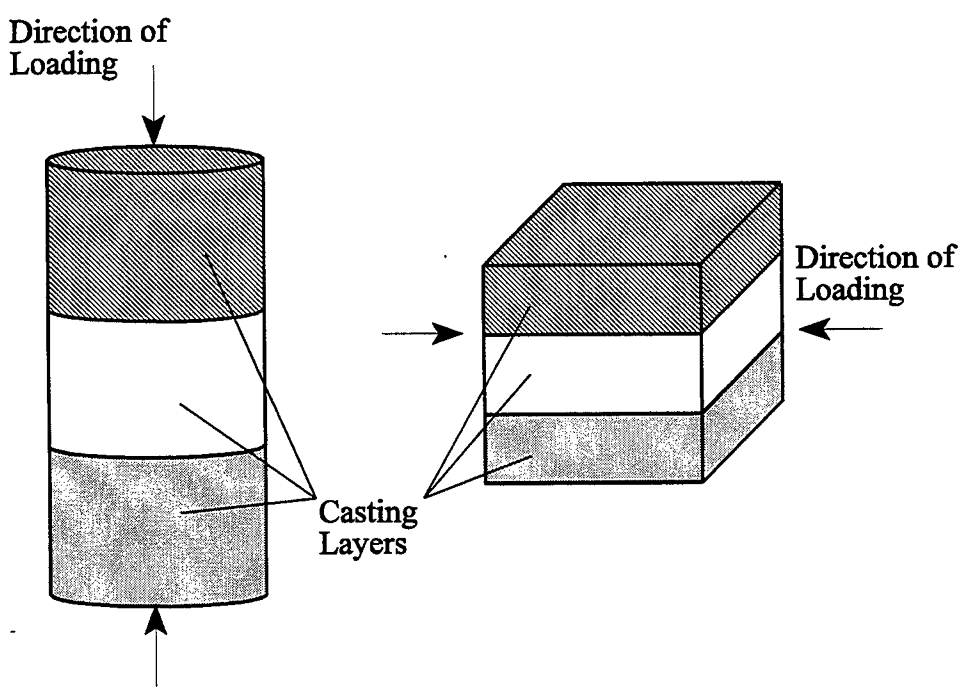
Specimen volume *V* affects strength in two ways. First, distribution of stress throughout a specimen is relatively more uniform for specimens of larger volume . This is important, since high stress concentrations can increase the chances of premature failure, and increase the variation of test results (*11*). A 150 × 300 mm (6 × 12 in.) cylinder has a volume about 1.65 times that of a 150 mm cube, making cubes more susceptible to stress concentrations. The second effect of *V* is that greater volumes are more likely to contain a weak unit that reduces strength. This second volume effect is closely related to the effect of *d*.

Cross-sectional shape is not believed to have a significant effect on strength test results. Tests on cubes and cylinders with *h/d* = 1 yield similar results (*11,13*). A comparative study between 150 × 150 × 300 mm (6 × 6 × 12 in.) prisms and 150 × 300 mm (6 × 12 in.) cylinders showed little difference between strengths of the two specimen types (*14*). Thus, corrections based on shape are not needed.

Table 1. Evans data relating strength to cylinder/cube strength ratio (*1,15*).

| Strength, MPa (ksi) | | Cylinder/Cube Ratio |
|---|---|---|
| Cubes | Cylinders | |
| 9.0 (1.3) | 6.9 (1.0) | 0.77 |
| 15.2 (2.2) | 11.7 (1.7) | 0.77 |
| 20.0 (2.9) | 15.2 (2.2) | 0.76 |
| 24.8 (3.6) | 20.0 (2.9) | 0.81 |
| 27.6 (4.0) | 24.1 (3.5) | 0.87 |
| 29.0 (4.2) | 26.2 (3.8) | 0.91 |
| 29.6 (4.3) | 26.9 (3.9) | 0.91 |
| 35.8 (5.0) | 31.7 (4.6) | 0.98 |
| 36.5 (5.3) | 34.5 (5.0) | 0.94 |
| 42.1 (6.1) | 36.5 (5.3) | 0.87 |
| 44.1 (6.4) | 40.7 (5.9) | 0.92 |
| 48.3 (7.0) | 44.1 (6.4) | 0.91 |
| 52.4 (7.6) | 50.3 (7.3) | 0.96 |

Figure 3. Direction of loading relative to casting direction.



## C. Effect of Strength Level ($f_c'$)

Nominal strength of concrete has been shown to affect the cylinder/cube strength ratio. Research by Evans (*15*) indicates that this ratio decreases with decreasing concrete strength. Table 1 indicates that the cylinder/cube strength ratio ranges from 0.77 to 0.96, depending on concrete strength level. The relationship between strength and cylinder/cube strength ratio is noticeable, and should be considered whenever the two geometries are compared.

## D. Effects of Direction of Loading and Machine Characteristics

Compression loads are applied in the direction of casting for cylinders, and perpendicular to the direction of casting for cubes. Because both cylinders and cubes are cast and consolidated in multiple layers, direction of loading is an important factor in the relationship between cylinder strength and cube strength. Figure 3 shows the difference. When cylinders are loaded, each casting layer occupies an entire cross-section, and receives the total load from the testing machine. When cubes are loaded, each layer extends from top to bottom, and receives a portion of the total load.

The effect of flipping a cube on its side depends on two related factors: aggregate segregation and platen fixity. Segregation is important because it can cause variations in strength and elasticity between the casting layers (*16*). When cubes are flipped, these variations exist in every cross-section perpendicular to the direction of loading. Each casting layer receives its load from a different part of the platen. If non-segregating concrete is used, then strength across a plane should not vary significantly.

The second effect — platen fixity — comes into play only when segregation occurs. Tarrant (*16*) showed that when the upper platen is not allowed to rotate, the strongest layers carry most of the load. This results from weak layers yielding more than strong layers. Failure occurs only after the strong layers are loaded to capacity, and the weak layers are forced to carry the remaining load. The observed cube strength is higher than that of an equivalent cube loaded in the direction of casting. If the upper platen is free to rotate, it adjusts to deformations that vary between casting layers. Each layer carries the same amount of load, and failure occurs when capacity of the weakest layer is reached. Strength of the stronger layers is never fully used. The observed strength is less than that of an equivalent cube loaded in the direction of casting.

Experimental results have shown the effects of segregated concrete on cube and cylinder strength. Sigvaldason (*17*) found that segregating concretes generally gave smaller cylinder strength/cube strength ratios than more uniform concrete. His results showed the cylinder/cube strength ratio to be 0.71 to 0.77 for segregated concrete, and 0.76 to 0.84 for non-segregated concrete. Also, cube strength was more sensitive to the method of end loading. Sigvaldason observed strength variations of about 7 percent for cubes and 1 percent for cylinders for varying end conditions (pinned-pinned, pinned-fixed, and fixed-fixed). Neville (*18*) found no statistical difference between strengths of cubes of non-segregating concrete loaded perpendicular and parallel to the direction of casting.

Figure 4. Wall effect.


Tarrant (*15*) studied effects of lubrication in the pin of the platen. He found that the type of lubrication used determined the extent to which such a platen could be considered pinned. Type of lubrication used in the pin, combined with cube flipping effects, also affects the cylinder/cube strength ratio.

## E. Effects of Aggregate Grading

Aggregate grading is known to affect concrete strength in any structure or specimen. The effect is magnified for compression test specimens due to the relative size of aggregate particles to specimen dimensions. Most standards set a lower limit for the ratio of *d* to maximum nominal aggregate size. Typically, this allowable minimum is around 3 or 4.

Aggregate grading affects specimen strength through the "wall effect" (*1*), as shown in Figure 4. In concrete specimens a greater volume of space exists between the aggregate and mold wall than between aggregate particles within the specimen. The extra mortar at the walls increases the specimen's compressive strength. Because this is a surface effect, compressive strength increase is greater for specimens with larger surface/volume ratios.

Comparing the surface/volume ratio for standard cylinders and cubes indicates how aggregate grading may affect the cylinder/cube strength ratio. The surface/volume ratio of 150 × 300 mm (6 × 12 in.) cylinders is 0.033/mm, but it is 0.040/mm for 150 mm (6-in.) cubes, suggesting that cubes are more sensitive to changes in aggregate grading than cylinders. In fact, Gyengo's research (*14*) showed 1) that cylinder strength is less affected by changes in aggregate grading, and 2) that the cylinder/cube strength ratio decreases with increasing coarseness of aggregate grading.

## III. STRENGTH CONVERSION FACTORS AND EQUATIONS

Past studies have resulted in equations or factors for converting strength test results among specimen types. In addition, some standards specify conversion factors for specimens of different sizes. Conversion factors and equations from several studies and standards are presented here.

AASHTO/ASTM (*2,3*)

Conversion factors are provided in the AASHTO and ASTM codes for evaluating strength test results when $h/d < 1.8$. These factors convert strength test results to equivalent results for a specimen having $h/d = 2$. Generally, these factors are used for tests on cores taken from structures, from which it is not always possible to obtain $h/d = 2$ specimens. Factors from ASTM C 39 and AASHTO T 22 are as follows:

| *h/d*: | 1.75 | 1.50 | 1.25 | 1.00 |
|---|---|---|---|---|
| Factor: | 0.98 | 0.96 | 0.93 | 0.87 |

United States Bureau of Reclamation (*19*)

Conversion factors for variations in $h/d$ are provided in the U.S. Bureau of Reclamation's standards for concrete. These factors also convert strength test results to 150 × 300 mm (6 × 12 in.) cylinder strengths. The factors may be taken from a graph similar to Figure 2 or from a table, both provided in Bureau of Reclamation standards. Values from the table are given in Table 2. Also provided in the standards are conversion charts for cylinders with $h/d = 2$ and varying $d$.

UNESCO (*20*)

In UNESCO's reinforced concrete manual, conversion factors are provided for specimens of varying size and shape. Table 3 provides the factors recommended by UNESCO.

Table 2. U.S. Bureau of Reclamation conversion factors.

| *h/d* | Factor, % | *h/d* | Factor, % |
|---|---|---|---|
| 2.25 | 101.4 | 1.6 | 96.8 |
| 2.2 | 101.1 | 1.5 | 96.0 |
| 2.1 | 100.6 | 1.4 | 95.2 |
| 2.0 | 100.0 | 1.3 | 94.5 |
| 1.9 | 99.2 | 1.2 | 93.1 |
| 1.8 | 98.4 | 1.1 | 90.0 |
| 1.7 | 97.6 | 1.0 | 85.0 |

Table 3. UNESCO conversion factors.

| Specimen Shape | Specimen Size | Conversion Factor |
|---|---|---|
| Cylinder | 15 × 30 cm | 1.00 |
| | 10 × 20 cm | 0.97 |
| | 25 × 50 cm | 1.05 |
| Prism | 15 × 15 × 45 cm | 1.05 |
| | 20 × 20 × 60 cm | 1.05 |
| Cube | 10 cm | 0.80 |
| | 15 cm | 0.80 |
| | 20 cm | 0.83 |
| | 30 cm | 0.90 |

Neville's Equations (*11*)

In 1966, Neville used data from several previous studies to develop a general relationship between compression test specimens of varying shapes and sizes. He postulated that strength could be determined as a function of *V*, *d*, and *h/d*:

$$f'_c = f\left(V,\ d,\ \frac{h}{d}\right) \tag{1}$$

The result was two equations relating specimen strength to that of a 150 mm (6-in.) cube. His first equation includes all three variables:

$$\frac{P}{P_6} = 0.56 + \frac{0.697}{\frac{V}{6hd} + \frac{h}{d}} \tag{2}$$

where P = compressive strength,

$P_6$ = strength of a 150 mm (6-in.) cube,

$V$ = volume,

$h$ = height, and

$d$ = maximum lateral dimension.

The strength ratio of any specimen type to a 150 mm (6-in.) cube is obtained by inserting values of *V*, *h*, and *d* for the specimen of interest. Since these equations were developed using English units, all dimensions must be specified in inches. According to this equation, the ratio of 150 × 300 mm (6 × 12 in.) cylinder strength to 150 mm cube strength is 0.81.

When Neville dropped the variable *h/d*, he could still obtain a good fit with the data. The resulting equation is

$$\frac{P}{P_6} \times \frac{d}{d_6} = 0.8878 \times \left(\frac{A}{A_6}\right)^{0.4525} \tag{3}$$

where $d_6$ = maximum lateral dimension of a 150 mm (6-in.) cube = 150 mm (6-in.),

$A$ = cross-sectional area, and

$A_6$ = cross-sectional area of a 150 mm (6-in.) cube = 22,500 $mm^2$ (36 $in.^2$).

Table 4. Cylinder/cube strength ratios using L'Hermite's equation.

| Cube Strength, psi | Cylinder/Cube Ratio |
|---|---|
| 3000 | 0.765 |
| 4000 | 0.790 |
| 5000 | 0.809 |
| 6000 | 0.825 |
| 7000 | 0.838 |
| 8000 | 0.850 |

Table 5. Results of cylinder vs. cube comparative studies.

| Reference | Average cyl./cube ratio | Remarks |
|---|---|---|
| Cormack (*11*) | 0.87 | Study focused on high strength concrete. Few data were generated for $f_c'$<41 MPa (6 ksi) |
| Evans (*1,15*) | 0.77-0.96 | Lower-strength concretes had generally lower cylinder/cube strength ratios |
| Sigvaldason (*17*) | 0.71-0.77<br>0.76-0.84 | Segregating concrete<br>Non-segregating concrete |
| Lysle and Johansen (*21*) | 0.86 | |
| Gyengo (*14*) | 0.65-0.84 | Variation due to varying coarseness of aggregate grading |
| Gonnerman (*10*) | 0.85-0.88 | Tests performed using standard cylinders and 6" and 8" cubes |
| Plowman, Smith, and Sheriff (*13*) | 0.74<br>0.64 | Water-cured specimens<br>Air-cured specimens<br>} In all cases, portions of steel bars were embedded in cylinder specimens |
| Raju and Basavarajaiah (*22*) | 0.61<br>0.51 | Using 150 mm cubes<br>Using 100 mm cubes |
| Lasisi, Osunade, and Olorunniwo (*23*) | 0.67-0.76<br>0.55-0.86 | Landcrete specimens (small aggregate from lateric soil)<br>Concrete specimens |

According to Equation 3, the ratio of 150 × 300 mm (6 × 12 in.) cylinder strength to 150 mm (6 in.) cube strength is 0.79. Test results used to create these equations were compared with predictions using these equations. Neville's equations predicted actual strength test results to within 10- to 15-percent difference.

L'Hermite's Equation (*1*)

In 1955, R. L'Hermite proposed a simple equation for the cylinder/cube strength ratio as a function of the cube strength:

$$\frac{\text{Cylinder Strength}}{\text{Cube Strength}} = 0.76 + 0.2\times\log_{10}\frac{f_{cu}}{2840} \tag{4}$$

where $f_{cu}$ is cube strength in psi. Some strength ratios based on L'Hermite's equation are given in Table 4.

Results of Other Comparative Studies

Numerous studies have sought to determine an experimental relationship between cylinder and cube strengths, many of which appeared in the earlier discussion. Results for nine studies are summarized Table 5. It is evident from these results that the relationship between cylinder strength and cube strength cannot be easily represented by simple equations or conversion factors.

## IV. ADVANTAGES OF CUBES AND CYLINDERS

Several considerations may be evaluated in choosing the type of specimen to be tested. Cubes and cylinders should be evaluated with respect to both testing procedures and quality of results. Important advantages and disadvantages of each specimen type are listed here.

### Cubes

Advantages:

- Rigid molds and loading cubes on their sides eliminate need for a capping system.
- Cubes are lighter, making them easier to handle. Cube weight is 64 percent of cylinder weight for cylinders with $h/d$=2 and identical $d$. For 2400 kg/m$^3$ (150 pcf) concrete, a 150 mm (6-in.) cube is 8.1 kg (18.8 lb), and a 150 × 300 mm (6 × 12 in.) cylinder is 12.7 kg (29.5 lb).
- Less concrete is required to cast cubes.
- Cubes require less storage space in curing rooms.

Disadvantages:

- The higher compressive strength and greater cross-sectional area of cubes require a higher-capacity testing machine.
- More cubes are needed due to the greater variability associated with smaller specimens.
- Cubes are more sensitive to changes in aggregate grading, platen fixity, and variations in the $h/d$ ratio.
- If concrete segregates, cube flipping may result in misleading test data.
- Only rigid multi-use molds are permitted for cubes.

### Cylinders

Advantages:

- Cylinders with high $h/d$ ratios have a region free of friction effects at the platens, which contributes to less variation in test results.
- Lower variations in test results reduce the required number of cylinders.
- Both single-use and multi-use molds are permitted for cylinders.
- Cylinders are tested in the direction of casting.

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Disadvantages:

- Cylinders have a weight more than 1.5 times that of cubes, when *d* is identical and *h*/*d*=2.
- Capping is required, because cylinder surfaces seldom meet the tolerances set by AASHTO and ASTM. Capping adds extra material and labor costs to the compression testing process. For example, the cost of neoprene caps, based on NYSDOT experience, is $10 to $36 per cap pair, with 100 specimens tested per pair. Additional costs appear for extrusion controllers and labor.

## V. SUMMARY

Two main types of concrete specimens are used for compression testing. Cylinder specimens are used in the United States, Australia, Canada, France, and New Zealand. Cube specimens are used for compression tests throughout much of Europe, including Great Britain and Germany. The significant differences between the two procedures are twofold. First, cylinders may be cast in single-use or rigid metal molds, but cubes must be cast in rigid metal molds. Second, cylinder specimens must be capped to distribute the applied load evenly over the ends, but cubes need not be capped and are flipped on their sides for loading.

Numerous factors influence the cylinder/cube strength ratio, these five being the most important:

1. Testing procedure — type of cylinder mold and capping system, and planeness of cube surfaces.

2. Specimen geometry — ratio of height-to-maximum lateral dimension ($h/d$) is recognized as the most important geometrical factor, and is inversely related to specimen strength. Other factors are $d$ and volume $V$.

3. Strength level — this is positively correlated with the cylinder/cube strength ratio.

4. Pattern of load distribution — fixity of the loading platens and loading direction for cubes perpendicular to the direction of casting are significant, for segregating concretes.

5. Aggregate Grading — changing aggregate grading affects cube strength more than cylinder strength, and increasing aggregate coarseness decreases the cylinder/cube strength ratio.

Strength test results have not been accurately converted between specimen types. Substantial variation exists among the numerous conversion factors and equations developed for this purpose. Although results vary among investigations, the cylinder/cube strength ratio is between 0.65 and 0.90 for 150 × 300 mm (6 × 12 in.) cylinders and 150 mm (6-in.) cubes.

In conclusion, this survey of past research provides no strong support for recommending that cube testing replace cylinder testing. It was suggested at the beginning of this investigation that should previous research results lead toward a positive recommendation, then limited physical testing might be performed to verify those results. In particular, verification was considered for empirical conversion relationships, conversion factors, and affecting factors. As summarized here, numerous factors influence the cylinder/cube strength ratio, and empirical relationships and conversion factors are associated with relatively large scatter. A limited testing program would be insufficient to verify previous research results, and cube testing is not being recommended. Physical testing to support such a recommendation thus was not undertaken.

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