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The Use of Cold-Formed Steel as a Substitute for Reinforcement on Structural of Lightweight Concrete Beams

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ABSTRACT

Cold-formed steel has the advantage such as it is not flammable and eaten by termite, its installation is relatively fast and has almost no expansion and shrinkage values. However, it has disadvantages when it is exposed directly, apart from looking less attractive, it can also cause post-buckling behavior when the ultimate strength occurs. This research will use cold-formed steel C-Section type Galvanized and Galvalume, as a substitute for reinforcing steel in a reinforced lightweight Concrete beam, so that a lightweight beam with cold-formed steel reinforcing will be obtained. The aim of this research was to obtain the ultimate load and modulus of rupture (MOR) that can be detained by the beam and the stiffness (MOE) and cracked fields that occur in lightweight concrete beams, 2 specimen beams will be made each with variations: formed steel C-section beam with nail bolt (fig. 2.c), Cold-formed steel C-section beam with nail bolt and three-stiffeners (fig. 2.d) compared to reinforced lightweight concrete beams (fig. 2 .a). Lightweight concrete used has a compression strength (fc ± 20 MPa) and a density of ± 1825 Kg/m^3. The test of reinforced lightweight concrete beams undertaken after treatment on 28 days based on the standard simple beam with center-point loading test. Based on the results of the research that has been done, it indicated that he use of cold-formed steel as a substitute for reinforcement in lightweight concrete beams would increase the stiffness (MOE) of the beam, ultimate load and modulus of rupture (MOR) which the beam can withstand. Collapse that occurred in lightweight concrete beam Cold-formed steel C-section and concrete beam of reinforced steel, it started from the cracked at the very bottom of the beam, in the middle of the span in the tensile area.

Keywords: Cold-formed steel, modulus of rupture, modulus of elasticity

1. INTRODUCTION

The beam is a transverse/longitudinal structural element in a building that is rigid and designed to carry the lateral load and transfer it to the column. A simply supported beam is type of beam that has pinned support at one end and roller support at one at the other and it will produce vertical reaction, shear strength and bending moment on the beam, so that it will cause inner force in the form of tensile force and compressive force and deflection/displacement on the beam. In a reinforced concrete beam, the tensile force/bending moment is usually held back by the reinforcing steel, while the compressive force is held by the concrete.

Cold-formed steel has a yield strength between 250 MPa and 550 MPa, while reinforcing steel ranges from 240-400 MPa. Other advantages include: it is not easy to burn and is eaten by termites, installation is relatively fast and has almost no expansion and shrinkage value. Cold-formed steel also has disadvantages, namely: it cannot be exposed like a wood frame, the frame system is in the form of a net, less attractive without a ceiling cover. Based on the material and coating process, cold-formed steel can be divided into Galvanized and Galvalume. Galvanized has a weight of ± 180 gr/m^2, is corrosive resistant to mortar but not corrosive to salt water. While Galvalume has a weight of ± 150 gr/m^2, is corrosive to salt water, not corrosive to mortar.

Cold-formed steel, apart from being unattractive when it is exposed directly, it can also lead to post-buckling behavior at the time of ultimate strength. Based on research [1] using cold-formed steel Channel profiles as beams and it is analyzed with the condition of under pinned and warping free end, during ultimate strength, there will be post-buckling behavior on rolled steel lipped which is influenced by the interaction of local distortion, and the same conditions on the major of axis. Concrete has a weakness, namely it has a low compressive strength when it is compared to its density, which is around 2300 kg/m^3, this will greatly affect on the dead load beam. A large dead load beam will greatly affect the bending moment of the beam, thus, a large beam size and more reinforcement area will be required compared to using Lightweight Concrete.

Research [2], using Crushed clay bricks as coarse aggregate on Lightweight Foamed Concrete, the results showed that: if the foam agent was added 2-3.5% to the weight of water then it was classified as Moderate Strength Concrete, whereas if the foam agent was added < 2 % , it was classified as Structural Concrete, which had a density < 1825 Kg/m^3 and a compressive strength of ± 21.83 MPa.

Previous studies using cold-formed steel C-Section as a beam have been carried out, it covers: [3], observing Flexural Performance of Bolted-Side-Plated Reinforced Concrete Beams with Buckling Restraining using steel plate with anchor bolts 300 mm spacing, steel bars with anchor bolts 300 mm spacing, steel angle with anchor bolts 300 mm spacing, steel plate with anchor bolts halving spacing on a reinforced concrete beam measuring 225x350x4000mm, it was found that the largest load was on the reinforced concrete beam using steel plate with anchor bolts 300mm spacing and steel bars with anchor bolts 300mm spacing.

Research [4] using cold-formed steel C-Section which is assembled into I-Section beam with Vertical Stiffeners (I-VS), I- Section beam with Longitudinal Stiffeners (I-LS), I- Section beam with Diagonal end Stiffeners (I-DS) with a spacing of 350 mm, I-Section beam with Cross-Diagonal Stiffeners (I-CDS) with a spacing of 700 mm compared to the Control I-Section beam. The results indicated that the largest load that cold-formed steel beams can withstand were: I-beam with Cross-Diagonal Stiffeners (I-CDS), I-beam with Longitudinal Stiffeners (I-LS), I-beam with Vertical Stiffeners (I-VS), I-beam with Diagonal end Stiffeners (I-DS) and Control I-Beam.

An experimental study on the flexural behavior of cold-formed steel composite beams [5], using cold-formed steel C-Section, forming I-Section composite beam with 4 model variations including: model I uses hollow PVC for packing in flange and web, model II uses cardboard for packing in flange and hollow PVC for web packing, model III uses cardboard for packing in flange and web, model IV uses timber for packing in flange and web. The results pointed out that the largest loads that could be withheld by cold-formed steel composite beams as follows: model IV, model III, model II and model I.

Research [6], using cold-formed steel C-Section as beam is analyzed with the condition under pinned with warping free end, when ultimate strength occurs post-buckling behavior and design of cold-formed steel lipped channel beam affected by local distortional buckling mode interaction, and the same bending on the major of axis.

In this study, it will use cold-formed steel C-Section types Galvanized and Galvalume, as a substitute for reinforcing steel in reinforced lightweight Concrete beams, so that a light beam with reinforcing cold-formed steel will be obtained which is economical and efficient. The main objective of this research was to determine whether the use of cold-formed steel as a substitute for reinforcement on structural of lightweight concrete beams is more efficient, by researching the ultimate load and modulus of rupture (MOR) that could be held back by beams as well as stiffnees/modulus of elasticity (MOE) and cracked fields that occur in lightweight concrete beams.

2. METHODOLOGY

This research has been motivated by looking at cases in the field and the results of previous studies, that buckling often occurs in cold-formed steel at the time of ultimate strength and if it is used as a beam after being used several years later (Figure 1).

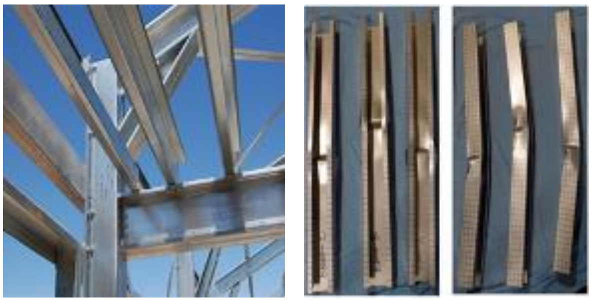
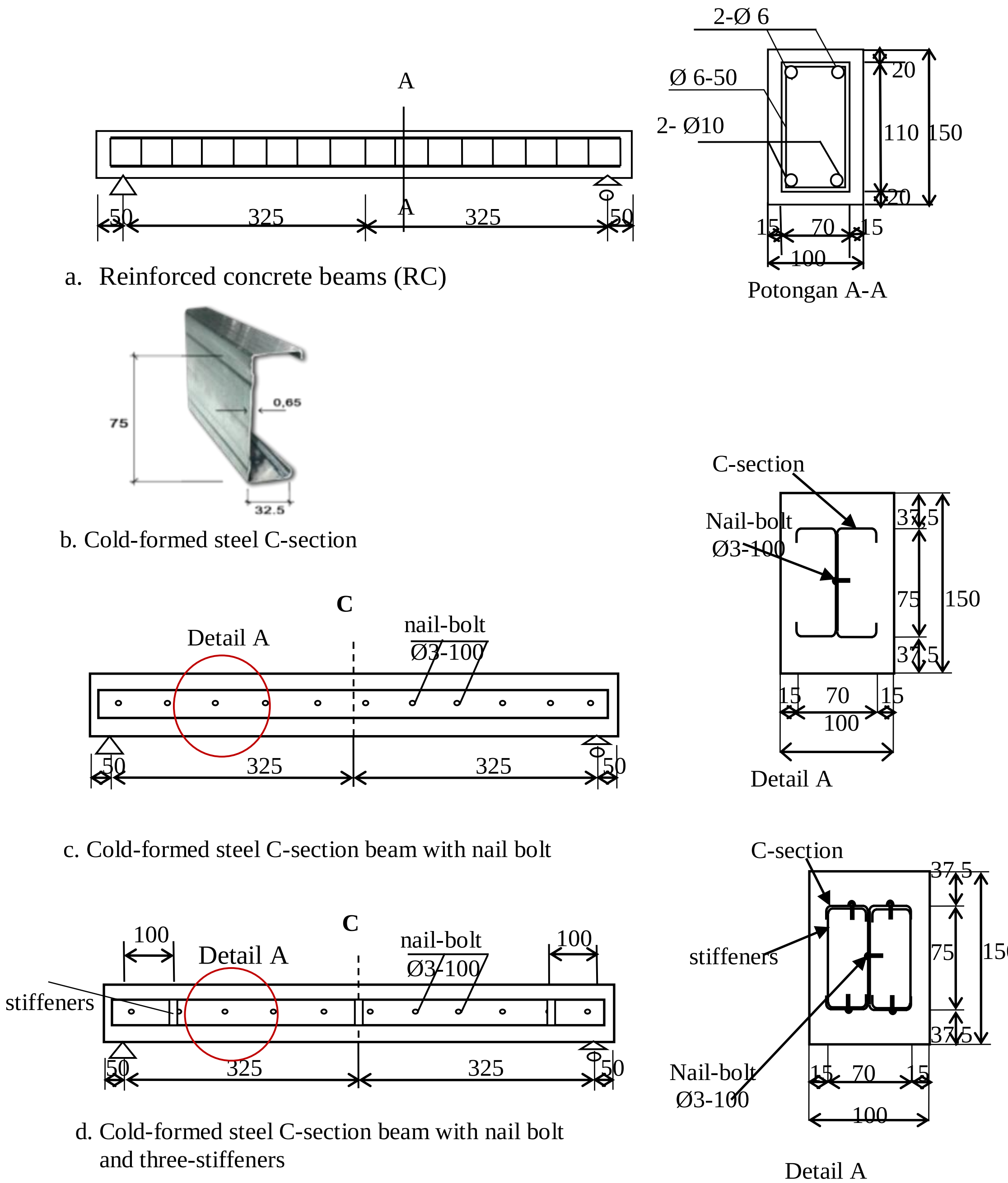


Figure 1. Buckling often occurs in cold-formed steel

Cold-formed steel is also less attractive and sturdy when it is exposed directly, such as wood frames. Therefore, this research used cold-formed steel C-Section type Galvanized and Galvalume as reinforced concrete beams, while the concrete used was structural Lightweight concrete with compression strength (fc ± 20 MPa). Lightweight concrete was designed using standards [7]. Testing of reinforced lightweight concrete beams was carried out based on the standard simple beam with center-point loading [8], using an Automatic Tension & Compression Testing Machine with a capacity of 3000 kN. Design reinforcement lightweight concrete beams as a comparison beam (Figure 2.a). The cold-formed C-section (Figure 2.b) to be used has specifications based on standards [9]. The nail-bolt and stiffeners placement design is based on literature [10], where reinforced concrete beams use cold-formed steel

C-section beam with nail-bolt (Figure 2.c) and cold-formed steel C-section beam with nail-bolt and stiffeners (Figure 2.d). Each variation of the specimens will be made 2 specimens of beams measuring 100x150x750 mm, using an aggregate composition based on the results of the study [11], namely: crushed clay brick: sand: stone ash with a ratio of 50%: 25%: 25%. Lightweight concrete with cement: aggregate: water composition with a ratio of 1:2:0.46. Compression strength of concrete can be determined by making 10 lightweight concrete specimens in the form of cylinders, and tested after the treatment for 28 days in accordance with the standard [12].



a. Reinforced concrete beams (RC)

b. Cold-formed steel C-section

c. Cold-formed steel C-section beam with nail bolt

d. Cold-formed steel C-section beam with nail bolt and three-stiffeners

Figure 2. Specimen of reinforced cold-formed steel lightweight concrete beams

The test results of a simple beam with center-point loading beams use of Cold-Formed Steel as a Substitute for Reinforcement and Reinforced Concrete beam on Structural of lightweight Concrete Beams would be calculated using the formulas (1), (2) and (3), would be illustrated in the form of relation between Modulus of Rupture and modulus of elasticity histogram of specimens and form of relation between load-displacement curves of specimens, it would be analyzed through the ultimate load and flexural strength that the beam can withstand as well as the stiffness and cracked fields that occured in the beam, so that the conclusions of this research will be obtained. The modulus of rupture (MOR) and modulus of elasticity (MOE) of the simple beam test with center-point loading, used the following formula (ASTM C293/C293M-16):

$$MOR = \frac{3P.L}{2.b.h^2} \quad (1)$$

$$MOE = \frac{\sigma}{\varepsilon} \quad MOE = \frac{\sigma}{\varepsilon} \quad (2)$$

$$\sigma = \frac{P}{A}\ ;\ \varepsilon = \frac{\Delta L}{L_o} = \frac{L_1 - L_o}{L_o} \quad (3)$$

where:

MOR= Modulus of rupture (MPa)
MOE= Modulus of elasticity (MPa)
σ = Stress (MPa)
A = cross sectional area (mm2)
ΔL = is change of the length (mm)
ε = Strain (%)
L = Span length (mm)
P = Maksimum load (N)
b = Average width (mm)
h = Average depth (mm)
Lo = length after elongation (mm)
L1 = original length (mm)

3. RESULTS AND DISCUSSION

The test results for 10 samples of cylinder lightweight concrete obtained Compression strength ranging from 20 MPa and a density of 1800 Kg/m^3.

The test results of reinforced lightweight concrete simple beam with center-point loading can be seen in Figure 3, it indicates that the comparison between load-displacement of specimens and summary of ultimate load (Table 1), that the strength of lightweight concrete using Cold-formed steel C-section has increased when it is compared to the use of reinforced steel.

The modulus of elasticity is a number used to measure the resistance of a material when it experiences elastic deformation, when a force is applied to the object. Modulus of rupture is the value of the ultimate flexural strength that works on the structure prior to collapse of concrete beam loading (are analyzed under pinned with warping free end conditions) simple support with the placement of a roller joint.

The results of the research in (Table 1 and figure 4), show that the use of cold-formed steel C-section as a substitute for reinforced concrete beam has increased flexural strength (M0R) and stiffness (MOE). The largest increase in stiffness occurs in the Galvanized Cold-formed steel C-section beam with nail bolts and three-stiffeners (fig. 2.d), which is 94% when compared to reinforced concrete beams (fig. 2.a). The Galvalume Cold-formed steel C-section (fig. 2.c) is 83%, the Galvalume Cold-formed steel C-section beam with nail bolts and three-stiffeners is 44% and the Galvanized Cold-formed steel C-section beam with nail bolt by 36%. The greatest increase in flexural strength (M0R) occurrs in Galvalume cold-formed steel C-section (fig. 2.c) of 44%, when compared to reinforced concrete beams (fig. 2.a). In Galvanized Cold-formed steel C-section beam with nail bolt and three-stiffeners (fig. 2.d), namely 28%, Galvanized Cold-formed steel C-section beam with nail bolt is 16% and Galvalume Cold-formed steel The C-section beam with nail bolts and three-stiffeners is merely 1%.

Table 1. Summary of specimens and Ultimate Load, MOR, MOE

No. specimen	Material of reinforced	Figure.	Ultimate Load (N)	MOR (MPa)	MOE (MPa)
RC-1	Reinforced stell (fy 240 MPa)	2.a	28,000	11.20	12,894
RC-2			26,880	10.75	23,571
CFSGu0-1	Galvalume Cold-formed steel C-section	2.c	41,617	16.65	34,099
CFSGu0-2			37,328	14.93	32.612
CFSGu3-1		2.d	27,969	11.19	28.490
CFSGu3-2			27,296	10.92	23.999
CFSGz0-1	Galvanized Cold-formed steel C-section	2.c	31,464	12.59	24.923
CFSGz0-2			31,989	12.80	24.493
CFSGz3-1		2.d	34,900	13.96	35.550
CFSGz3-2			35,455	14.18	35.284

Based on the observation, it can be concluded that the use of cold-formed steel C-section had an effect of increasing stiffness (MOE), so that the maximum displacement that occured was relatively smaller than the beam that used reinforced steel. Besides, there was also an increase in flexural strength (M0R), this implied that the load that could be detained by a cold-formed steel C-section concrete beam was greater than a beam using reinforced steel with the same beam size.

The steeper the slope of the curve, so then the beam is more likely to be the stiffness, or vice versa. Inertia moment is the tendency of an object to rotate about its axis while carrying a load. The inertia moment of a section greatly affects flexural strength, shear strength and torsion strength.

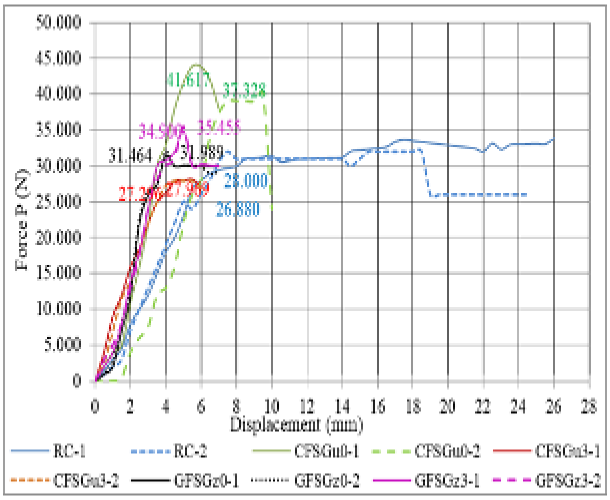


Figure 3. Relation between load-displacement curves of specimens

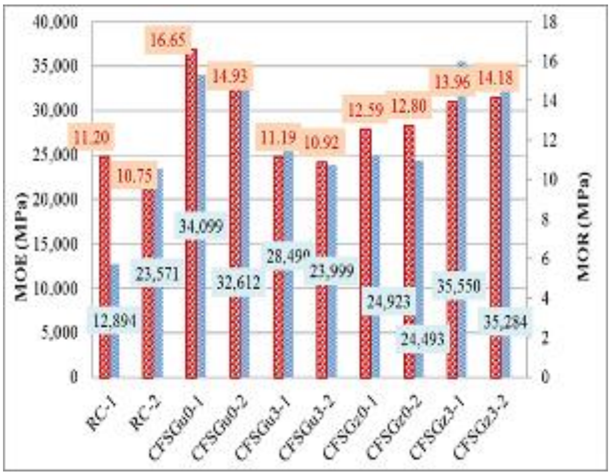
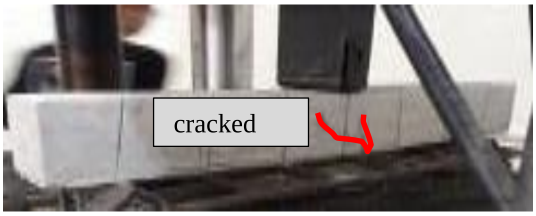


Figure 4. Modulus of rupture and Modulus of elasticty

Based on observations during the testing (Figure 5), on cold-formed steel C-section concrete beam and concrete beam of reinforced steel, beam collapse occured, it started from the crack at the bottom of the beam in the middle of the span in the tensile area.

Dealing with the observations when testing the flexural cold-formed steel as a substitute for reinforcement on structural of lightweight concrete beams and reinforced steel on structural of lightweight concrete beams until the load has been decreased, it can be observed that the crack pattern that occurs in the reinforcement on structural of lightweight concrete beams and reinforced steel on structural of lightweight concrete beams can be seen in (Figure 2.a, 2.c and 2.d), where the crack patterns that occur can be seen in (Figure 5.a, 5.b, 5.c). The crack pattern that occurs in all specimens is tensile crack (flexural crack). Flexural cracks occur in the tensile strees starting from the very bottom of the beam in the middle of the span and spreading upwards, followed by other cracks, it is still in the tensile area.



a. Reinforced concrete beams

b. Cold-formed steel C-section with nailbolt

c. Cold-formed steel C-section with nailbolt and 3 stiffners

Figure 5. Failure modes and crack patterns of specimens

4. CONCLUSION

Based on the research that has been undertaken, it can be concluded that:

The use of cold-formed steel C-section could be applied to Lightweight Concrete Beams, because it could increase the stiffness (MOE) of the beam, ultimate load and modulus of rupture (MOR) that could be heldback by the beam.

The collapse that occurred in the lightweight concrete beam Cold-formed steel C-section and concrete beam of reinforced steel, it started from the cracked at the very bottom of the beam, in the middle of the span in the tensile area.

REFERENCES

[1] M. Anbarasu, Local-distortional buckling interaction on cold-formed steel lipped channel beams,Thin-Walled Structure, 2016, vol. 98, pp. 351–359, doi: 10.1016/j.tws. 2015.10.003.

[2] Sumiati, Mahmuda, Sukarman, S. Indra, and D. Prabudi, The Utilization of Crushed Clay Brick as Coarse Aggregate on Eco-Green Lightweight Foamed Concrete, in Journal of Physics: Conference Series, 2020, vol. 1500, no. 1, doi: 10.1088/1742-6596/1500/1/012070.

[3] L. Z. Li, X. Liu, Y. Luo, M. N. Su, and J. H. Zhu, Flexural performance of bolted-side-plated reinforced concrete beams with buckling restraining, ACI Structural Journal, 2019, vol. 116, no. 2, pp. 77–87, doi: 10.14359/51712277.

[4] M. Anbarasu, A. R. Dar, A. I. Rather, and M. A. Dar, Effect of external strengthening on the flexural capacity of cold-formed steel beams, Materials Today: Proceedings, 2020, no. xxxx, pp. 2–6, doi: 10.1016/j.matpr.2020.04.171.

[5] R. Dar, An experimental study on the flexural behavior of cold-formed steel composite beams, Today Materials: Proceedings, 2019, vol. 27, no. xxxx, pp. 340–343, doi: 10.1016/j.matpr.2019.11.098.

[6] M. Anbarasu, Local-distortional buckling interaction on cold-formed steel lipped channel beams," Thin-Walled Structure, 2016, vol. 98, pp. 351–359, doi: 10.1016/j.tws. 2015.10.003.

[7] ACI Committee 213R-14, Guide for structural lightweight aggregate concrete, Farmington Hills, MI, 2014, http://www.concrete.org.

[8] ASTM C293/C293M-10, 2010, "Standard Test Method for Flexural Strength of Concrete (Using Simple Beam With Center-Point Loading)", ASTM International, West Conshohocken, PA, www.astm.org

[9] Wei Wen Yu for Centre Cold-Formed Steel Structures, AISI Manual Cold-Formed Steel Design 2002, Edition American Iron and Steel Institute, 2003.

[10] G J Hancock, Design of cold-formed steel structures : to Australian/New Zealand standard AS/NZS 4600: 2005, Australian Steel Institute, North Sydney, 2007.

[11] Sumiati, Mahmuda, Sukarman, and Siswa Indra, Effect of Foam Agent and Polycarboxylate on compression strength structural lightweight concrete, Portal, 2020, Vol. 12, No. 1, April, pp. 33–39.

[12] ASTM C873/C873M-15, Standard Test Method for Compressive Strength of Concrete Cylinders Cast in Place in Cylindrical Molds, ASTM International, West Conshohocken, PA, 2015.