ICC-ES Evaluation Report

ESR-4652

Reissued June 2024

Subject to renewal June 2025

DIVISION: 03 00 00—CONCRETE Section: 03 37 00—Specialty Placed Concrete	REPORT HOLDER: ICON TECHNOLOGY INC.	EVALUATION SUBJECT: ICON 3-BEAD WALL SYSTEM	

1.0 EVALUATION SCOPE

Compliance with the following codes:

- 2021 and 2018 *International Building Code*® (IBC)
- 2021 and 2018 *International Residential Code*® (IRC)

Properties evaluated:

- Physical
- Structural
- Durability

2.0 USES

The ICON 3-bead wall system consists of structural walls printed using 3D automated construction technology. The walls are intended for use as bearing walls, non-load bearing walls, and shear walls, with wall heights from 8 feet (2.4 m) to 10 feet (3.0 m) tall, in Seismic Design Categories A or B. The ICON 3-bead walls are alternatives to concrete walls as described in ACI 318-19 (2021 IBC) and ACI 318-14 (2018 IBC), and as permitted by Section 104.11 of the IBC. For structures regulated under the IRC, the ICON 3-bead wall system may be used where an engineering design is submitted in accordance with Section R301.1.3 and where approved by the building official in accordance with IRC Section R104.11.

3.0 DESCRIPTION

3.1 General:

The ICON 3D Printed Concrete Walls are constructed through the placement of layers (beads) using 3D construction technology. The beads are 2.5 inches (63.5 mm) in width with a bead height varying between 3/4 inch and 1 1/2 inch. The wall assembly consists of a double-bead structural wall with integral grouted vertical cores spaced at a maximum of 6 feet (1.8 m) on center, and a parallel single-bead, non- structural, veneer wall. See Figure 1.

The wall system is reinforced with #5 vertical reinforcing bars placed within the grouted cores and #3 horizontal reinforcing bars placed between beads at both the single-and double-bead walls at a maximum spacing of 12 inches (304.8 mm) on center starting 6 inches (152.4 m) from the base of the wall. The vertical reinforcing bars in the grouted vertical cores are installed either as the wall layers are placed or following full height wall placement. Grout is then placed in the core using one or multiple lifts. The double-bead wall and single-bead veneer wall are connected with 3/16-inch (4.8 mm) diameter steel cross ties at a maximum spacing of 18 inches on center vertical and horizontal, starting at a maximum distance of 6.75 inches (171 mm) from the base of the wall.

3.2 Material:

All materials must comply with the approved specifications outlined in ICON Technology, Inc. quality documentation.

3.2.1 3D Printer: Proprietary Vulcan Printer Model 2.5 series is provided by ICON Technology, Inc.

3.2.2 3D Concrete and Grouted Core: The 3D concrete mix used for printed beads and core infill must be proprietary ICON Lavacrete 4.0 GCC, Lavacrete 4.0 DOLO or Lavacrete 5.0 material, provided by the ICON Technology, Inc., with an average 28-day compressive strength of 2,500 psi (17.2 MPa) or higher after placement at jobsite. Mean slump must be 3 to 9 inches (76.2 to 229 mm) in accordance with ASTM C143.

3.2.3 Steel Reinforcement: Steel reinforcing bars are #5 vertical bars and #3 horizontal bars complying with ASTM A615 and have a minimum yield strength of 60,000 psi (414 MPa). Steel cross ties must be 3/16-inch (4.8 mm) diameter complying with ASTM A580 Grade 304 stainless steel with minimum 4 inch (101.6 mm) hooks each end in-line with the beads.

4.0 DESIGN AND INSTALLATION

4.1 Design:

ICON 3-bead walls must be designed in accordance with ACI 318 as modified by Section 4.1 of this report. ICON 3-bead walls are not to be used in combination with other lateral force-resisting systems within the same structure.

Design of the ICON 3-bead wall system is based on the following assumptions:

a) The value of f'c used for design is 2,500 psi (17.2 MPa).

b) Lightweight concrete factor, λ, is 1.0.

c) Lavacrete 4.0 GCC, 4.0 DOLO and 5.0 unit weight is 130 pounds per cubic foot (2082 kg/m^3).

d) The minimum wall height is 8 feet (2.4 m) tall and the maximum wall height is 10 feet (3.0 m) tall.

e) The maximum integral core spacing is 6 feet (1.8 m) on center.

f) Design strengths, determined in accordance with Section 4.1.1 to 4.1.3 of this report, must be used with load combinations calculated in accordance with the strength load combinations referenced in Section 1605.1 of the 2021 IBC or Section 1605.2 of the 2018 IBC.

4.1.1 Axial Strength Design:

Axial load, P_u, must not exceed the compressive strength of the wall, ϕP_n,determined by ACI 318 Equation 11.5.3.1, as modified below:

$$\phi P_n = \phi \phi_{UC} 0.55 f'_c A_g \left[1 - \left(\frac{k l_c}{32h}\right)^2\right] \qquad \textit{Eq. 1}$$

Where,

$\phi = 0.65$	Axial strength reduction factor for compression-controlled section per ACI 318 Table 21.2.2.
$\phi_{UC} = 0.45$	Unconfined core strength reduction factor determined from testing.
f'_c	Compressive strength of concrete, *psi*
A_g	Cross sectional area of compression section, *in.²*
k	Effective length factor per ACI 318 Table 11.5.3.2
l_c	Length of compression member, *in.*
h	Equivalent thickness of the member, *in.*

The equivalent wall thickness, h, must be considered as the solid wall thickness that results in the same moment of inertia as the double-bead structural wall with integral grouted cores. The gross area, A_g, is to be calculated considering the area of the double-bead structural wall with integrated core, using the effective width of the double-bead structural wall as shown in Figure 2. The area of the single-bead veneer wall must not be considered to contribute to the axial capacity.

4.1.2 Flexural Strength Design:

Flexural load, $M_{u,}$y must not exceed the flexural strength, ϕM_n, determined by:

$$\phi M_n = \phi \phi_b A_s f_y \left(d - \frac{a}{2}\right) \qquad \textit{Eq. 2}$$

Where,

ϕ	Moment strength reduction factor ACI 318 Table 21.2.2
ϕ_b	Bead reduction factor determined from testing.
d	Extreme compression fiber to centroid of reinforcement, *in.*
A_s	Area of reinforcement, *in.*^{2}
f'_c	Compressive strength of concrete, *psi*
f_y	Yield strength of reinforcement, *psi*
$a = \frac{A_s f_y}{0.85 f'_c b}$	depth of equivalent rectangular compressive stress block, *in.*
b	Width of equivalent compressive stress block, *in.*

The veneer bead shall not be considered to contribute to the out-of-plane flexural capacity of the ICON 3-bead wall system. The double-bead structural wall is assumed to span horizontally between integral cores which then span vertically from floor or roof to the floor or foundation.

The capacity of the double-beads spanning horizontally between integral cores must not exceed the flexural strength, ϕM_n, calculated in accordance with *Eq. 2,* where the width of the equivalent compressive stress block, *b,* is taken as 12 in (305 mm), the extreme compression fiber to centroid of reinforcement, *d,* is taken as 4.25 in (108 mm) divided by 2, the bead reduction factor, $\phi_{b,}$ is to be taken as 0.7, and the area of reinforcement, $A_{s,}$ is the area of reinforcement per foot of wall, as shown in Figure 3.

The capacity of the integral cores must not exceed the flexural strength, ϕM_n, as calculated in accordance with *Eq. 2*, where the width of the equivalent compressive stress block, *b,* is the core width as shown in Figure 4 (for exterior pressure) or as shown in Figure 4 using the effective overhanging flange width in accordance with Table 6.3.2.1 in ACI 318 (for interior pressure); the extreme compression fiber to centroid of reinforcement, *d,* is shown in Figure 4; the bead reduction factor, $\phi_{b,}$ is to be taken as 1.0, and the area of reinforcement, $A_{s,}$ is the area of vertical reinforcement in the integral core, 0.31 in^2.

The steel cross ties must be designed to transfer the out-of-plane loads from the one-bead veneer wall to the double-bead structural wall. Cross tie load determined in accordance with Section 4.1(f) must not exceed 250 lbs. (113 kg) per tie, as determined by the tributary area of the tie.

4.1.3 In-Plane Shear Strength Design:

In-plane shear load, $V_{u,}$ must not exceed the shear strength of the wall, ϕV_n, determined by ACI 318 Equation 22.9.4.2, as modified below,

$$\phi V_n = \phi \mu A_{vf} f_y \qquad \textit{Eq. 3}$$

Where,

$\phi = 0.75$	Shear strength reduction factor per ACI 318 Table 21.2.1
$\mu = 0.4$	Friction coefficient for ICON 3D printed walls determined from testing.
A_{vf}	Area of reinforcement located within the integral cores crossing the shear plane, *in.*^{2}
f_y	Yield strength of reinforcement, *psi*

Portions of wall without vertical reinforcement shall not be considered to be part of the vertical lateral load resisting system.

4.2 Installation:

The ICON 3-bead wall must be placed using the proprietary ICON Vulcan printer, operated by qualified personnel as determined by ICON. Once on site, the printer and Lavacrete material must be calibrated and tested in accordance with ICON quality control procedures.

Printing must be conducted under the following environmental conditions:

- Temperature greater than 40˚ F (4.4˚ Celsius)
- Wind speed less than 25 mph (11.2 m/s)
- No precipitation

On site, dry material is mixed with admixtures and water. The material is conveyed through hoses to the printer nozzle. From the nozzle, material is extruded and placed into beads, following predefined print paths. Reinforcement is placed at specified intervals in accordance with the structural details. Cores are filled in one or more staged lifts.

4.3 Special inspection:

Special inspection must be in accordance with Sections 1705.1.1 and 1705.3 of the IBC during the mixing, printing, and placing of the 3D Concrete beads, grouted core and reinforcing bars. In addition, the report applicant must submit inspection procedures to verify proper usage. The inspection must include verification that the concrete compressive strength and flexural bond strength is in compliance with this report. Concrete cylinders of the outer face shells and cores are to be field cured in accordance with ASTM C31 and tested in accordance with ASTM C39. Average flexural bond strength values, tested in accordance with ASTM E518, must meet or exceed 110 psi (793 kPa) for Lavacrete 4.0 mixes, and 52 psi (379 kPa) for Lavacrete 5.0 when printed at a minimum 60-minute extrusion time interval.

5.0 CONDITIONS OF USE:

The ICON 3D Printed Concrete Wall System described in this report complies with or is a suitable alternative to what is specified in, those codes listed in Section 1.0 of this report, subject to the following conditions. In case of conflict, this report governs.

5.1 Design and installation of ICON 3D Printed Concrete Walls must be in accordance with Section 4.1 of this report, the manufacturer's instructions, ACI 318-19 (2021 IBC) or ACI 318-14 (2018 IBC).

5.2 Complete construction documents, including plans and calculations verifying compliance with this report, must be submitted to the code official for each project at the time of permit application. The construction documents must be prepared and sealed by a registered design professional where required by the statutes of the jurisdiction in which the project is to be constructed.

5.3 Special inspection must be provided in accordance with Section 4.3 of this report.

5.4 The ICON 3-bead wall system are limited to non-fire-resistance-rated construction.

5.5 The ICON 3-bead wall system used as the lateral-force-resisting system are limited to Seismic Design Categories (SDC) A and B only.

5.6 The foundation, roof, and their anchorage to the ICON 3-bead wall system are outside the scope of this report and must comply with applicable sections of the IBC and IRC.

5.7 The design provisions given in this section are applicable for ICON 3-bead wall systems with beads printed with an extrusion time interval between 30 minutes and 60 minutes. Pauses in printing longer than 60 minutes shall be reported to the code official and registered design professional in charge of construction. If requested by the code official and/or registered design professional, evidence of equivalent bond strength between printer layers before and after the pause shall be provided to the satisfaction of the code official using the direct tension test method of ASTM C1583.

5.8 The use of bonding agent between printed layers is outside the scope of this report.

5.9 For combined transverse and axial loads, the sum of the ratios of actual loads over design strengths shall not exceed one.

5.10 The use of post-installed anchors in the ICON 3-bead wall system is outside the scope of this report.

5.11 Exterior envelope requirements of the applicable codes have not been evaluated and are outside the scope of the report.

5.12 When applicable and requested by the authority in charge of the construction, water-soluble chloride content of proprietary Lavacrete must be shown to be in compliance with the limits of ACI 318-19 (2021 IBC) or 318-14 (2018 IBC).

5.13 Use of Lavacrete 4.0 DOLO and Lavacrete 4.0 GCC materials for freeze-thaw conditions have not been evaluated and is outside the scope of this report. When requested by the code official, test data for freeze-thaw applications must be submitted by the report holder to the code official for approval.

5.14 Lavacrete is manufactured under a quality control program with inspections by ICC-ES. Proprietary Vulcan Printer 2.5 Series is maintained under a quality control program with inspections by ICC-ES.

6.0 EVIDENCE SUBMITTED

Data in accordance with the ICC-ES Acceptance Criteria for 3D Automated Construction Technology for 3D Concrete Walls (AC509), approved October 2022.

7.0 IDENTIFICATION

7.1 The ICC-ES mark of conformity, electronic labeling, or the evaluation report number (ICC-ES ESR-4652) along with the name, registered trademark, or registered logo of the report holder must be included in the product label.

7.2 The proprietary Vulcan Printer 2.5 Series is provided by the report holder (ICON Technology, Inc.). Printer labeling includes the name of the report holder (ICON Technology, Inc.), and the ICC-ES evaluation report number (ICC-ES ESR-4652). Lavacrete is provided by the report holder (ICON Technology, Inc). Lavacrete labeling includes the name of the report holder (ICON Technology, Inc), and the ICC-ES evaluation report number (ICC-ES ESR-4652).

7.3 The report holder's contact information is the following:

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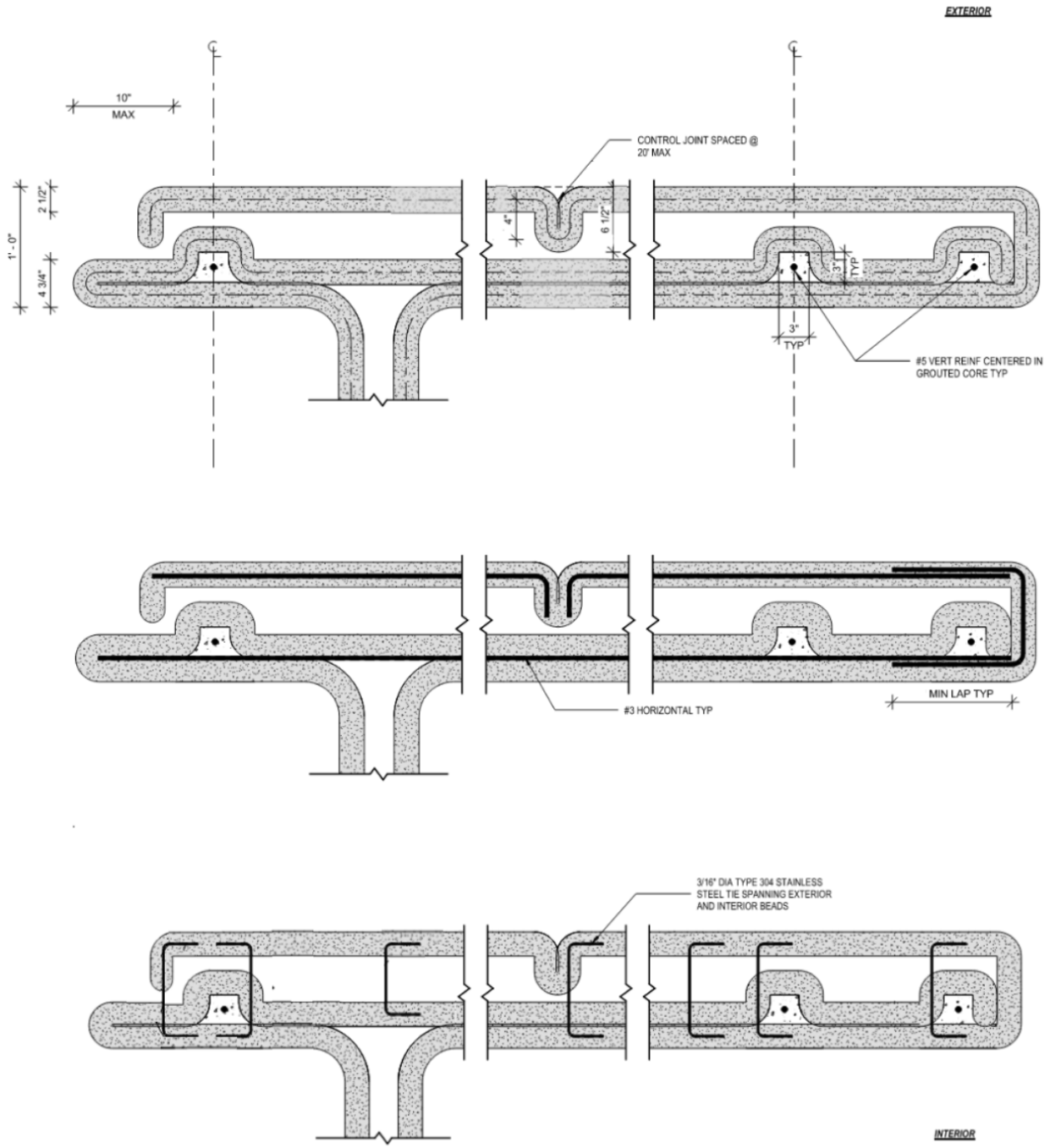

Figure 1: Typical ICON 3-bead Wall Assembly (Plan View)

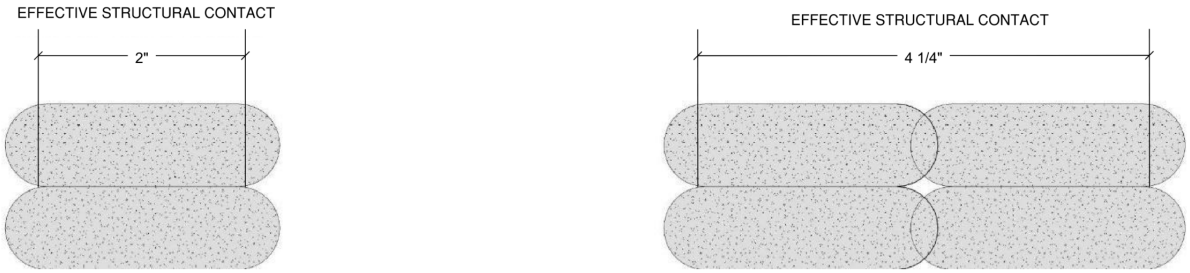

Figure 2: Effective width of wall sections

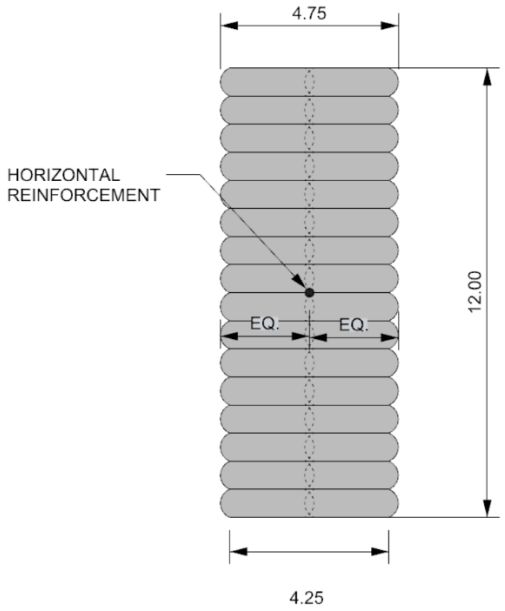

Figure 3: Double bead Section for Horizontal Span between Grouted Cores

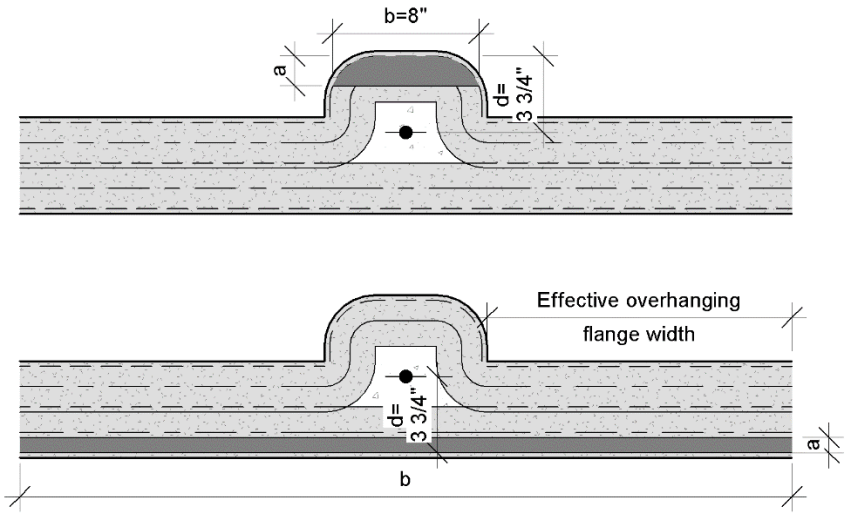

Figure 4: Stress blocks for exterior pressure (top) and interior pressure (bottom)