ICC-ES Evaluation Report

ESR-4623

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DIVISION: 03 00 00 — CONCRETE **Section: 03 37 00 — Specialty Placed Concrete**	**REPORT HOLDER: BLACK BUFFALO 3D CORPORATION**	**EVALUATION SUBJECT: BLACK BUFFALO 3D CONCRETE WALLS**	

1.0 EVALUATION SCOPE

Compliance with the following codes:

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

Property evaluated:

- Physical
- Structural
- Durability

2.0 USES

The Black Buffalo 3D Concrete walls are structural walls printed using 3D automated construction technology, used as bearing walls, non-load bearing walls, and shear walls in multi-story structures up to a maximum height of 40 feet (12 m) in Seismic Design Categories A or B. The Black Buffalo 3D Concrete walls are an alternative 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 Black Buffalo 3D Concrete walls may be used where an engineering design is submitted in accordance with IRC 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 Black Buffalo 3D Concrete walls are constructed by extruding 3D Concrete in layers using 3D construction technology to create two face shells. The face shells are tied together with truss type reinforcing bars, and ACI 318 code compliant normal-weight concrete core is placed between the face shells to form a solid wall.

3.2 Material:

All materials must comply with the approved specifications outlined in the Black Buffalo 3D Corporation quality documentation.

3.3 3D Printer: Proprietary Black Buffalo 3D Nexcon Printer is provided by the Black Buffalo 3D Corporation.

3.4 3D Concrete Mix: Proprietary BB3D AC509 Concrete Mix (MAPEI Planitop 3D) is provided through the Black Buffalo 3D Corporation and must have minimum 28-day compressive strength of 10,000 psi (69 MPa) after placement at jobsite. Mean slump must be 6 ± 1 inches (152 ± 25 mm) in accordance with ASTM C143.

3.5 Concrete Core: Concrete core must be an ACI 318 code compliant structural normal-weight concrete with minimum specified compressive strength (f'c) of 3,000 psi (21 MPa). Before concrete core is placed, the printed face shells must be cured for a minimum of 7 days in compliance with the manufacturer's installation instructions.

3.6 Steel Reinforcing: Steel reinforcing must be 9-gauge (0.144-inch or 3.7 mm) truss type building code compliant reinforcing bars.

4.0 DESIGN AND INSTALLATION

4.1 Design:

4.1.1 General: The extrusion thickness of each face shell is 2¼ inches (57 mm). The maximum unbraced printed wall height is 10 feet (3.04 m) with a concrete core thickness of 3 ½ inches (89 mm). In all Black Buffalo 3D Concrete walls, 9-gauge (0.144-inch or 3.7 mm) truss type reinforcing bars are placed at 8-inch (203 mm) on-center starting 8 inches (203 mm) above the base of the wall. Axial and flexure reinforcing are not considered in the following design equations and are outside the scope of this report. All design equations and limits given in this section are for an extrusion time interval of 5 minutes. Design must follow applicable provisions of TMS 402-16, ACI 304R-00 and Sections 4.1.2 through 4.1.4 of this report. The Black Buffalo 3D Concrete walls may not be used in combination with other lateral force-resisting systems within the same structure. The following design equations and limits can only be applied when the lateral force-resisting system consists of Black Buffalo 3D Concrete shear walls only.

4.1.2 Allowable Axial capacity Design:

$$f'_a \leq 490\ psi\ (3.37\ MPa)$$

The axial load on the wall must not exceed the lower of the following:

$$F_a = \frac{1}{4} * f'_{m3D} * \left[1 - \left(\frac{h}{140r}\right)^2\right] \leq 490\ psi\ (3.37\ MPa)$$

$$P \leq \frac{1}{4} * P_e$$

Where:

$$P_e = \frac{\pi^2 * E_{3D} * I_n}{h^2} * (1 - 0.577 * \frac{e}{r})^3$$

$F_a = Allowable\ axial\ compressive$

$stress\ available\ to\ resist\ axial\ load\ only\ (psi)$

$f'_{m3D} = Specified\ compressive\ strength = 1960\ psi$ *(13.5 MPa)*

$P = Axial\ load\ (lbs)$

$E_{3D} = Modulus\ of\ Elasticity = 1764\ ksi\ (12.2\ Gpa)$

$h = unbraced\ height\ of\ the\ wall\ (in)$

$r = radius\ of\ gyration\ (in)$

e = eccentricity of axial compressive load with respect to the member longitudinal centroidal axis

I_n = moment of inertia of net cross-sectional area of a member, in.^{4} (mm^4)

Axial tension loads have not been evaluated and are outside the scope of this report.

4.1.3 Allowable Flexural Capacity Design:

$$F_t \leq \frac{1}{3} * f'_{tu} = \frac{90psi}{3} = 30\ psi\ (0.21\ MPa)$$

$$F_b \leq \frac{1}{3} * f'_{m3D} = \frac{1}{3} * 1960psi \leq 653\ psi\ (4.50\ MPa)$$

Where:

$F_t = Allowable\ tensile\ stress$ available to resist flexure only (psi)

$F_b = Allowable\ compressive$ stress available to resist flexure only (psi)

$f'_{tu} = Ultimate\ flexural\ tension\ strength\ (psi) \leq 90\ psi\ (0.6\ MPa)$

The combination of axial compression and flexure shall not exceed:

$$\frac{f'_a}{F_a} + \frac{f'_b}{F_b} \leq 1.0$$

$$P \leq (\frac{1}{4}) * P_e$$

Where:

$F_a = Allowable\ Axial\ Strength\ (psi) \leq 490\ psi\ (3.37\ MPa)$

$F_b = Allowable\ Flexural\ Compression\ Strength\ (psi) \leq 653\ psi\ (4.50\ MPa)$

4.1.4 Shear Capacity Design:

The allowable in-plane shear stress, F_v, must not exceed:

$$F_v = 1.5 * \sqrt{f'_{m3D}}$$

Shear failure of the 3D concrete wall due to out-of-plane loading has not been evaluated and is outside the scope of the report.

4.1.5 Reduction factor for extrusion times: Design provisions published in this evaluation report are based on extrusion printing time interval between 5 and 15 minutes. The registered design professional in charge of design must limit the allowable extrusion printing time between layers for each project in construction documents to a maximum of 15 minutes and must consider a 20 percent reduction in structural capacity of the printed walls for each 5 minutes increase in extrusion time interval beyond 5 minutes. The tested flexural bond strength in accordance with ASTM E518 is 92.5 psi (kPa) at a 15-minute extrusion interval between printed layers.

4.2 Installation:

4.2.1 Preparation: Before installation, the Black Buffalo 3D Corporation approved technical team (3DCP Technical Team) performs a preparatory inspection of the machine and material, which includes the following:

- Identification of abnormalities of the system including deformation, vibration, and audible abnormalities.
- Verification of availability and quality inspection status of required materials.
- Performance of dry runs of the printing paths.
- Discussion of any potential problems with the Black Buffalo 3D Corporation Quality Manager.

4.2.2 3D printing process: The 3D printed face shells are constructed with 3D automated technology in accordance with the Black Buffalo 3D Corporation 3D printing process. The dry mix and water are supplied to the mixer. The dry mix is mixed with water to produce the wet mixture. The wet mixture is pumped through the hose into the nozzle. The wet mixture is extruded through a nozzle.

4.2.3 Construction process: Components of construction other than 3D Concrete walls are to be integrated following the printing and curing of the 3D concrete walls. The face shells of the 3D printed concrete structure are to be printed in accordance with the procedures described in Section 4.2.1 and the Black Buffalo 3D Corporation 3D printing process. The face shells of the walls are 2¼ inches (57 mm) thick. No. 9 gage horizontal truss type steel wire reinforcing is placed 8 inches on-center (203 mm on-center) starting 8 inches (203 mm) above the base of the wall. The core is filled with ACI 318 code compliant concrete core material after 7 days of curing of the printed 3D concrete.

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 face shells, proprietary concrete 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 face shells and concrete core are to be field cured in accordance with ASTM C31 and tested in accordance with ASTM C39. Flexural bond strength tested in accordance with ASTM E518 must be within ± 10 percent of the 15-minute value reported in Section 4.1.5 of this report.

5.0 CONDITIONS OF USE:

The Black Buffalo 3D Concrete walls described in this report comply with, or are a suitable alternative to what are 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 Black Buffalo 3D concrete walls must be in accordance with Section 4.1 of this report, the manufacturer's instructions, IBC, or IRC.

5.2 The Black Buffalo 3D Concrete walls are limited to use in multi-story structures up to maximum 40 feet (12 m) height with a minimum story to story height of 4 feet (1.22 m), and a maximum story to story height of 10 feet (3.05 m).

5.3 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.

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

5.5 The Black Buffalo 3D Concrete walls are limited to non-fire-resistance-rated construction.

5.6 The Black Buffalo 3D Concrete walls used as the lateral-force-resisting system are limited to Seismic Design Categories (SDC) A and B only.

5.7 The foundation, roof, and their anchorage to the Black Buffalo 3D Concrete walls are outside the scope of this report and must comply with applicable sections of the IBC and IRC.

5.8 For combined transverse and axial loads, the sum of the ratios of actual loads over design loads shall not exceed the limits outlined in Section 4.1.3 of this report.

5.9 The use of reinforcement other than as described in Section 4.1.1 and 4.2.3 of this report in Black Buffalo 3D Concrete walls is outside the scope of this report. Post-installed anchors in Black Buffalo 3D Concrete walls are outside the scope of this report.

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

5.11 When applicable and requested by the authority in charge of the construction, water-soluble chloride content of proprietary BB3D AC509 Concrete mixture (MAPEI Planitop 3D) must be shown to be in compliance with the limits of ACI 318-19 (2021 IBC) or 318-14 (2018 IBC).

5.12 The proprietary BB3D AC509 concrete mix (MAPEI Planitop 3D) is manufactured under a quality control program with inspections by ICC-ES. The proprietary 3D printer 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 December 2021.

7.0 IDENTIFICATION

7.1 Proprietary Black Buffalo Nexcon Printer is provided by the report holder (Black Buffalo 3D Corporation). Printer labeling includes the name of the report holder (Black Buffalo Corporation), and the ICC-ES evaluation report number (ICC-ES ESR-4623). Proprietary BB3D AC509 Concrete mix (MAPEI Planitop

3D) is provided through the report holder (Black Buffalo 3D Corporation). 3D Concrete labeling includes the name of the report holder (Black Buffalo 3D Corporation), and the ICC-ES evaluation report number (ICC-ES ESR-4623).

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

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