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<th><strong>Docket Number:</strong></th>
<th>20-DECARB-01</th>
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<tr>
<td><strong>Project Title:</strong></td>
<td>Building Initiative for Low-Emissions Development (BUILD) Program</td>
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<tr>
<td><strong>TN #:</strong></td>
<td>234277</td>
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<tr>
<td><strong>Document Title:</strong></td>
<td>Alaska Applied Sciences, Inc. Comments - Thin-shell concrete structures, multi-purpose, for low embodied and operating energy and durability</td>
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<td><strong>Description:</strong></td>
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<td><strong>Filer:</strong></td>
<td>System</td>
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<tr>
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<td>Alaska Applied Sciences, Inc.</td>
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<td>8/10/2020</td>
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Thin-shell concrete structures, multi-purpose, for low embodied and operating energy and durability

Thin-shell concrete structures, necessarily quasi-spherical in shape, consequently limited to large radii of curvature to achieve structural integrity, also provide durable, low-cost, multi-purpose shelter with low embodied and operating and maintenance (O&M) costs. Built on-site, about one structure per forms set, per four days. California's extant concrete construction industry will easily adapt to this construction method, for residential and diverse uses -- perhaps, at first, to accommodate a wave of COVID-caused homelessness, and to welcome temporary ag workers. Structure cost will depend primarily upon finish level: insulation (interior: sprayed, closed-cell urethane foam); plumbing and wiring; cabinetry and appliances -- if any. Concrete shell cost is relatively low; shell thickness ~ 2 cm; < 1 inch.

Please consider scaling-up our proof-of-concept, scale model, prototype work from 2009, in Juneau, AK. About $ 250 - 500 K investment will be needed for CAD, building the tools by which the concrete forms sets may be manufactured, by which the thin-shell concrete structures are built on-site, and for building several sets of forms for field tests and shelters production. Please see: www.AlaskaAppliedSciences.com/thin-shell-concrete-structures Please see attached slide presentation; larger slide presentation available on request. The original forms set, by which the prototype scale models were built in 1990, are available for further R&D use, although they were not designed for, nor probably durable enough for, production of more than a few structures.

Additional submitted attachment is included below.
Thin-shell Concrete Structures for Low Embodied and Operating Energy and Durability

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Rev: 15 Jan 10

TechConnect 2015
Abstract # 747
Washington, DC  14-18 June 15

For:  CEC  20-DECARB-01
Submitted:  8 Aug 20

Juneau, AK  1977:    16’ diameter concrete dome:  ½” thick, ~ 5/8 sphere
Thin-shell Concrete Dome Rapid Construction Method
for Remote Sites and Severe Climates
Proof-of-concept scale model prototype
Juneau, AK 2010

- Complete reusable form sets
- 8 ft 6 in = 2.6 m equatorial diameter, 5/8 sphere

2010 Juneau, Alaska
~ 1/2” thick concrete shell
46% proof-of-concept scale model of 18 ft diam
Interior sprayed UR foam super-insulation
Goals

1. Minimize imported:
   a. Materials, including aggregate
   b. Tooling
   c. Tools
   d. Expert labor
   e. Use local sand, water, semi-skilled labor
   f. Minimize Earth impact
2. Build many on-site, in-situ
   a. Reusable forms set
   b. One every 3 – 4 days
3. Non-ferrous primary reinforcement
4. Spray-in insulation
5. Durable, strong, fireproof, vermin-proof, waterproof
6. Earth sheltered: compatible
7. Alaska village housing replace
Prototype: 8’ 6” equatorial ID concrete shell, ~ 5/8 sphere
Framed Entry

Foam Insulated
2-pound UR, closed cell

Treated wood floor framing and plywood
• 46% scale model of 18’ ID full-size concrete dome
• ~ 5/8 sphere (volume)
• 8’ 6” equatorial ID (concrete shell)
• < 1/2” thick concrete shell
  – Need engineering to confirm adequate structurally at full scale
  – FEA necessary for stress concentrations
  – Integral waterproofing: no coating needed
  – Earth berming or burying compatible
• Unique, reusable tooling
• Mortar:
  – Rich, portland cement
  – Sand only aggregate
  – High-fiber
• Reinforcement:
  – Primary: Chomarat C-Grid
  – Secondary: Fibermesh 150
• 13-part dome form (12 side + top cap)
• Teflon dome form release surface
• UR foam insulated + protection layer
Prototype mortared:
- 12 Nov 09
- Hand troweled; no vibration
- Dome form removed 14 Nov

No shrinkage cracking in dome; cracks in entry roof

Concrete form sets:
- Foundation, dome sets
- Hand-made tooling
- Reusable; many cycles → refurbish
- Teflon release surface

“Circus ring” minimal foundation: 3” x 4” cross-section

5/8 sphere (volume) dome
- Shim-assembled dome: unique
- Easy assembly, removal: team of two
- Easy removal from cured shell
- Staples captured by outer rubber plies

Foundation + dome + entry = integrated structure
Proof - of – Concept Prototype
Slide 3 of 3

- Shoestring R+D project
- No engineering: concept only
- No load testing:
  - Prototype not representative: poor mortar application QC
  - Establish protocol
- Concrete Form Sets: Hand-made tooling
  - Foundation: plywood + foam + “Integument” Teflon
  - Dome:
    - Wet-layup epoxy glass: 12 + 1 pieces
    - 60 mil EPDM roofing
    - 30 mil butyl PSA
    - 5 mil Teflon
- Non-ferrous, non-corroding reinforcements
  - C-Grid primary (carbon-epoxy fiber grid)
  - SS staples tile rectangles to form
  - 1/4” self-stick rubber chairs
  - Fibermesh 150: 1/4 “ + 3/4 “ cut, in mortar mix
- Easy mortar application:
  - Sand-only aggregate
  - Trowel
  - Spray
  - Shotcrete
- Ideal for superinsulation:
  - Minimum surface area for volume
  - No thermal bridging through structural elements
  - Easy UR foam and interior finish spray application
1. Dome form removable, reusable
   a. Removable shims liberate segments
   b. Teflon surface releases concrete
2. Non-ferrous, non-corroding reinforcements
   a. C-Grid primary (carbon-epoxy fiber grid)
      I. 1/4” self-stick rubber chairs center C-Grid
      II. Rectangles easily “tile” spherical surface
      III. SS staples tile C-Grid rectangles to form
   b. Fibermesh 150: 1/4 “ + 3/4 “ cut, in mortar mix
3. < 1/2” thick concrete shell achievable
4. Easy mortar application
   a. Trowel proven, but poor QC in prototype
   b. Unproven: Spray or shotcrete
5. Minimal “circus ring” foundation adequate
   a. 3” x 4” cross-section
   b. One #3 rebar continuous, centered
   c. Continuous embedded fiberglass mesh: dome tie-in
   d. 6 embedded lifting lugs
   e. Entry framed structure bolted to ring
   f. Easy to build on-grade
   g. Many floor options

6. Integral concrete structure combines:
   a. Foundation ring
   b. Dome
   c. Entry roof
Designed for:

- Alaska village housing, classroom, clinic, storage
- Permanent structures built on-site
- Minimum
  - Embodied energy
  - Operating energy: UR foam superinsulation
  - First cost
  - LCC
- Minimum imported
  - Tooling and tools
  - Materials
  - Expert labor
- External structural shell
  - Durable
  - Waterproof
  - Fireproof
  - Impervious to corrosion, vermin
- Rapid replication of shell
- Reusable male form; long life
Also useful for:

- Strategies combining development + combat
- Afghanistan and others
- Civilian
- Military
- Disaster relief
- Low cost housing
- Classrooms
- Clinics
- Storage
- Emergency shelter
- Potentially transportable
Dome Reusable Form System

Slide 1 of 2

• Fiberglass structure
• 13 pieces
  – 12 identical side “orange peel” segments;
  – Door opening in one
  – Integral threaded inserts for bolted assembly
• Top cap
• Outer adhered plies:
  – 60 mil EPDM unreinforced roofing membrane
  – “Integument”:
    • P500W-MX-36 Fluorogrip MX membrane
    • 30 mil butyl adhesive
    • 5 mil Teflon film concrete release surface
    • Adhered over 60 mil EPDM
  – 95 mil outer plies capture primary reinforcement staples
• Two-person assembly and removal
• 12 removable side shims
  – Assemble between 12 side segments
  – 1/4” plywood + “Integument” Teflon
  – ~ 5/16” total thickness
• 12 removable bottom shims
  – Assemble under 12 side segments
  – 1/4” plywood + “Integument” Teflon
  – ~ 5/16” total thickness
• 12 removable sheet steel skid plates
  – Placed on concrete foundation
  – Ease bottom shim removal
Foundation Reusable Form System

- Designed for on-grade, permanent construction
- May be truck-transportable, depending on size
- 4” wide x 3” high foundation ring cross-section @ 46% scale
- Outer 1/2” ledge prevents water migration
- Inner 1/2” ledge supports floor
- Concentric rings, 6 segments each
- Precision splice plate ring assembly
- Precision alignment of rings
- 5/16” foam shim on inner “key” segment
- One continuous circumferential #3 bar
- Embedded continuous Sto fiberglass mesh for dome tie-in
- Embedded 1/2” steel studs for outer lifting lugs
- Teflon and vinyl concrete release surfaces
Foundation Form Set

- Outer ring set
- Inner ring set
- Key section
- 1/2" allthread lifting lugs
- Outer ring splice plates
- Inner ring splice plates
- Ring alignment interconnections
- Center
- Fiberglass mesh continuous dome tie-in
- Vibrator
Assembled foundation form, ready for pour

- Fiberglass mesh
dome tie-in

- Precision ring
  alignment fixtures

- “Key” segment

- Center

- Lifting lug studs (6 pl)

Assembled foundation form, ready for pour
1/2” Lifting lug stud

Fiberglass mesh dome tie-in

Dome form rests here

1/2” ledge inside and outside prevents water migration

“Circus ring” foundation: 4” W x 3” H, outward view
Begin dome form assembly

- Side wall shim (1 of 12)
- Bottom shims
- Framed entry
- Sheet steel skid plates
Removable side shim: this joint will be covered with 1” blue masking tape.

Sto fiberglass mesh continuous dome tie-in: prototype radius too large, requiring too much mortar to encapsulate mesh.

Removable bottom shim.

Removable sheet steel skid plate, under bottom shim.

Doorway

Entry floor

Entry-to-foundation bolt joint.
Continuous first course
C-Grid SS stapled
Masking tape covers side shims joint; may be unnecessary for production tooling
Skylight, vent
8” chimney (at full scale)
**Prototype Mortar Mix Batch**  
**Sand — only aggregate**

<table>
<thead>
<tr>
<th>Component</th>
<th>Weight</th>
</tr>
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<tbody>
<tr>
<td>Sand, ungraded, bagged “play sand”</td>
<td>61 lbs</td>
</tr>
<tr>
<td>Portland cement (Lafarge Type I &amp; II)</td>
<td>25 lbs</td>
</tr>
<tr>
<td>Water</td>
<td>17 lbs</td>
</tr>
<tr>
<td>Silica Fume (BASF SF100)</td>
<td>6 lbs</td>
</tr>
<tr>
<td>Xypex #500 crystalline waterproofing</td>
<td>7.4 oz</td>
</tr>
<tr>
<td>Superplasticizer (BASF PS-1466)</td>
<td>1.5 oz</td>
</tr>
<tr>
<td>Fibermesh 150: 1/4 “ cut (polyprop)</td>
<td>1.5 oz</td>
</tr>
<tr>
<td>Fibermesh 150: 3/4 “ cut (polyprop)</td>
<td>1.5 oz</td>
</tr>
</tbody>
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**TOTAL** 110 lbs

7 batches used = 770 lbs  
770 lbs / 3,915 lbs / cu yd = 0.2 cu yd = 5.4 cu ft x 1,728 = 9,330 cu in  
Total area (dome + entry roof) = 172 sq ft = 24,800 sq in  
Inferred average concrete thickness: 9,330 / 24,800 = **0.38 inch**
After dome ~ 80% mortared, hinged entry roof dropped into place for continuous concrete structural continuity
Hinged Entry roof dropped into place
Continuous C-Grid embedded for structural integrity of dome and entry
Entry roof hinge
Removable entry roof form
Z-flashing (4 pcs)
• Interior concrete shell after form set removed
• Blue masking tape sealed joints; easily removed
• 1/4” high UR rubber self-stick “chairs” on lower region
• Thinner white felt chairs used on upper region
• Mortar consolidation, penetration and C-Grid capture varies
• No vibration used during mortar placement
14 Nov 09
Remaining Challenges + Opportunities

Slide 1 of 4

• Engineering design:
  – FEA for stress concentrations (windows, door, entry roof)
  – Reinforcing design at concentrations
  – Optimize C-Grid or other primary reinforcement
• Load testing: static, dynamic protocols
• Materials and process experiments
  – Mortar mix recipe
  – Indigenous aggregates: selection, qualification, preparation
  – Mortar application: potential spray or shotcrete
  – Mortar consolidation
    • Encapsulate C-Grid
    • Voids removal
    • Vibration
      – Multiple points
      – Devices integral to form
      – Manual control strategy
      – Air or electric
• Interior foam protection + finish
  • Spray: hopper gun or other
  • Same machine as concrete shell spray
  • Product: bagged mix, properties
  • Thickness required; control
Remaining Challenges + Opportunities

Slide 2 of 4

• Process quality control:
  – Mixes
  – Thickness
  – Consolidation
  – Cure; insure hydration

• Special tools
  – Interior + exterior arc ladders
  – Form removal post-cure
  – Vibration, consolidation

• Potential to replace or eliminate primary reinforcement
  – May be necessary to capture and position mortar
  – C-Grid alternatives:
    • Lower cost
    • Easier to handle and apply
    • fiberglass grid
    – “ECC” Engineered Cementitious Composite only

• Potential to replace EPDM + Integument Teflon release surface
  – Silicone paint, roofing
  – Bedliner spray
Remaining Challenges + Opportunities

Slide 3 of 4

- Tool for “full size” ~ 18 ft diam @ equator: $300 – 500K?
  - 3D CAD design
  - Mold tooling build:
    - Side wall “orange peel” segment
    - Top cap
    - Foundation outer ring
    - Foundation inner ring
  - Form sets build: fiberglass boat processes for precision
    - Foundation
    - Dome
  - Framed entry kit develop
- Full-size development work by contractor & subcontractors
  - Funding source(s)
  - Markets:
    - Customers and applications
    - Cost models: various
  - Business model:
    - Franchise: sell tooling and tool sets + training + QC
    - Others
• Revise design from field experience
• Window, skylight options
  – Add interior partition wall:
  – Support loft
  – Private space
• Ventilation options (climate and cost determined)
  – Manual vs powered
  – Air-to-air heat exchanger
  – Equipment in entry roof peak
• Heating / cooling options (climate and cost determined)
  – Stove – chimney system
  – Passive solar via south-facing window
  – Thermal mass
• Floor options (on grade; thermal break required)
  – Compacted earth
  – Foam board underlayment, closed cell, thermal insulation
  – Soil cement
  – Concrete
• Floor options (on pilings or stem wall; thermal break required)
  – Framed structurally supported by foundation ring
  – Other
Goals

1. Minimize imported:
   a. Materials, including aggregate
   b. Tooling
   c. Tools
   d. Expert labor
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References

Chomarat NA  http://carbongrid.com/
   "Broadway, Andrew" <andrew.broadway@chomaratna.com>
Integument  http://www.integument.com/
   "Jennifer Smyth" <jsmyth@integument.com>
CCHRC (Cold Climate Housing Research Center, Fairbanks, AK)  http://www.cchrc.org/
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Xypex  http://www.xypex.com/
   “Les Faure” <les@xypex.com>
Intershelter  http://intershelter.com/
   Don Kubley  (907) 789-9273
Flexible concrete  Prof. V. S. Li, University of Michigan
   Prof. Michael Lepech, Stanford University
BASF (superplasticizer, silica fume, fibermesh)
Sto (fiberglass mesh, SilcoLastic paint)
Thin-shell Concrete Structures for Low Embodied and Operating Energy and Durability

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