Design & Usage of Micro-Reinforced Concrete Ducon for Seismic Jacketing

& Other Applications in Buildings and Infrastructure for both New Construction and Retrofit

PEER Annual Meeting
UC Berkley October 1st 2011
Philipp Hofmann, Dipl.- Ing., MBA
U.S. Largest Specialty Repair Contractor with 25 offices across United States

Successfully completed over 15,000 Structural Repair and Strengthening Projects

Structural Technologies as Engineered Product Arm for Specialty Solutions

Track Record of Technology Adoption and Implementation
Post tensioning Systems (VSL)

Structural Strengthening Systems

Seismic Systems

Force Protection Systems

Corrosion Control Systems

Waterproofing Systems
Micro-Reinforced Concrete Ducon
Agenda

- Technology Overview
- Material Properties and Design
- Performance and Sustainability
- Seismic Applications
- Technology Adoption in U.S.
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Concrete Reinforcement Technology Leaps

- SFRC = Steel fiber reinforced concrete
- SIFCON = Slurry infiltrated fiber concrete
- SIMCON = Slurry infiltrated mat concrete
- SIMRC = Slurry infiltrated micro-reinforced concrete

DUCON 6 1999
SIMCON
Slurry infiltrated mat concrete
DUCON (DUctile CONcrete)

- Slurry infiltrated micro reinforced concrete invented in 1999
- High performance concrete with high strength micro steel reinforcement (18ksi)
- Micro reinforcement is throughout entire section vs. outsides only
- Patented technology backed by extensive testing
- Enormous ductility and therefore suited for Seismic and ATFP applications
DUCON Slurry Infiltrated Micro Reinforced Concrete
Concrete Slurry Infiltration
SLURRY INFILTRATION (SCC)
DUCON High Performance Concrete
Flexible Dense Watertight Durable
Technology Overview

Material Properties and Design

Performance and Sustainability

Seismic Applications

Technology Adoption in U.S.
Different Steel Qualities

- High Strength
- Normal Strength
- Stainless Steel

Stress [ksi]

- 120ksi
- 80ksi (Hardwire)
- 60ksi (Softwire)
DUCON – Adjustable properties

Ductility

Standard concrete
Fiber reinforced concrete
DUCON (adjustable)

Flexural strength [psi]

Deflection [%]
DUCON Highest Ductility and Strength

Flexural strength **DUCON ductile**
Stress-Strain-Curve

- **DUCON**
- **ECC**
- Standard Concrete

Deflection [Strain]

Flexural Stress [N/mm²]
DUCTAL is **NOT** a ductile concrete
Contact Detonation

Rear Side
Shear Test
Shear Test
Shear Test
Shear Test
# Technical Data

<table>
<thead>
<tr>
<th>Property</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compressive Strength</td>
<td>16,000 psi – 18,000 psi</td>
</tr>
<tr>
<td>Tensile Strength</td>
<td>2,100 – 2,900 psi</td>
</tr>
<tr>
<td>Shear Strength</td>
<td>1,800 - 2,300 psi</td>
</tr>
<tr>
<td>Minimum Thickness</td>
<td>&gt; 0.4 inches</td>
</tr>
<tr>
<td>Minimum Cover</td>
<td>&gt; 0.04 inch</td>
</tr>
<tr>
<td>Young’s-Modulus</td>
<td>3.200 ksi - 4.200 ksi – 5.800 ksi</td>
</tr>
<tr>
<td>Ductility factor</td>
<td>&gt; 10 (strain ultimate/ strain yield)</td>
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</table>
DUCON Stress Strain Design (ACI)
Agenda

- Technology Overview
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Comparison experimental and analytical strength
More design efficiency, lower scattering
Stress Strain Curves of cylinders with different number of mesh layers

![Stress Strain Curves](image)
Residual load bearing capacity after blast

Reinforced Concrete

4.8%
Residual Load Capacity

DUCON

65.9%
Residual Load Capacity
Watertight above 0.75"

$\text{d} = 20\text{mm}$

$\text{d} = 10\text{mm}$
Performance Aspects

- Homogenous and isotropic material
- High performance concrete  High ductility
- Precise crack control by micro-reinforcement (crack width < 0.04")
- Reduction of concrete cover to a minimum (1 - 2mm)
  → High density and Low depth of carbonation
  → Stainless steel to exposed side
- Programmable material behavior by choice of steel type and quality
- Higher design efficiency due to more reliable material behavior
- Pre-cast as well as cast-in place
- Long term durability  - Freeze thaw and water penetration resistant
Comparison of RC and MRC

Reinforced Concrete
- Rebar congestion
- Brittle failure
- Corrosion
- Shrinkage cracking
- Durability problems

Micro-reinforced Concrete
- Innovative Micro-reinforcement
- Steel volume between 5%-12%
- Unprecedented Ductility
- Reduction of thickness
- Perfect crack control
- Long term durability

8” 8"
Sustainability Aspects

More efficient structural elements:
• Less dead load on superstructure & foundations.
• Smaller footprint. Reduced floor-to-floor height.
• Reinforce existing structural elements.

50% Reduction of material-quantity:
• Less energy for production
• Less exploitation of natural resources
• Less material to extract, export, and handle.

Long-life performance and durability
• Less repair effort
• Larger intervals of restoration
• Less pollution of environment
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DUCON Seismic Jacketing

15 ft

DUCON
DUCON Seismic Column Confinement

Load transfer

Confinement

Dynamic load transfer

Rebars for load transfer
DUCON Seismic Column Confinement

100 Columns in Industrial Facility Turkey – High Seismic Zone
**DUCON Seismic Column Confinement**

**Load bearing columns of one-storey warehouse**

<table>
<thead>
<tr>
<th>System</th>
<th>Cantilever column</th>
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<tbody>
<tr>
<td>Dead load</td>
<td>300 kN</td>
</tr>
<tr>
<td>Snow</td>
<td>200 kN</td>
</tr>
<tr>
<td>Wind (only in main direction)</td>
<td>8 kN</td>
</tr>
</tbody>
</table>

- Concrete existing column: C20/25
- Steel grade existing column: BST 500
- Existing reinforcement: 8Ø20

**Earthquake loading**

- Soil classification: 2C
- Response spectrum
- Earthquake main direction: (see table)
- Earthquake other direction: 30% of loading of main direction
- Earthquake vertical: negligible according EC 8

**Retrofit, column confinement (DUCON)**

- Steel grade: S600
- Concrete: C90

<table>
<thead>
<tr>
<th>System</th>
<th>Earthquake zone</th>
<th>Ground acceleration [m/s²]</th>
<th>a [cm]</th>
<th>b [cm]</th>
<th>l [m]</th>
<th>University section (DUCON)</th>
<th>Earthquake H-load [kN]</th>
<th>a_s [cm²]</th>
<th>Thickness [cm]</th>
<th>a_s [cm²]</th>
<th>%</th>
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<td>0</td>
<td>35</td>
<td>35</td>
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<td>--</td>
<td>0.0</td>
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<td>35</td>
<td>35</td>
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<td>46.5</td>
<td>68.1</td>
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<td>2</td>
<td>1.47</td>
<td>35</td>
<td>35</td>
<td>4.50</td>
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<td>27.9</td>
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<td>3</td>
<td>2.45</td>
<td>35</td>
<td>35</td>
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<td>2</td>
<td>1.47</td>
<td>35</td>
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<tr>
<td>3b</td>
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<td>7.2</td>
<td>1</td>
<td>1</td>
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</tbody>
</table>
DUCON Seismic Column Confinement

Form and pump
DUCON Seismic Column Confinement
DUCON Column Jacketing

7 ft x 7 ft  H = 9 ft

3 ft  H = 15 ft
Bridge Pilar Jacketing

Structural Strengthening Germany
DUCON Column Strengthening in Highrise
DUCON Column Strengthening

2.4” thick
Column Forms as Confinement
Column Forms as Confinement
DUCON
Column Forms
DUCON Column Forms
Thin load bearing elements (0.6\" / 15mm)
Prestressed DUCON Panel 20′ long

Panel:  $l=6,0m$, $b=1,0m$, $d=6,0cm$
Span = 5,2m
Prestressed DUCON Panel
20' long 2.25" thick
Shear Walls
Shear Walls
Shear Walls
Large Load Bearing Precast Elements
Thin load bearing elements (3.25“)

Stairs as folded framework  \( d = 3.25\)“  14-stairs free-span
Public Infrastructure
Thin Structural Micro-Overlay

Structural Strengthening
Structural and Abrasion Resistant Overlays
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Challenges/barriers in bringing DUCON to the U.S.

- **Code approval**
  - Civil Structures: FHWA / DOT

- **Massive Testing Regime and Standardization**

- **Cost of Welded Wire Mesh**
  - Cheaper Sources overseas vs. Buy America

- **Nationwide distribution of DUCON Cement Mix**
  - Looking for Cement Manufacturers/ Blenders as Partners

- **Facilitation of cast in place production**
  - Modify mix for ready mix operation

- **Information and know-how transfer**
  - Education and edification of A/E, Contractors, Precaster Community
  - Institutionalized know transfer to academia, government and public
Successes to date in bringing DUCON to U.S.

U.S. MILITARY EARLY ADOPTION
• U.S. Army Corps of Engineers – Protective Design Center (PDC)
• Testing at Tyndall Air Force Research Laboratory
• Deployed Operational Bases (DOBs) for Overhead Protection System

ACADEMIA
• Lehigh University – Professor Clay Naito, Seismic & Blast Expert/ Material Testing

A&E COMMUNITY
• Special Finite Element Model and Material Model
• AECOM, Thornton Tomasetti, Weidlinger Associates first partners on engineering side
• Charlie Thornton as Board Member and Strategic Technical Advisor

CONSTRUCTION INDUSTRY
• Largest Speciality Contractor as Parent Company and Technology Implementer
• Turner and Tishman are supporting market entry
  Available to entire industry by licensing model on a non-exclusive basis

REGULATORY BODY
• Design Guidelines as Consensus Standard both through ATC as well as ITG of ACI
• ICC-ES: Two Acceptance Criteria Developed by Dr. S.K.Ghosh (AC 373 & AC 391)
Regulatory Approval

International Code Council Applications

1. ARCHITECTURAL
   - Architectural Wall Panels
   - Facade
   - Non Seismic
   - Not Load Bearing
   - Precast/Not CIP
   - New Build & Retrofit

2. STRUCTURAL
   - Curtain Wall Panels,
     Walls, Columns,
     Horizontal Member
   - Low & High Seismic
   - Load Bearing
   - Cast-in-Place/Precast
   - New Build

3. RETROFIT
   - Column Wraps
   - Column Confinement
   - Low & High Seismic
   - Load Bearing
   - Cast-in-Place/Precast
   - Retrofit (Existing & New)

AC 373  AC 373  AC 391
THANK YOU!

With thin comes light.....