MMFX STEEL DMCC

*A Subsidiary of*

MMFX TECHNOLOGIES CORPORATION

**MMFX 2 STEEL Concrete Reinforcing Bars**

**TECHNICAL PRESENTATION – June 30, 2009**

**NACE - JUBAIL**

## CORE OF THE TECHNOLOGY

- MMFX initial core technology was the result of 25 years of research at UC Berkeley and Lawrence Berkeley National Laboratory.
- MMFX's initial proprietary technology was developed at the University of California Berkeley under the guidance of world-renowned scientist and inventor, Professor Gareth Thomas.

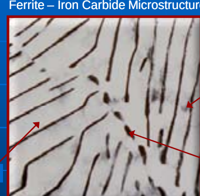
*The first high-voltage transmission Electron Microscope*

*Photo Courtesy of the National Center for Electron Microscopy*

## Corrosion of Conventional Pearlitic Steels

Schematic of Micro Galvanic Cells in the Ferrite-Iron Carbide Microstructure

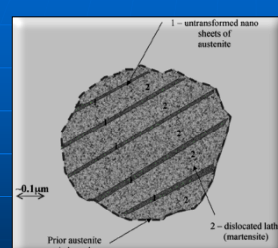

Transmission Electron Microscope (TEM) Micrograph of the Ferrite – Iron Carbide Microstructure




***Microgalvanic Cell Formation Between Iron-Carbide and Ferrite Phases***

***Corrosion Can Be Minimized By Avoiding Microgalvanic Cell Formation***

## MICROCOMPOSITE STEELS




**Microcomposite Steels, Packet Lath Martensite**

**Dislocated laths of martensite enveloped by stable retained austenite films**

**CARBIDE FREE MICROSTRUCTURE to Eliminate Formation of Microstructural Galvanic Cells**

## What Makes MMFX 2 (ASTM A1035) Different?

### 1. Chemical Composition

Low-carbon

Chromium alloy

Chemical Constituents (Weight %)

| Element | ASTM A1035/A1035M Maximum Amount * | Typical MMFX2 |
|---|---|---|
| Carbon | 0.15% | 0.08% |
| Chromium | 8 to 10.9% | 9% |
| Manganese | 1.5% | 0.5% |
| Nitrogen | 0.05% | 0.05% |
| Phosphorus | 0.035% | 0.035 |
| Sulfur | 0.045% | 0.045% |
| Silicon | 0.50% | 0.50% |

*Maximum unless range indicated.

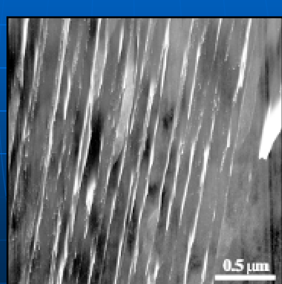
### 2. Processing

Controlled - rolling and production process



## What Makes MMFX 2 (ASTM A1035) Different?

RESULTS IN NEW MICROSTRUCTURE



## MMFX STEEL
## A Green Commercial Reality

- Utilizes 90% recycled material
- Operates on hydroelectric power
- Less steel to accomplish the same job greatly reduces greenhouse emissions
- Lowest cost construction system


## ASTM A1035

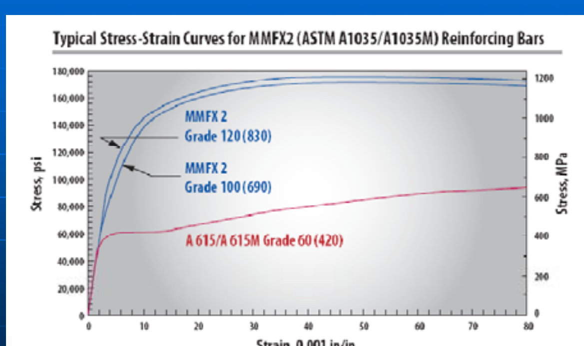
## The MMFX 2 (ASTM A1035) ADVANTAGES

- **Mechanical Properties**

**Tensile Properties of MMFX 2 (ASTM A1035/A1035M) Reinforcing Bars**

**Tensile Properties Requirements**

| | Grade 100 [690] | Grade 120 [830] |
|---|---|---|
| Tensile strength, min, psi [MPa] | 150 000 [1030] | 150 000 [1030] |
| Yield strength (0.2% offste, min, psi [MPa] | 100 000 [690] | 120 000 [830] |
| Stress corresponding to an extension under load of 0.0035 in./in (0.0035), min, psi [MPa] | 80 000 [550] | 90 000 [620] |
| Elongation in 8 in. [203.2 mm], min.%; Bar Designation No. 3 through 11 [10 through 36] | 7 | 7 |
| 14, 18, [43, 57] | 6 | -- |




## Physical Properties

**Physical Properties per ASTM A1035/A1035M**

| Bar Designation No. | Diameter, in. [mm] | Cross-Sectional Area, In.$^2$ [mm$^2$] | Weight, LB/ft [Nominal Mass, kg/m] |
|---|---|---|---|
| 3[10] | 0.375 [9.5] | 0.11 [71] | 0.376 [0.560] |
| 4[13] | 0.500 [12.7] | 0.20 [129] | 0.668 [0.994] |
| 5[16] | 0.625 [15.9] | 0.31 [199] | 1.043 [1.552] |
| 6[19] | 0.750 [19.1] | 0.44 [284] | 1.502 [2.235] |
| 7[22] | 0.875 [22.2] | 0.60 [387] | 2.044 [3.042] |
| 8[25] | 1.000 [25.4] | 0.79 [510] | 2.670 [3.973] |
| 9[29] | 1.128 [28.7] | 1.00 [645] | 3.400 [5.060] |
| 10 [32] | 1.270 [32.3] | 1.27 [819] | 4.303 [6.404] |
| 11 [36] | 1.410 [35.8] | 1.56 [1006] | 5.313 [7.907] |
| 14 [43] | 1.693 [43.0] | 2.25 [1452] | 7.65 [11.38] |
| 18 [57] | 2.257 [57.3] | 4.00 [2581] | 13.60 [20.24] |

**Physical Properties per BS 4449**

| Nominal diameter mm | Cross Seccional Area mm$^2$ | Mass per metre kg |
|---|---|---|
| 10 | 78.5 | 0.617 |
| 12 | 113 | 0.888 |
| 16 | 201 | 1.58 |
| 20 | 314 | 2.47 |
| 25 | 491 | 3.85 |
| 32 | 804 | 6.31 |
| 40 | 1257 | 9.86 |
| 50 | 1963 | 15.4 |

## Production and Availability

MMFX + Zamil Group → UNIROL

MMFX Steel Billets are produced at MMFX Steel Mill in Welland, Canada 400,000 Ton Capacity

MMFX Steel Billets Shipped to UNIROL Steel for rolling into different bar sizes per ASTM A1035 Specifications

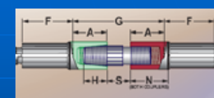
MMFX steel bars and coils are stocked and distributed in Bahrain by UNIROL Steel

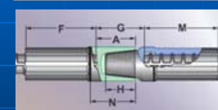
## GRIP-TWIST 'XT' Mechanical Splices

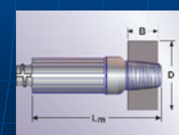
BarSplice PRODUCTS INC.
SUBSIDIARY OF FC INDUSTRIES, INC.

- FOR HIGH STRENGTH, LOW CARBON, CHROMIUM STEEL BARS, ASTM A 1035
- FAST, EFFICIENT INSTALLATION
- ELIMINATES LONG LAP LENGTHS, REDUCES CONGESTION
- DEVELOPS STRENGTH: 1.25 x $f_y$, GRADE 100
- ULTIMATE CAPACITY: 1.50 x $f_y$, GRADE 100

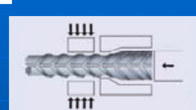
$f_y$ = SPECIFIED YIELD OF REINFORCING BAR

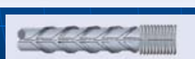


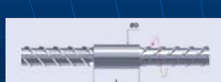




## Dextra — BARTEC Parallel Thread Couplers





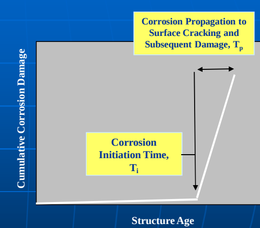


## MMFX 2 (ASTM A1035) THE SOLUTION TO THE CORROSION PROBLEM

## The Corrosion Process and the Result

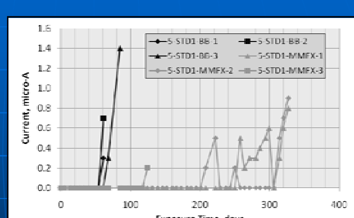

## Critical Issues Associated with Corrosion Induced Reinforced Concrete Deterioration

The onset of active corrosion at $T_i$ occurs when a critical $Cl^-$ concentration, $C_T$, is reached at the steel depth. Consequently, $C_T$ is a fundamental parameter that must be understood in order to project service life of reinforced concrete structures.



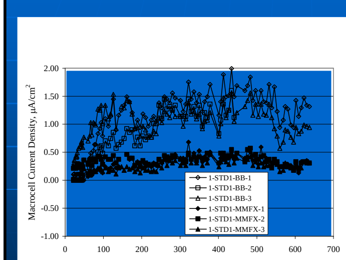

$C_T$ is a function of 1) pore water composition (pH), 2) in-place concrete quality, 3) reinforcement composition, microstructure, surface condition, and 4) type of exposure.

## Simulated Deck Slab Specimens – Determination of $C_T$




Definition of $C_T$: Time at which a sustained macro-cell current ≥ 0.1 mA occurs.

## Rate of Attack Once Corrosion Has Initiated – Defining $T_p$: MMFX 2 and BB




| Alloy | Steady-State CR(BB)/CR(alloy) |
|---|---|
| 2201 | x2 |
| MMFX-2 | x3 |

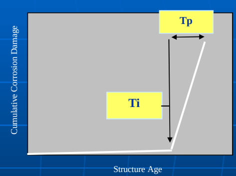
For BB, corrosion induced cracks typically appear at the concrete surface about five years subsequent to $C_T$ being achieved at the rebar depth. Consequently, the corresponding time for such cracking in the case of a corrosion resistant rebar should be five years multiplied by the above difference factor.

## Life-Cycle Modeling

The universally accepted approach to calculating $T_i$ is based upon Fick's second law for non steady-state diffusion:

$$\frac{\partial^2 C}{\partial T^2} = \frac{\partial}{\partial x}\left[D\frac{\partial C}{\partial x}\right]$$

The one-dimensional solution to Fick's Second Law applied to defining the time at which corrosion initiates, $T_i$:

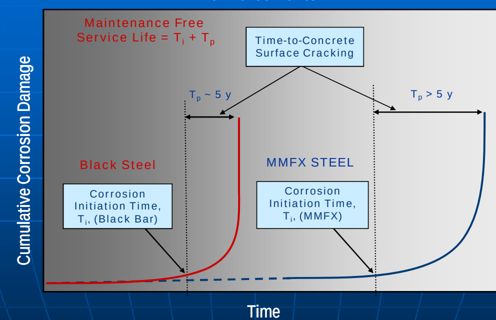



$$\frac{C_s - C_T}{C_s} = \operatorname{erf}\left[\frac{x}{2\sqrt{D_e \cdot T_i}}\right]$$

$C_s$ = Surface [$Cl^-$]
x = Reinforcement cover
$D_e$ = Effective diffusion coefficient

Time-to-Repair / Rehabilitation = $T_i + T_p$.

## Damage Accumulation Projection for Black Steel vs MMFX Steel Reinforcements




## Corrosion Properties

**Based on macro-cell current in reinforced concrete slabs, ASTM A1035 corrosion rate is up to 20% of black steel bars.**

**ASTM A1035 Provides a four-fold enhancement of the chloride threshold and up to 5 fold reductions in wastage rate once corrosion initiates.**

**Corrosion performance compared to 2201 LDX Stainless Steels**

Choice for corrosion applications requiring 75+ years service life at the lowest cost.

## Service Life Projection Examples – Black Bar and MMFX 2

**Black Steel:**

$C_T$ (black steel) ~ 1.0 kg / $m^3$ (corresponds to 2 % of steel having initiated corrosion)

Design Parameters:
$Cl^-$ Diffusion Coefficient $10^{-12}$ $m^2$ / s
Concrete Cover 63 mm. Time-to-Corrosion: 17 years.

Time after corrosion initiation for surface cracks to appear: ~ 5 years.

If repair commences 10 years later: Maintenance-free life: ~ 32 years.

**MMFX 2:**

$C_T$ (MMFX 2) ~ 4x greater: 4.0 kg / $m^3$ (corresponds to 2 % of steel having initiated corrosion) Time-to-corrosion: ~ 37 years.

Design Parameters:
$Cl^-$ Diffusion Coefficient $10^{-12}$ $m^2$ / s
Concrete Cover 63 mm.

If corrosion rate, once initiated, is 3x less than for black bar, then time after initiation for surface cracks to appear: ~ 15 years.

If repair commences 30 years later: Maintenance-free life: ~ 82 years.

## VTRC Recommendations

- "Corrosion protection for structures designed for a 100-year+ service life as currently recommended by FHWA, the report recommends that the Virginia Department of Transportation (VDOT) amend its specifications regarding the use of ECR to require the use of corrosion-resistant metallic reinforcing bars such as ASTM A1035, stainless steel clad, and solid stainless steel."
- "ASTM A1035 costs about the same as ECR but can extend the life of a deck approximately 5 times longer."
- "ASTM A1035 is clearly the most cost-effective reinforcement for the majority of VDOT decks."

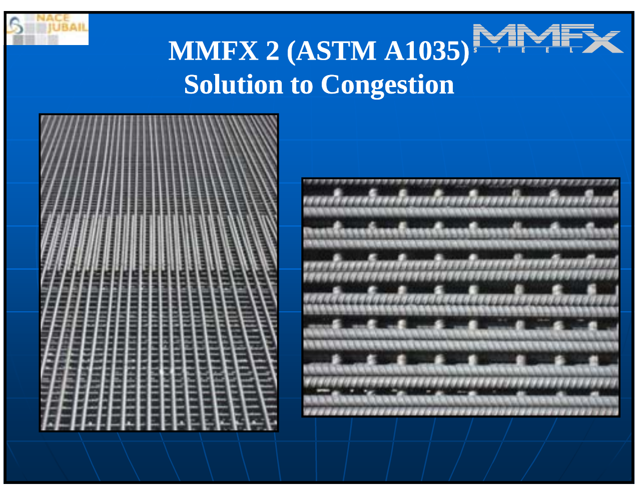
## CORROSION APPLICATIONS

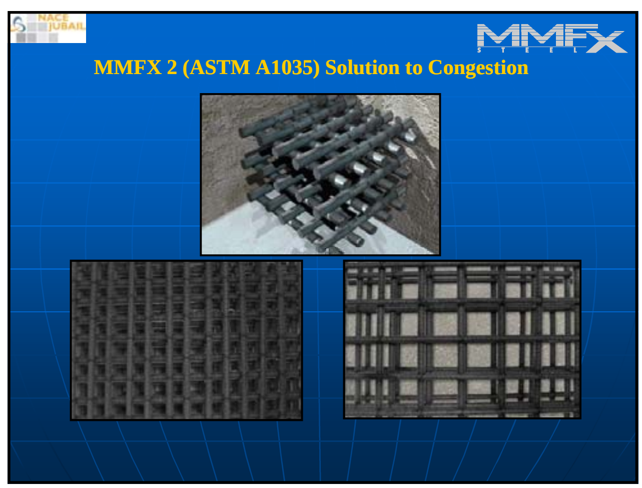
**CONNECTICUT DEPARTMENT OF TRANSPORTATION**
**Church Street Extension Bridge over Metro North Railroad**
**New Haven, CT**

**CALIFORNIA ACADEMY OF SCIENCES**
**California Academy – Exhibition Education and Research Center, San Francisco, CA**


MARINELAND OF FLORIDA
Seawater Lagoon Dolphin Tank – Marineland, FL


US NAVY NAVAL FACILITIES ENGINEERING
COMMAND (NFSEC)
Modular Hybrid Pier – San Diego, CA (Constructed - Tacoma, WA)


MMFX 2 (ASTM A1035)
Solution to Congestion


MMFX 2 (ASTM A1035) Solution to Congestion

## Using The MMFX 2 (ASTM A1035) Strength And Corrosion Advantages

**The use of MMFX 2 (ASTM A1035) allows the structural engineer and design team to achieve the following:**

- Reduce rebar congestion (at selected structural components)
- Reduce member dimensions (e.g. mat foundation thickness)
- Improves constructability
- Extends Service Life of Structure
- Deliver project cost savings

## MAT FOUNDATION APPLICATIONS

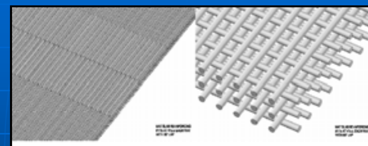


Figure 4 - 3D Rendering of #11@4" o.c. (A615 Grade 60 Reinforcing)

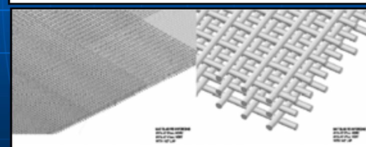


Figure 6 - 3D Rendering of #11@6" o.c. (MMFX Grade 100 Reinforcing)

## MMFX 2 (ASTM A1035) CONFINEMENT

Full-Size Replica of two columns:

**Column in Back is reinforced with 60 ksi #5 confinement ties at 2-1/4" vertical spacing**

**Column in Front is reinforced with 690 (100ksi) ASTM A1035 #5 confinement ties at 4" vertical spacing**

## Confinement Application

3D Models of two columns:

**Column on left is reinforced with 60 ksi #5 confinement ties at 4" vertical spacing**

**Column on right is reinforced with 690 (100ksi) ASTM A1035 #5 confinement ties at 4" vertical spacing (same spacing, but with almost half the number of cross ties)**

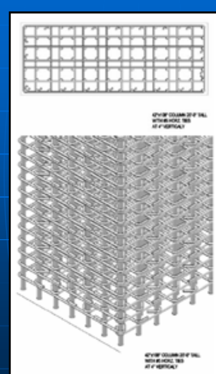


Figure 7 – A615 Gr. 60 Ties

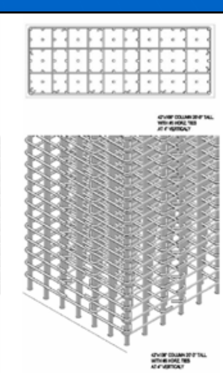


Figure 8 – MMFX 100ksi Ties

## MMFX 2 (ASTM A1035) APPROVALS
## (Alternate Method of Construction per IBC)

- City of Los Angeles, CA (LARR)
- City of Long Beach, CA
- City of San Diego, CA
- City of Irvine, CA
- Clark County, Nevada (Las Vegas Strip)
- Miami-Dade County, FL (incl. City of Miami)
- City of Orlando, FL
- Abu Dhabi, UAE
- JAFZA, UAE

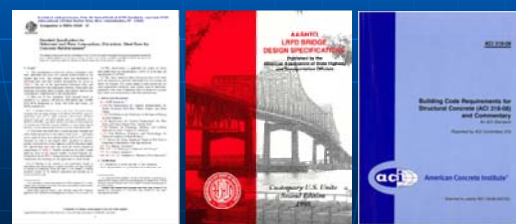
## MMFX - Proven, Credible, Effective

American Society of Testing Materials (ASTM)

American Association of State Highway and Transportation Officials (AASHTO)

American Concrete Institute (ACI)

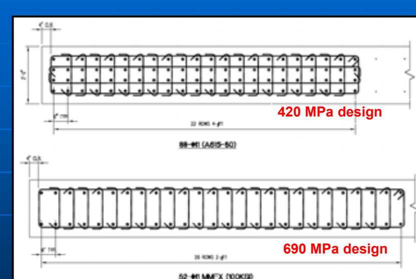
**FHWA validated – used by 24 state DOTs**



# Project Cost Savings Utilizing MMFX 2 (ASTM A1035) Rebar

## Example Project in Las Vegas

- Original Design with #11 jamb steel
- A1035 alternate design with 40% less #11 jamb steel
- Reduces or eliminates intermediate layers of jamb steel
- Reduces or eliminates intermediate crossties
- LEADS TO MORE EFFICIENY PLACEMENT $$$



## MAT FOUNDATION CONCRETE SAVINGS USING NEW 690 MPA DESIGN

Mat Foundation Comparisons

| Drawing Sheet ID | PC ID | Overall Dimensions L (ft) | H (ft) | Area (ft^2) | Original Design Thick (ft) | Volume (cy) | Revised MMFX Alternate* Thick (ft) | Volume (cy) |
|---|---|---|---|---|---|---|---|---|
| S4.21 ALT | PC5 | 140.00 | 80.00 | 11,200 | 14 | 5,807 | 11 | 4,563 |
| S4.22 ALT | PC6 | 143.50 | 69.00 | 9,902 | 14 | 5,134 | 11 | 4,034 |
| S4.23 ALT | PC7 | 92.00 | 91.00 | 6,829 | 12 | 3,035 | 10.5 | 2,656 |
| S4.24 ALT | PC8 | 90.50 | 44.00 | 3,982 | 9 | 1,327 | 7 | 1,032 |
| S4.25 ALT | PC9 | 80.75 | 56.00 | 4,522 | 12 | 2,010 | 9 | 1,507 |
| S4.26 ALT | PC10 | 95.33 | 80.50 | 7,674 | 10 | 2,842 | 8 | 2,274 |
| | | | | | | 20,156 | | 16,066 |

* Reduction in mat thickness would require localized shear reinforcing

**Total Reduction 4,090 cy**

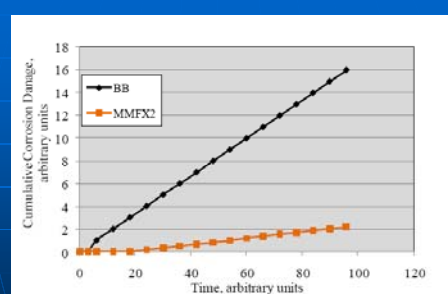
## Concrete Tension Pile Design

## Crack Width and Corrosion in Tension Pile Designs

**Based upon the work of Darwin et al.,**

- **A conservative estimate is that MMFX 2 reinforcement initiates corrosion at the base of relatively wide concrete cracks at exposure times about six times greater than for BB.**
- **Corrosion rate in cracked concrete, once initiated, is about six times less for MMFX 2 compared to BB.**

## Tension Pile Design BB versus MMFX 2




Schematic illustration based on assuming that BB initiates corrosion at an arbitrary time 3 and MMFX2 at time 18 (six times longer)

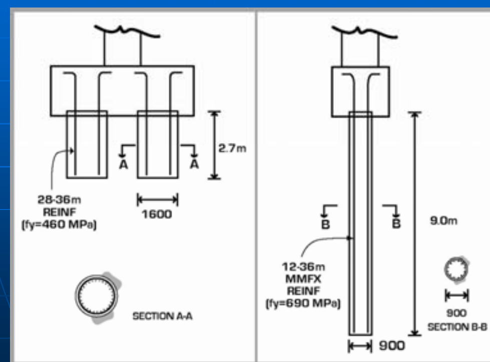
## Effect of Crack Width on Tension Concrete Pile Design

Crack Width Calculation
Based on ACI 224R-01, Section 4.8 for tension cracking

w = 0.0145 x fs x (dc x A)^(1/3) x 10^(-3)

| | | | | | | |
|---|---|---|---|---|---|---|
| Tension Load | P (kN) | 7000 | 7000 | 7000 | 7000 | 7000 |
| Pile Diameter | D (mm) | 1150 | 1150 | 1150 | 1150 | 1150 |
| Clear Cover | c (mm) | 75 | 75 | 75 | 75 | 75 |
| Transverse Bar Size | dbh (mm) | 16 | 16 | 16 | 16 | 16 |
| Vertical Bar Size | dbv (mm) | 36 | 36 | 36 | 36 | 36 |
| Vertical Bar Area | Abv (mm2) | 1006 | 1006 | 1006 | 1006 | 1006 |
| Number of Vertical Bars | n | 30 | 33 | 40 | 54 | 66 |
| Steel Yield Strength | fy (MPa) | 690 | 690 | 690 | 690 | 690 |
| Steel stress | fs (MPa) | 232 | 211 | 174 | 129 | 105 |
| Service Stress Ratio | fs / fy (%) | 34% | 31% | 25% | 19% | 15% |
| Centroid of Vertical Bars | dc (mm) | 109 | 109 | 109 | 109 | 109 |
| Effective Tension Area per Vertical Bar | A ($mm^2$) | 21277 | 19342 | 15957 | 11820 | 9671 |
| Bar Spacings | s (mm) | 98 | 89 | 73 | 54 | 44 |
| Maximum Crack Width (Tension) | $w_{max}$ (mm) | 0.45 | 0.39 | 0.30 | 0.20 | 0.16 |

## Pile Design Example




## Pile Design Example

**Total Design Load of 5,000 kN Tension per Location**

| | BASELINE Design | MMFX Design |
|---|---|---|
| Pile diameter | 1500mm diameter | 900 mm diameter |
| Reinforcement Grade | Reinf w/ fy = 460 MPa | Reinf w/ fy = 690 MPa |
| Reinforcement per pile | 28 – 36M bars | 12 – 36M bars |
| Number of Pile per Loc | 2 | 1 |
| Length of Pile per Loc | 2.7 m long | 9.0 m long |
| Concrete Volume | 9.56 m3 per location | 5.72 m3 per location 40% reduction |
| Steel Volume | 1.521 x 108 mm3 per loc | 1.086 x 108 mm3 per loc 29% reduction |

## CABI DEVELOPERS
## Everglades on the Bay Condominiums Miami, FL


The Tides – Chicago, IL
51 Floor Condominium Beams


Project City Center - Pelli Tower – Las Vegas, NV
Load Transfer Beams


HEAD COMPANIES
Mustique Condominiums, Gulf Shores, AL


Coastal Residence – Malibu, CA
Drilled Pier Foundation


- **The use of A1035 allows flexibility in design by engineer. In this case, the engineer chose to utilize the high-strength property of MMFX to reduce the thickness of the mat foundation.**
- **Preliminary Design Info:**
  - Mat Foundation (under 1 level basement – below water table):
    - Thickness reduced by an average of 3' (2,500 cy total), at selected heavily-reinforced mats under the structural cores.
    - Reduced excavation, haul-out, dewatering, concrete volume, etc.
  - Tension Piles (36" diameter caissons):
    - Total of about 370 piles supporting mat foundation. Approximately 200 would be utilized as tension piles using MMFX rebars, to resist high hurricane loading in the South Florida region.

## ACI Innovation Task Group 6

**Design Guide for the Use of High-Strength Steel Bars (ASTM A 1035-07) for Structural Concrete**

**A Document being developed by ITG - 6**

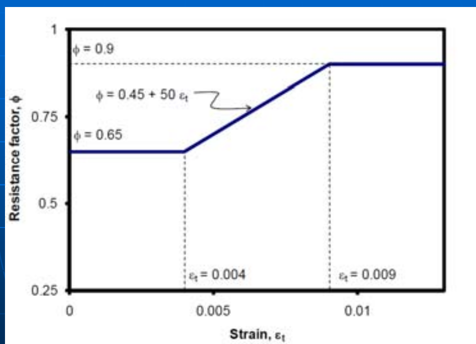
## Design Guide

- Use non-mandatory language
- Cover structural reinforced concrete members under low seismic regions (Category A, B and C):
  - Beams and Columns
  - One-way and two way slab systems
  - Walls and Footings
- Consider both strength and serviceability
- Limit application to slab systems, foundations, and members not designated as part of seismic-force-resisting system for moderate and high seismic regions (Category D, E, and F)
- Investigate use of high-strength bars as primary, secondary and confining reinforcement
- Address development length and anchorage issues

## Tension- and Compression-Controlled Limits

| STEEL TYPE | TENSION-CONTROLLED STRAIN LIMIT | COMPRESSION-CONTROLLED STRAIN LIMIT |
|---|---|---|
| ASTM A 615 Grade 60 | 0.005 | 0.002 |
| ASTM A1035 Grade 100 Theoretical | 0.0066 | 0.004 |
| ASTM A1035 Grade 100 Idealized | 0.009 | 0.004 |

## Φ Factor of Simplified Design Method




## Other Design Criteria

- Minimum Reinforcement Required by ACI 318-08
  Use $f_y$ = 100,000 psi [690 MPa] with Section 10.5 for flexural members and Section 7.12 for shrinkage and temperature
- No moment redistribution in continuous member
- Design Stress in Web Reinforcement
  Use $f_y$ = 60,000 psi [420 MPa] for crack control
  Use $f_y$ = 80,000 psi [550 MPa] if hairline cracking is not critical
- Compression Stress Limit
  Use $f_y$ = 80,000 psi [550 MPa] for flexure compression steel and column longitudinal steel in compression
  Use $f_y$ = 100,000 psi [690 MPa] for column longitudinal steel in tension and for column spirals
- Use moment magnification procedure for column slenderness effect

## CONCLUSIONS

- Building Code and Municipality Recognition
- Effective in corrosive environment application, including marine, humidity, corrosive soil, etc.
- Effective in mitigating rebar congestion
- Allows design flexibility
- Same processes:
  - Steel making (made in conventional steel mills)
  - Fabrication (same equipment)
  - Design (same ACI equations)
  - Detailing (same bend radius)
  - Installation
- PROJECT COST SAVINGS

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***Proven, Credible, Effective***

*Thank you*


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