Stainless Steel in Public Infrastructure & Buildings

Speaker: Catherine Houska

Sponsors:

Nickel Institute

Indian Stainless Steel Development Association

Why Should You Consider Stainless Steel?

- Sustainable
  - Longevity, energy savings, no VOCs
- Design flexibility
- Structural benefits include
  - Enhances safety & security
  - High strength
  - Reduces section sizes
  - Seismic performance

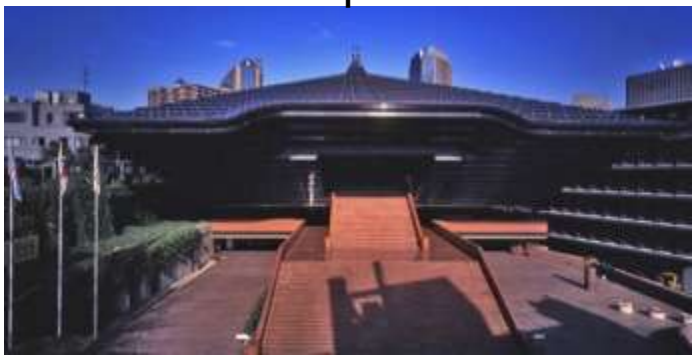
1 World Trade Center
Type 316 Linen & spire
Gold LEED expected

Stainless Steel Provides Long Life

Chrysler 1930

Savoy Hotel Canopy 1929

Shakaden Temple 1975



Empire State 1931

Thyssenhaus 1956

Gateway Arch, 1965

Other Metals Have Shorter Service Life & Require More Maintenance

Peeling painted carbon steel

Peeling painted aluminum roof, 25 years

Peeling painted Aluminum Florida, <10 yrs

Benefits of Long Life
Pier Progresso Mexico

- Reduced environmental impact
- No disruption and replacement cost
- Much lower long term operational costs
- Numerous reports including NACE 07240

Functioning pier

- Completed 1941
- Type 304 rebar

Non-functioning pier

- After 30 years
- Carbon steel rebar

Environmental & Economic Benefits

- Significant opportunity for decreased energy, water, & material resource use
  - Strategic & environmental advantages
  - Reduce dependence on foreign energy and material supplies
  - Reduce long term maintenance & replacement costs by avoiding replacement
  - Enhanced security
- US statistics for buildings
  - 36% energy use
  - 30% of greenhouse gas emissions
  - 12% of potable water consumption
  - 30% raw material production
  - International averages are higher

Empire State Building, 1931, LEED Gold
Stainless spandrel panels, window frames and spire

Defining Sustainability

- Government regulation, legislation, & executive orders
  - All government financed projects
    - Buildings, bridges, water treatment plants
  - 30% or greater energy savings
  - 100 year or longer building & infrastructure life
- Building codes tightened
- New green building codes

Council House 2 (CH2)
Australia, Green Star 6

Reducing Energy Use & Heat Islands

- Material and finish choice affects energy performance
- Solar Reflective Index (SRI)
  - Calculated based on ASTM E1980
  - Solar Reflectance & Emittance
    - Varies with material & finish
  - Roof slope (1:6) & exterior walls ≥ 39
  - Low slope roofs ≥ 82
- In 3 years, SRI values can not deteriorate below 32 and 64
  - Unlike other materials, stainless steel SRI values do not decrease over time

Pittsburgh Convention Center (2003)
Was Gold LEED after construction
Now LEED Platinum Existing Building
2/3% less water, 29%less energy
50+ year life requirement

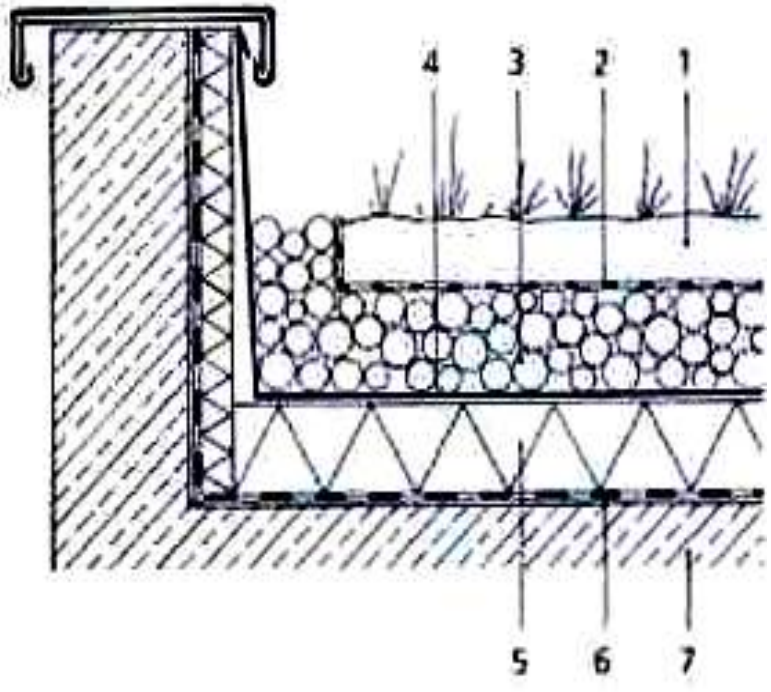
Product	Temperature Rise, at C (F)	Solar Reflective Index
Stainless Steel, bare	27 (48 F)	39-60
Galvanized steel, new bare	30 (55 F)	46
Aluminum, new bare	27 (48 F)	56
Any metal, white coating	9 (16 F)	107
Clay tile, red	32 (5 8F)	36
Concrete tile, red	39 (71 F)	17
Concrete, white dirty	37 (67 F)	22
Concrete, new white	12 (21 F)	90
Asphalt, generic white	36 (64 F)	26
Asphalt, generic black	46 (82 F)	1
Wood shingle, brown	37 (67 F)	22
Wood shingle, white	6 (10 F)	106

Sources: LBNL Cool Roofing Materials Database
and finish producers

US Gold LEED, Pacific Lutheran University

Renovation & expansion of existing masonry student activities center
Type 304 roofing and wall panels
100 year design life
Zimmer Gunsul Frasca Architects

Welded Stainless Green Roof Liners



1 Plants in soil
2 Filter membrane
3 Drainage layer
4 Welded molybdenum-containing stainless steel
5 Thermal insulation
6 Vapor barrier
7 Roof deck

Paul Klee Center, Berne

- Renzo Piano Building Workshop
- Undulating shape mimics the hills
- Type 316 roof trays are used to create vegetated roof

Minimize Potable Water Use

Capture Roof Run-Off - Avoid Toxic (Biocides & Chemicals Harmful to Humans) Averages (mg/m^2)

	Copper	Lead	Zinc
Rusty galvanized	20	302	12,200
Asphalt	11	10	1,980
Galvanized iron	ND	100	3,600
Concrete tile	ND	90	1,600

	Nickel	Chromium
Type 304 Stainless*	0.3 - 0.4	0.25 - 0.3

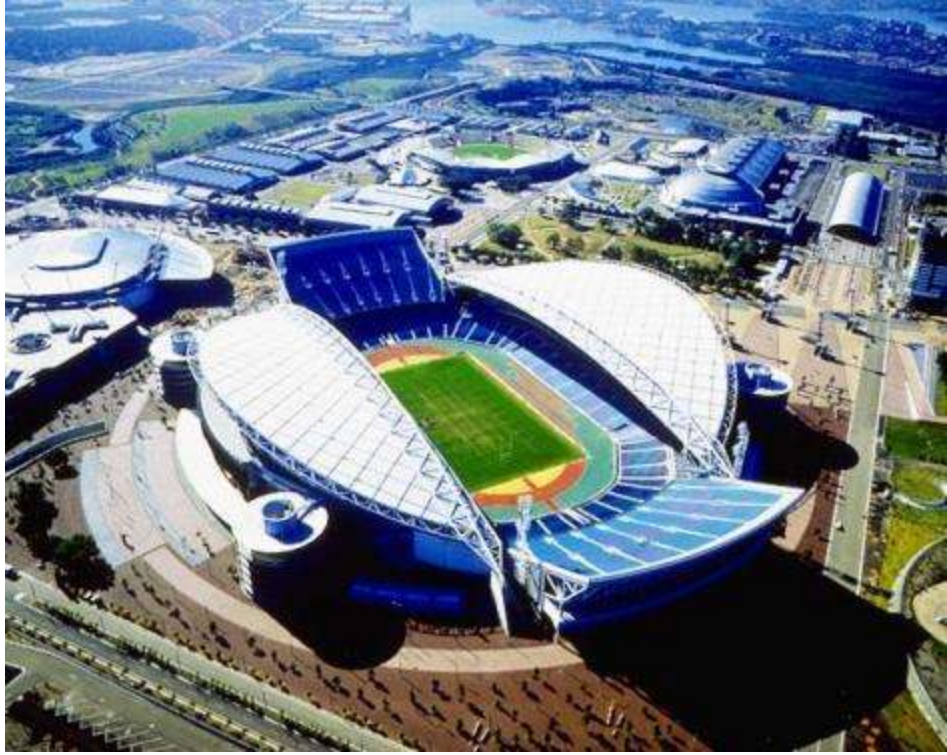
*In many samples, nickel and chromium levels were below detectable limits. The average concentration per liter was well below typical drinking water levels.

Stadium Australia

Type 316 , 2B finish

Drainage system collects water in underground tanks for watering grass and flushing toilets

Stainless is also used for in-building water treatment plants



Building Energy Modeling

- National governments requiring significant energy use reductions for their buildings
  - Usually at least 30% below typical
- Building energy modeling software leaps forward - fenestrations
  - **US DOE FREE COMFEN 5 software**
    - Large number of buildings analyzed
    - Calculates energy use/cost, CO_2
    - Full range of variables
    - Multi-room – not a cube approach
  - Exterior sunscreen impact determined
    - More relevant than % of open area
    - Sheltered locations are more corrosive application = stainless steel

San Francisco

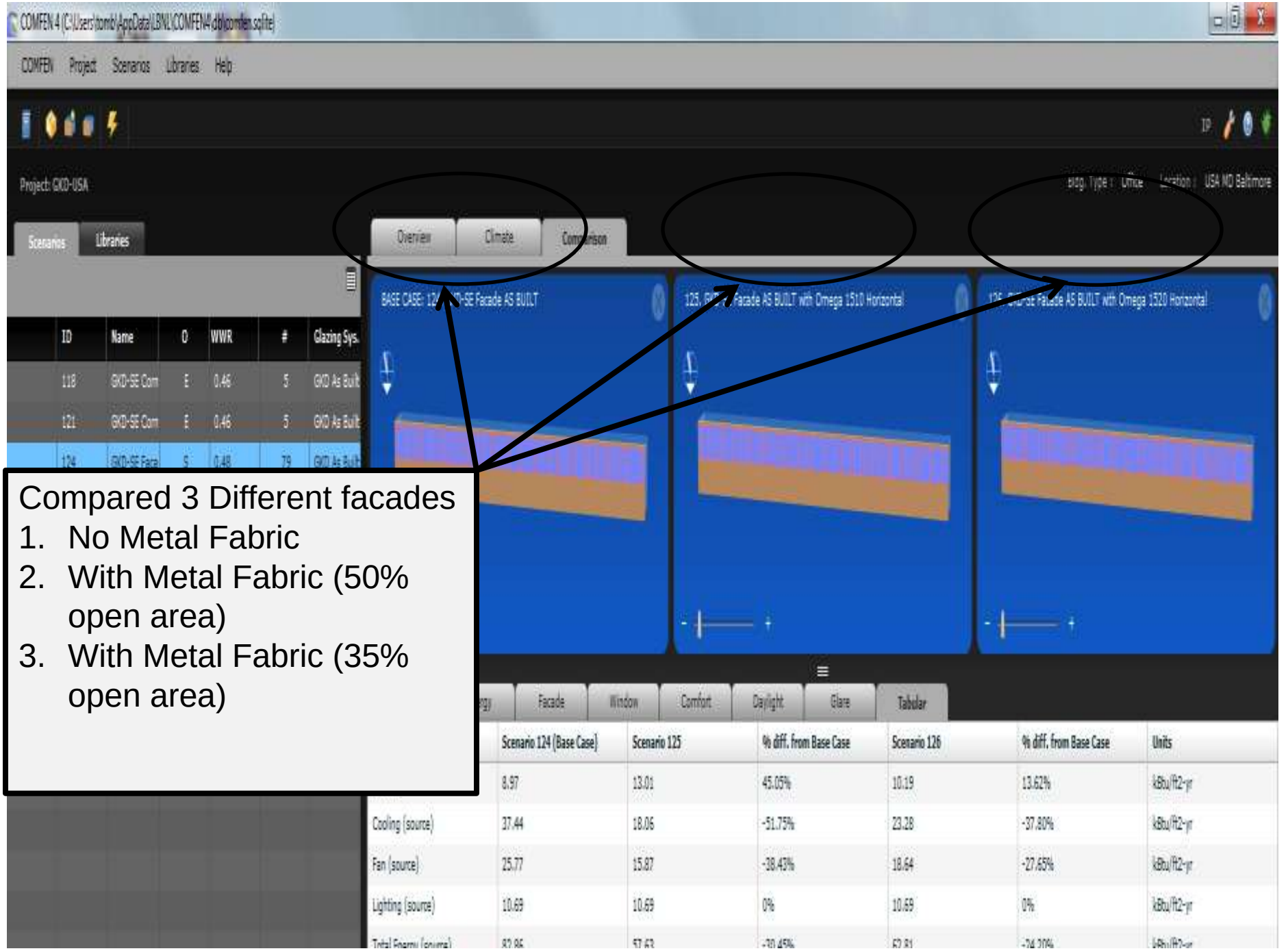
Federal Building

Type 316 sunscreens

Surpassed government energy performance criteria by 50%

COMFEN 5 Building Example
Eastern Michigan University, USA

- Woven mesh sunscreens, 35% open area
- US Department of Energy free COMFEN software predicted energy reduction
- Northern climate, air temperature 24 C
  - Building exterior temperature
    - 34.4 C no shading
    - 27.8 C with shading



Compared 3 Different facades

1. No Metal Fabric
2. With Metal Fabric (50% open area)
3. With Metal Fabric (35% open area)

Summary | Energy | Facade | Window | Comfort | Daylight | Glare | **Tabular**

Annual Values	Scenario 124 (Base Case)	Scenario 125	% diff. from Base Case	Scenario 126	% diff. from Base Case	Units
Heating	8.97	13.01	45.05%	10.19	13.62%	kBtu/ft2-yr
Cooling (source)	37.44	18.06	-51.75%	23.28	-37.80%	kBtu/ft2-yr
Fan (source)	25.77	15.87	-38.43%	18.64	-27.65%	kBtu/ft2-yr
Lighting (source)	10.69	10.69	0%	10.69	0%	kBtu/ft2-yr
Total Energy (source)	82.86	57.63	-30.45%	62.81	-24.20%	kBtu/ft2-yr
Peak Demand Electricity	10.60	7.25	-31.62%	8.10	-23.52%	W/ft2
Peak Demand Electricity Date	AUG 17 02:30 PM	AUG 14 01:00 PM	--	AUG 14 01:00 PM	--	
Peak De			-10.57%	20.52	-9.27%	W/ft2
Peak De			--	MAR 1 06:15 AM	--	
Avg. Day			-76.83%	85.85	-69.40%	fc
Avg. Disc			1.12%	10.57	8.45%	Index
Avg. The			0.09%	83.52	1.44%	PPS
CO2 emi			-36.65%	22.34	-27.31%	lb/ft2

% diff. from Base Case compares the total energy savings 35% open area (30.45%) or 50% open area (24.20%) GKD Metal fabric would save versus using no fabric at all.

Recent Stainless Sunscreen Examples

Guangzhou China
2nd Children's Activity Center
Woven mesh

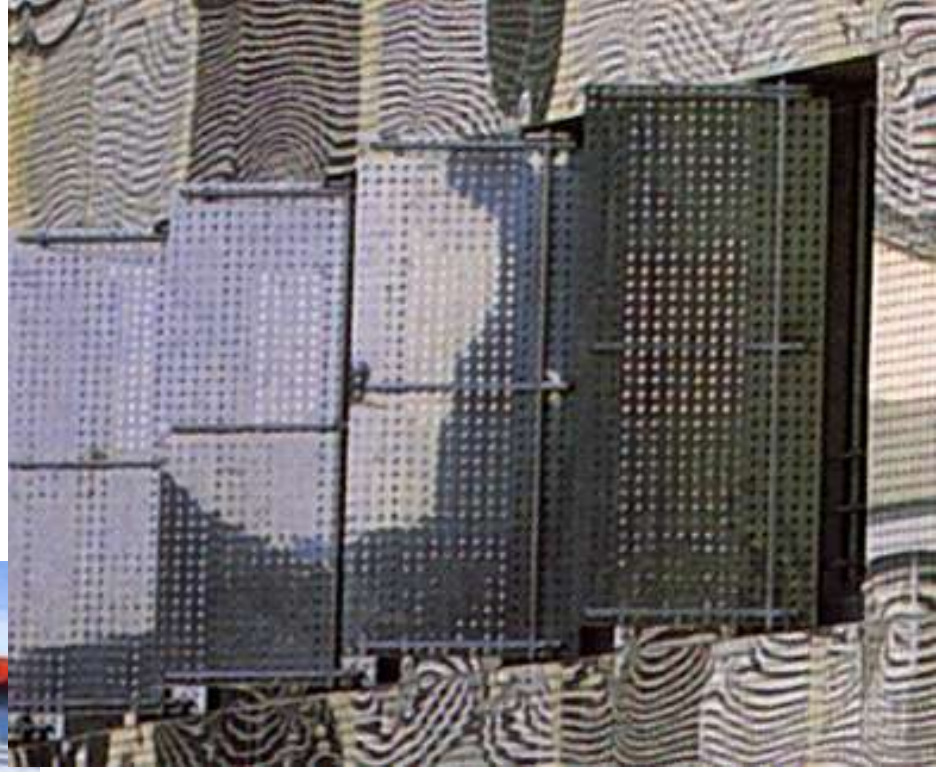
Cooper Union Univ, NYC
Perforated screens, LEED Platinum
40% energy savings

Stainless Steel Green (Plant) Sun Screens

- Stainless steel mesh supported plant screens
- Summer energy savings
- Improved air quality
- Enhanced security

Sun Screens

University of Chemistry, Physics, and Electrical Engineering (CPE), Lyon



Installation of perforated sunscreens over an existing glass wall dramatically reduced heat gain

Scottish Parliament

- Many common building materials release emissions
  - Reducing these creates a healthier environment
  - Bare uncoated metal has no emissions
- Stainless, wood and concrete
  - Interior stainless structural supports, wall and ceiling panels

Success Requires Picking The Correct Material
What Factors Influence Corrosion?

- Pollution
  - Acid rain
  - Sulfur Dioxide & particulate
- Coastal or deicing salt exposure
- Weather conditions
  - Rain type (rare, light, heavy)
  - Temperature
- Maintenance
- Design/specification
  - Crevices
  - Finish topography, roughness & application method

Select Type 304

- Rural/suburban
- Low to moderate pollution

Select Type 316

- Pollution
  - Moderate to high urban
  - Low to moderate industrial
- Coastal and deicing salt
  - Low to moderate exposure

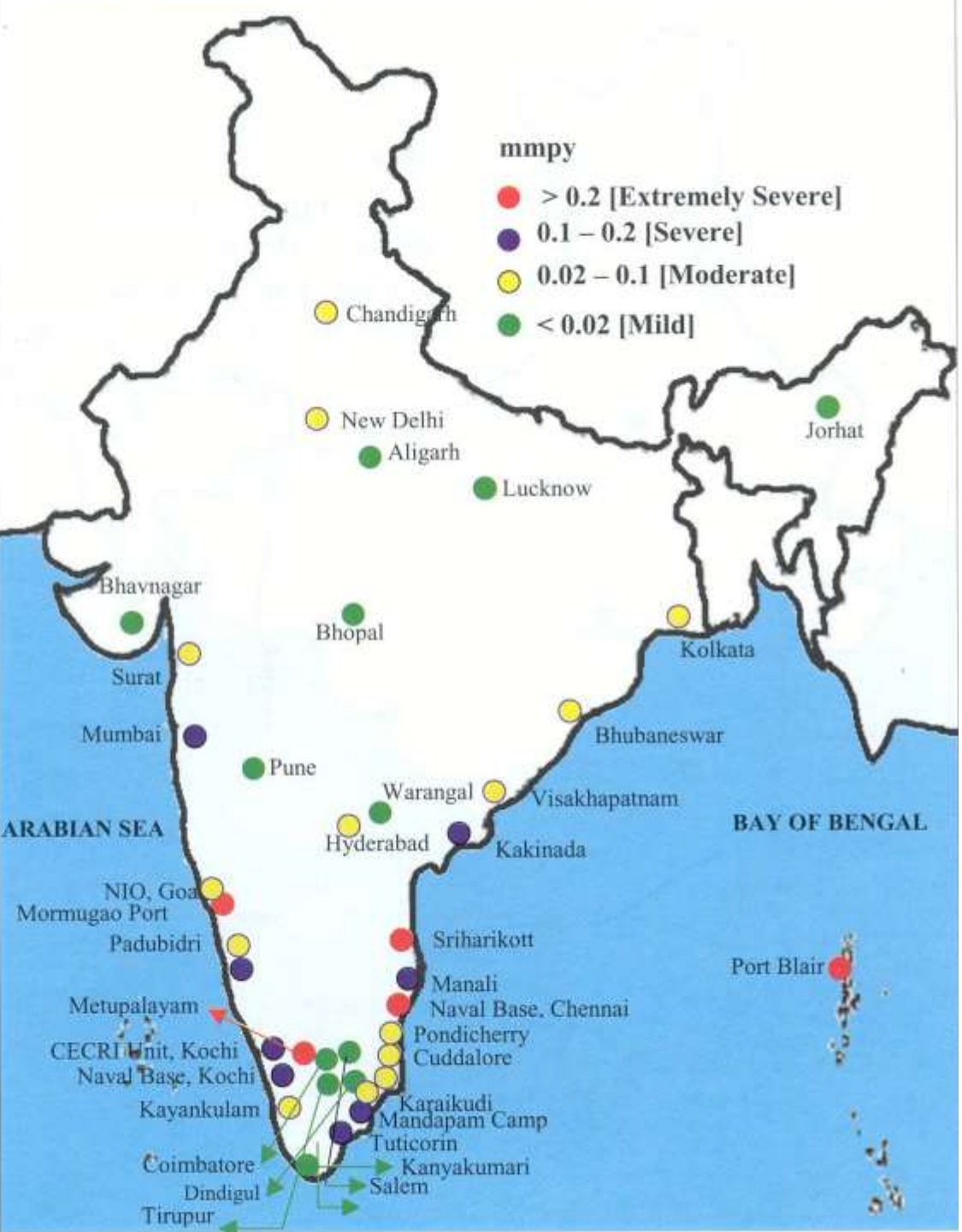
Higher Alloys Like 2205

- High pollution or salt exposure
- High particulate
- No rain washing

More Corrosive Locations

2205 Railings, Canary Island Park – salt spray/mist
In service for 30 years
Replaced painted galvanized steel that failed within 8 years

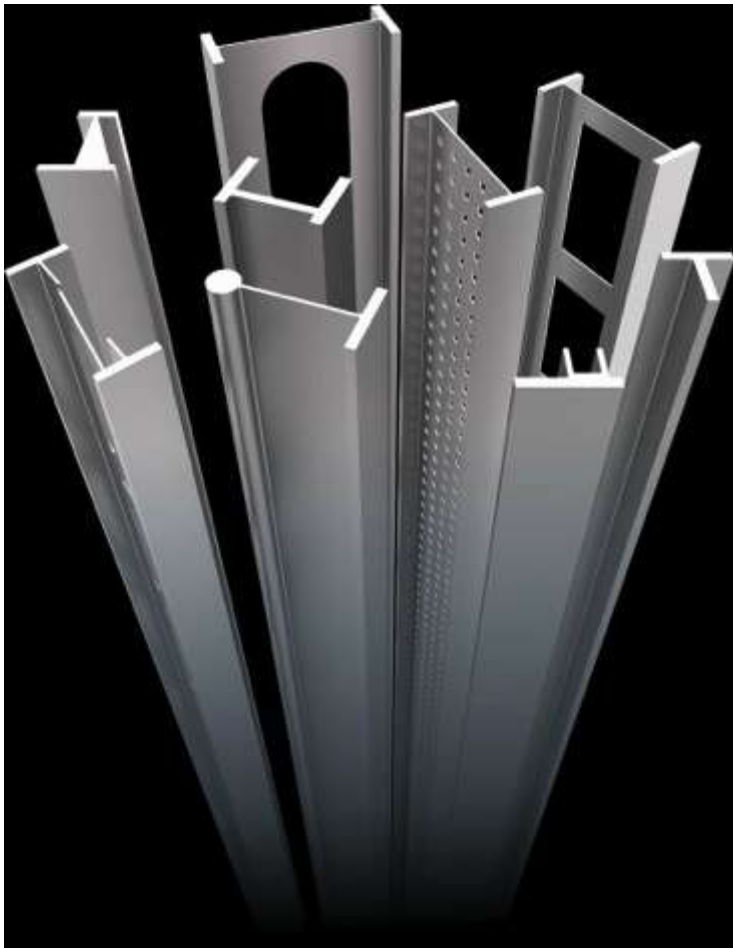
Stockholm Congress Ctr 2205 Sunscreen
Area behind the screen is not rain washed & highly visible



New Corrosion Corrosion Map for India

Material Specifications
(hollow sections, tees, channels, angles, etc.)

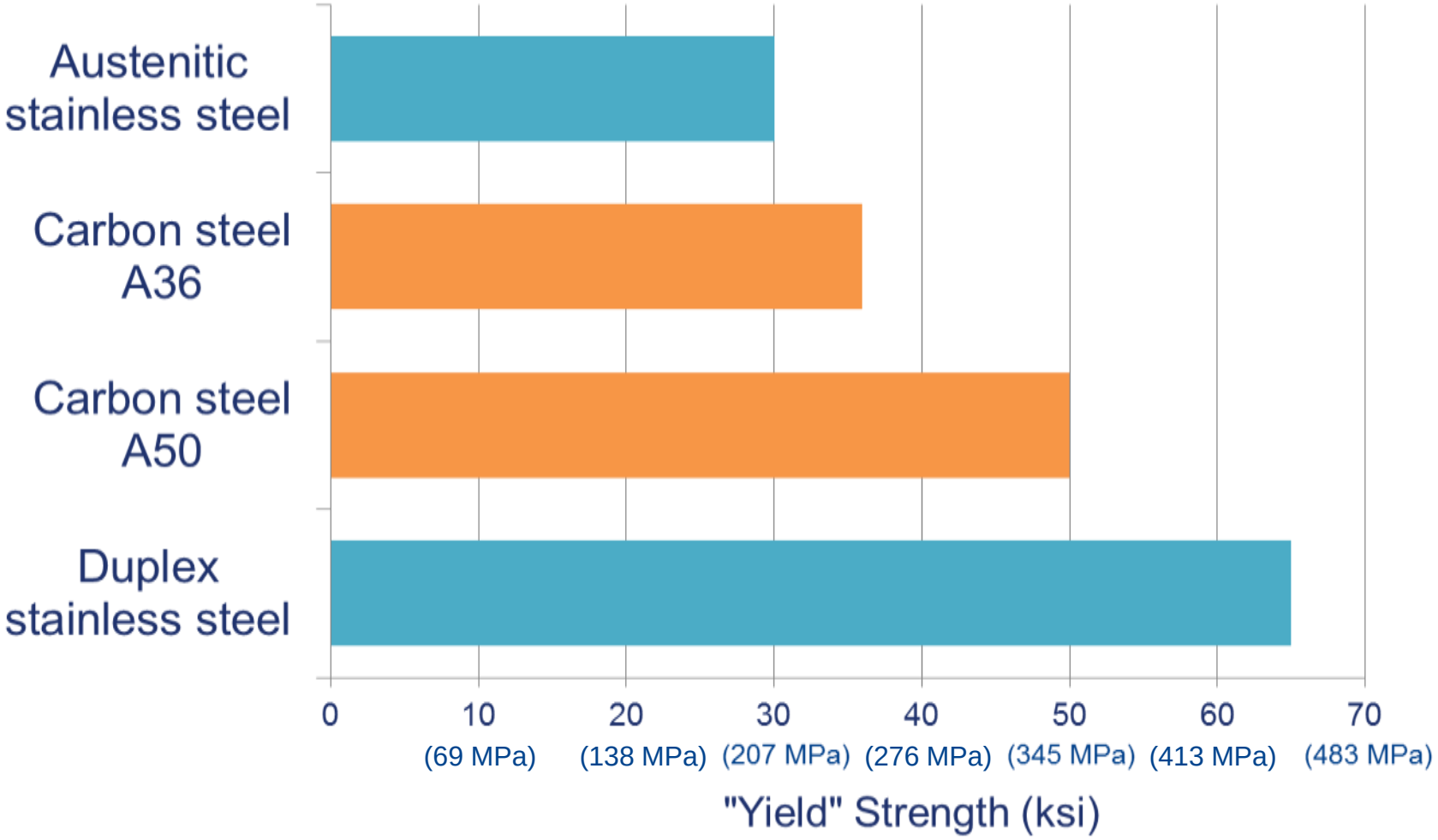
- ASTM A1069 – Laser welded structural sections
- ASTM A276 (bar and shapes)
  - Chemistry & mechanical properties
- ASTM A484 (bar and shapes)
  - Dimensional tolerances, finish
- ASTM A 955M (stainless rebar)
- ASTM A 554 (structural tubing)
  - Mechanical properties
- ASTM A 312 Austenitic pipe
- ASTM A 789 Duplex tubing
- ASTM A 790 Duplex pipe
- ASTM A 351/A351M – austenitic castings
- ASTM A 890/890M – duplex castings
- Fastener standards



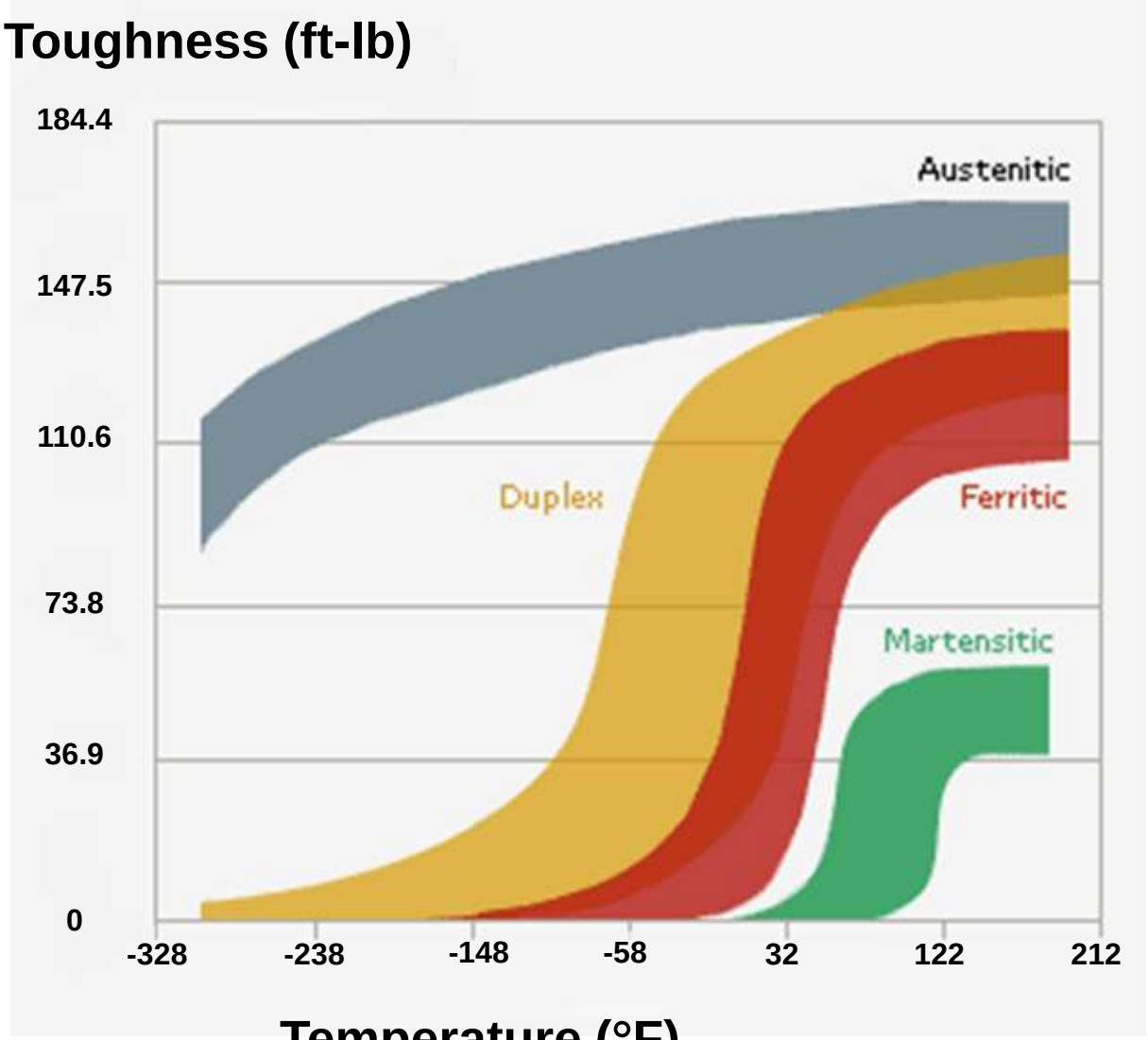
Structural Design Standards and Design Guides

- EuroCode 3
- ASCE Stainless Steel Cold-Formed Structural Members
- AISC Stainless Steel Structural Design Guide 27
  - AISC carbon steel standard format
  - Adapted from EuroCode
  - Larger hot rolled structural shapes
    - 3 mm (0.125 inch) or greater
  - Publication expected June 2013
  - Austenitic, duplex, and precipitation hardened stainless steels

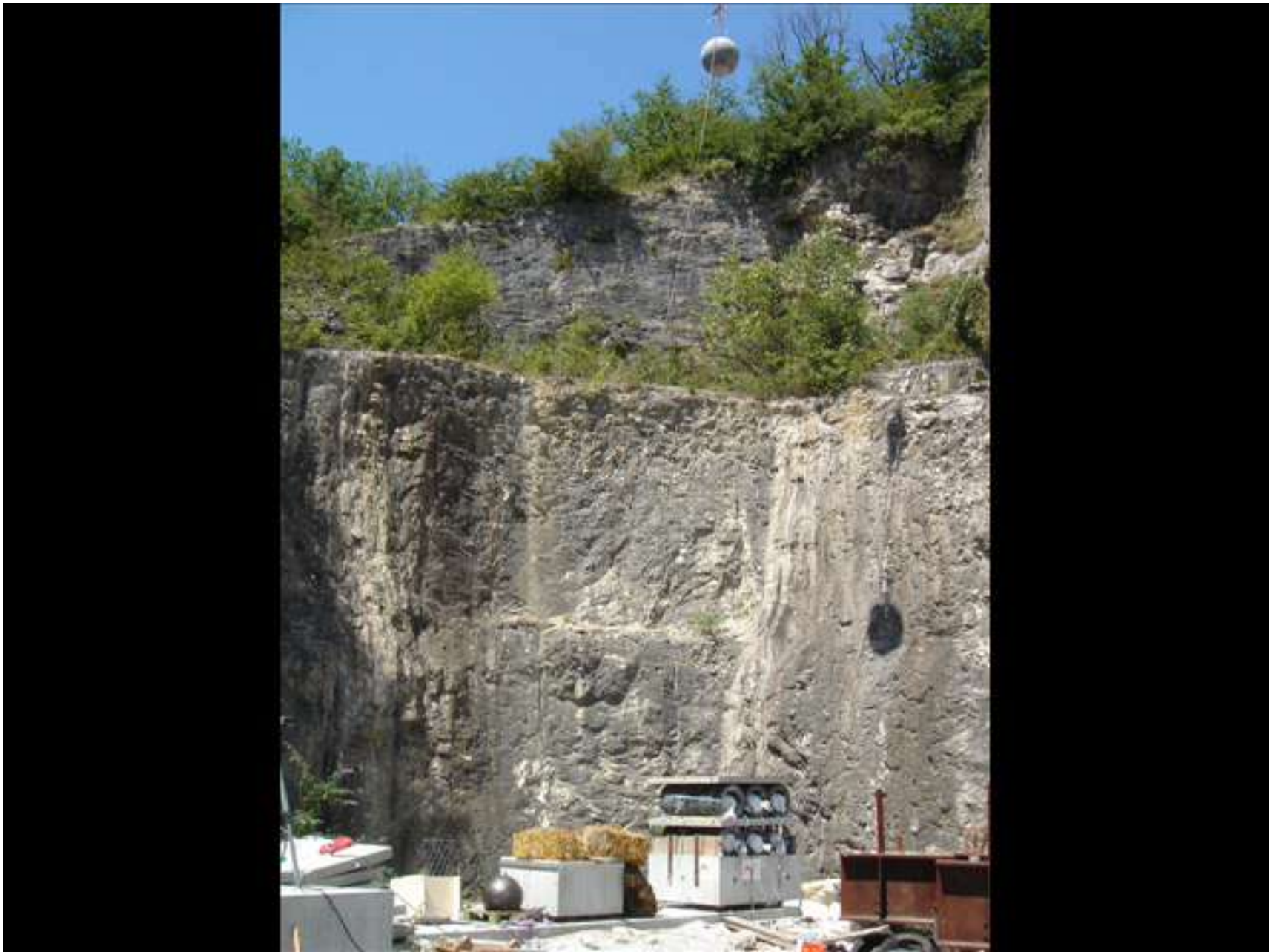
Minimum Design Strength



Impact Toughness at Low & Ambient Temperatures



700 KG Ball Impact – Carbon Steel Reinforced



700 KG Ball Impact – Type 304 Stainless Reinforced

7 World Trade Center, New York

Security: 316 bollards & 2205 structural sections below the canopy

Doha, Qatar, Convention Center & Tower (2015), Jahn

- 2205 stainless
- Convention center column covers, bollards
- Wall panels bottom 18 m of 550 m tall tower

Government Security Gate - UK

Resisting Salt Chloride Induced Corrosion

Norra Länken's Junction Värtan. Courtesy of Skanska

Concrete reinforcement
Stockholm Road Authority
Trafikverket

Toronto
Overpass

Where Should Stainless Concrete Reinforcement Be Used?

- Sensitive electronic equipment
  - MRIs, automated highway toll booths
  - Government facilities
- Coastal or deicing salt
  - Bridges, pavement, seawalls, piers, parking garages
  - Salt exposure levels
    - Immersion, spray, splashing
    - Coastal zone with high chloride deposition rates
- Seismic design (bridge piers, slab connections)
- High impact resistance - security, avalanche walls
- Fire resistance/containment

Sea Walls & Pier Concrete Corrosion

Sidney Opera House
Carbon steel reinforced concrete retaining wall corrosion
Replaced with Type 316 rebar

Stainless rebar for addition to 500 year old London government building

Coastal Ground Anchors & Retaining Walls

San Francisco ground anchors

Salt = corrosive soil

After >50 years, unprotected stainless ground anchors had no significant corrosion

Triple protected carbon steel deterioration after 15 years

Stainless initial cost is lower

Complementary Stainless Products

Lenton Stainless Steel Couplers

BarSplice Stainless Steel Form Savers

Stainless Steel Tie Wire

Stainless Steels Used in Reinforcement

- Specification ASTM A955/A955M
- Yield Strength grades: 60 and 75 (420 MPa, 520 MPa)
- Welding AWS D1.6
  - Reference AWS D1.4 for joint design & mechanical testing
  - Some welding techniques are different – never preheat stainless steel!
- Alloy families
  - Austenitic
    - Strengthened by cold work
    - Nonmagnetic
  - Duplex
    - Higher strength
    - Magnetic

Coastal Chloride Deposition/ Chloride Penetration Relationship Brazil, Cuba, Yucatan Peninsula

- Chloride penetration into various types of concrete and relationship to chloride deposition
  - 200 meters (656 ft) or less from shore had highest levels
  - Not limited to shore
- Locations with ~ 10 kg/ha (8.93 lbs/acre) of chloride deposition or greater
  - Wide range of concrete types tested
  - Only horizontal surfaces tested – simulating road applications
  - Measureable chloride penetration

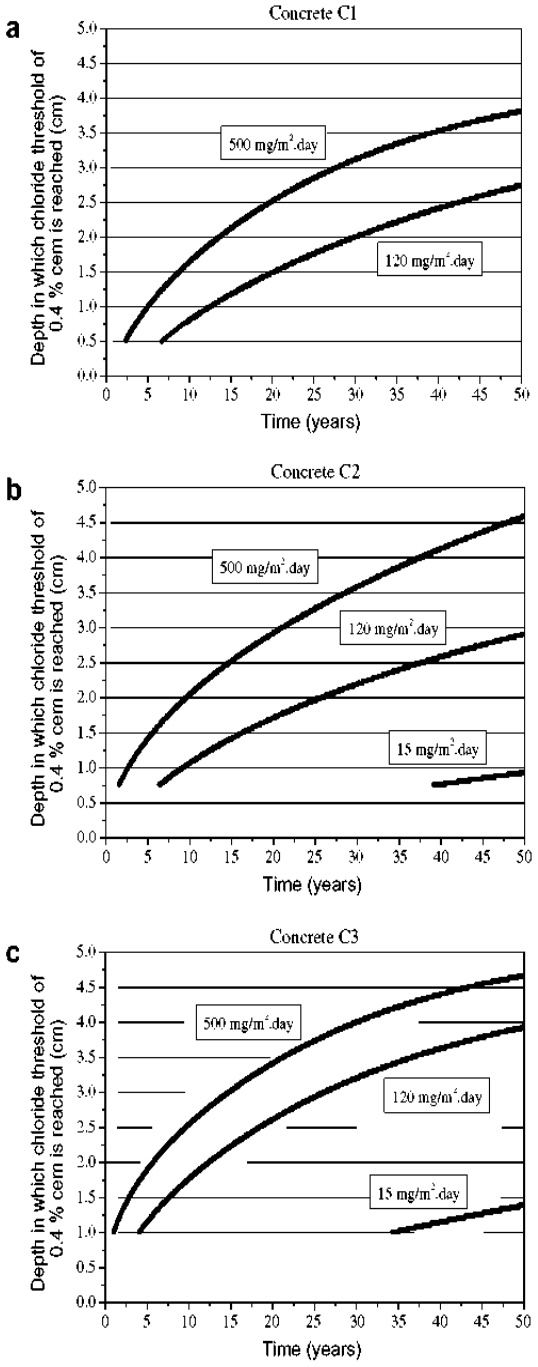
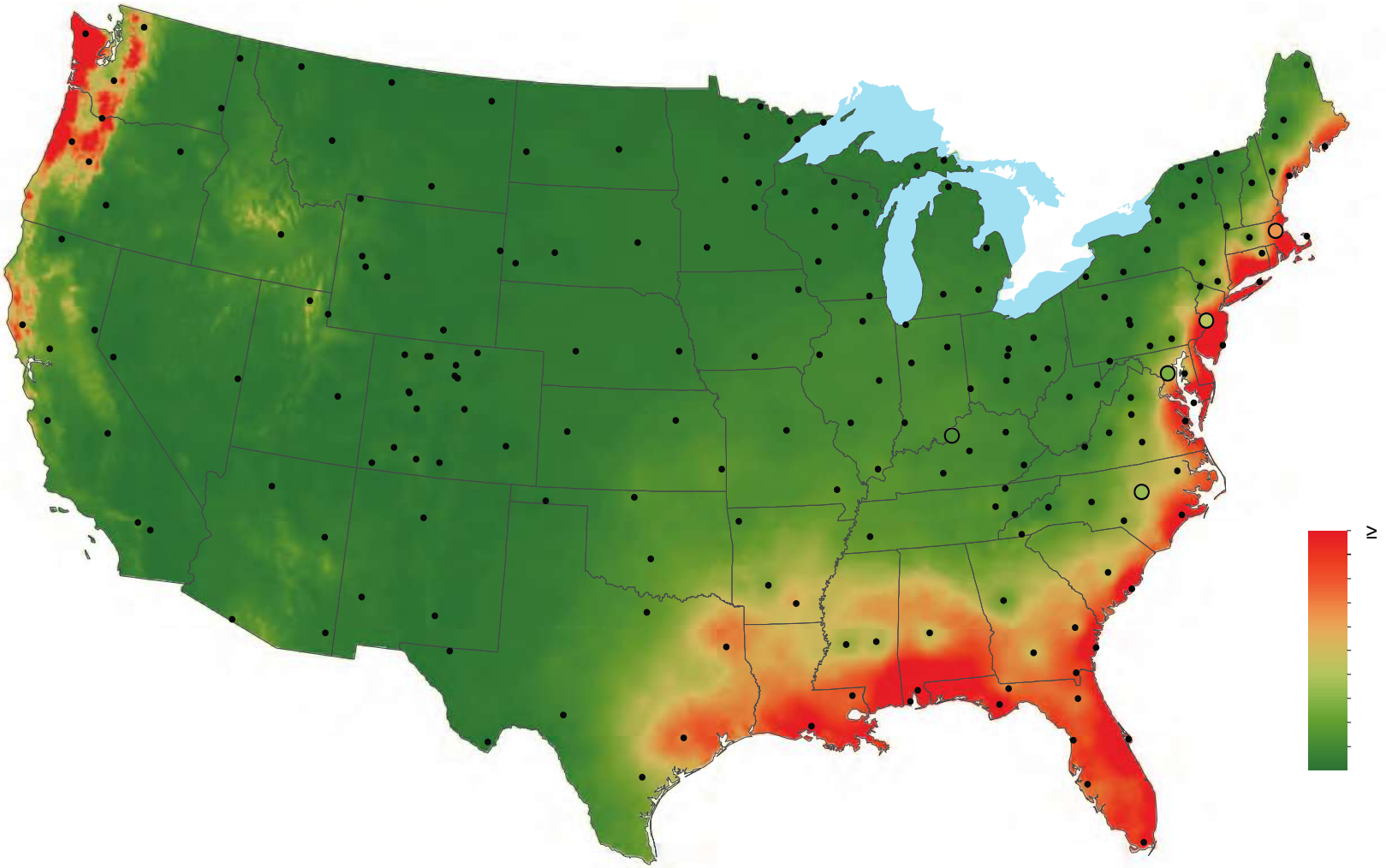


Fig. 8. Simulations of chloride threshold advance in concretes C1 (a), C2 (b) and C3 (c) for different chloride deposition levels.

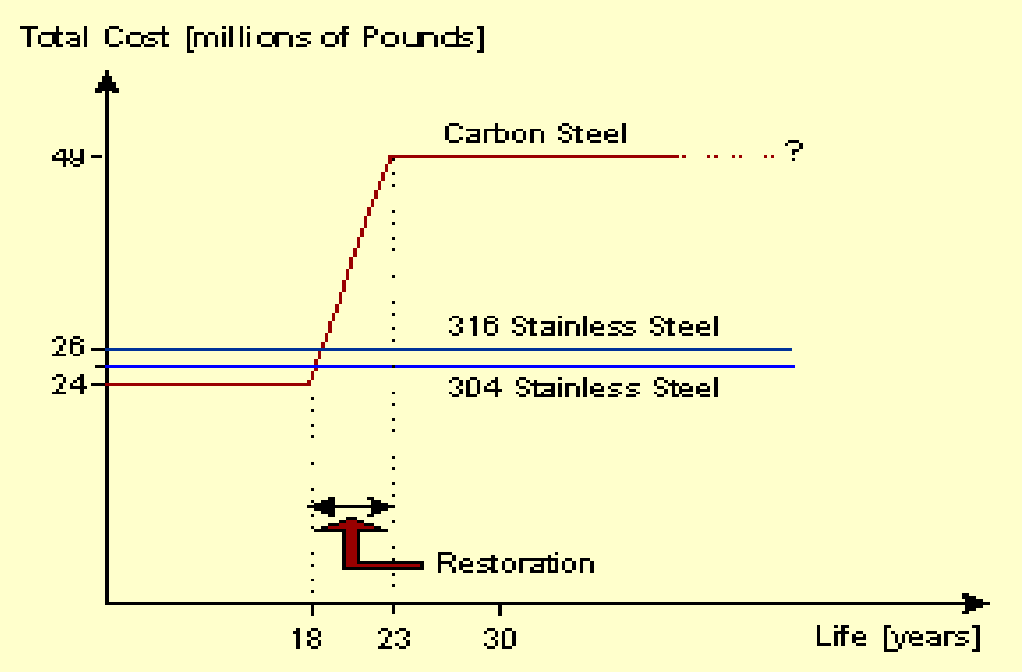
Revised Salt (Chloride) Deposition (kg/ha) – 2009
Data Varies From Year to Year



ttp://nadp.isws.illinois.edu

Cost Savings Opportunities

- Longer life of structure - life expectancy of 100+ years
- Installed cost difference generally 2 – 6% higher
- Can be used in combination with black bar – no galvanic corrosion
- Reduced concrete cover
  - Reduces the deck weight and installed cost
  - Reduced superstructure due to reduced deck weight
  - 2007 NYSDOT – more cover leads to increased deck cracking and increased crack width



Stainless Steel Reinforcement Research

- I-295 near Trenton installed 1983-84
  - Northbound lanes – epoxy-coated rebar
  - Southbound lanes – 304 stainless clad
  - NJ DOT inspection in 1994
    - Stainless in excellent condition
- I-696 near Detroit, 1984
  - Eastbound lanes – Type 304
  - Westbound lanes – epoxy-coated steel
  - 1993 Michigan DOT inspection
    - Cracked concrete at epoxy-coated bar
    - No concrete damage at stainless rebar
- Older European in situ studies

Haynes Inlet Bridge, Oregon, Highway US 101
2205 Stainless Rebar on deck

Bridge, Tunnel & Building Fires

Fire and Thermal Radiation Resistance

- Aluminum is least resistant
  - Aluminum's strength decreases above 100ºC
  - 6061-T6 tensile strength decreases 60% at 200ºC
- Carbon & weathering steel are normally fire proofed
  - Carbon steel limited to 370ºC under continuous loading
  - Carbon steel tensile strength drops 30% at 500ºC
  - Weathering steel tensile strength drops 50% >540ºC
- Stainless steel has better strength and stiffness retention
  - Stainless steel used for heat treating furnaces for other metals

Darchem Engineering
Fire Resistance Testing Summary

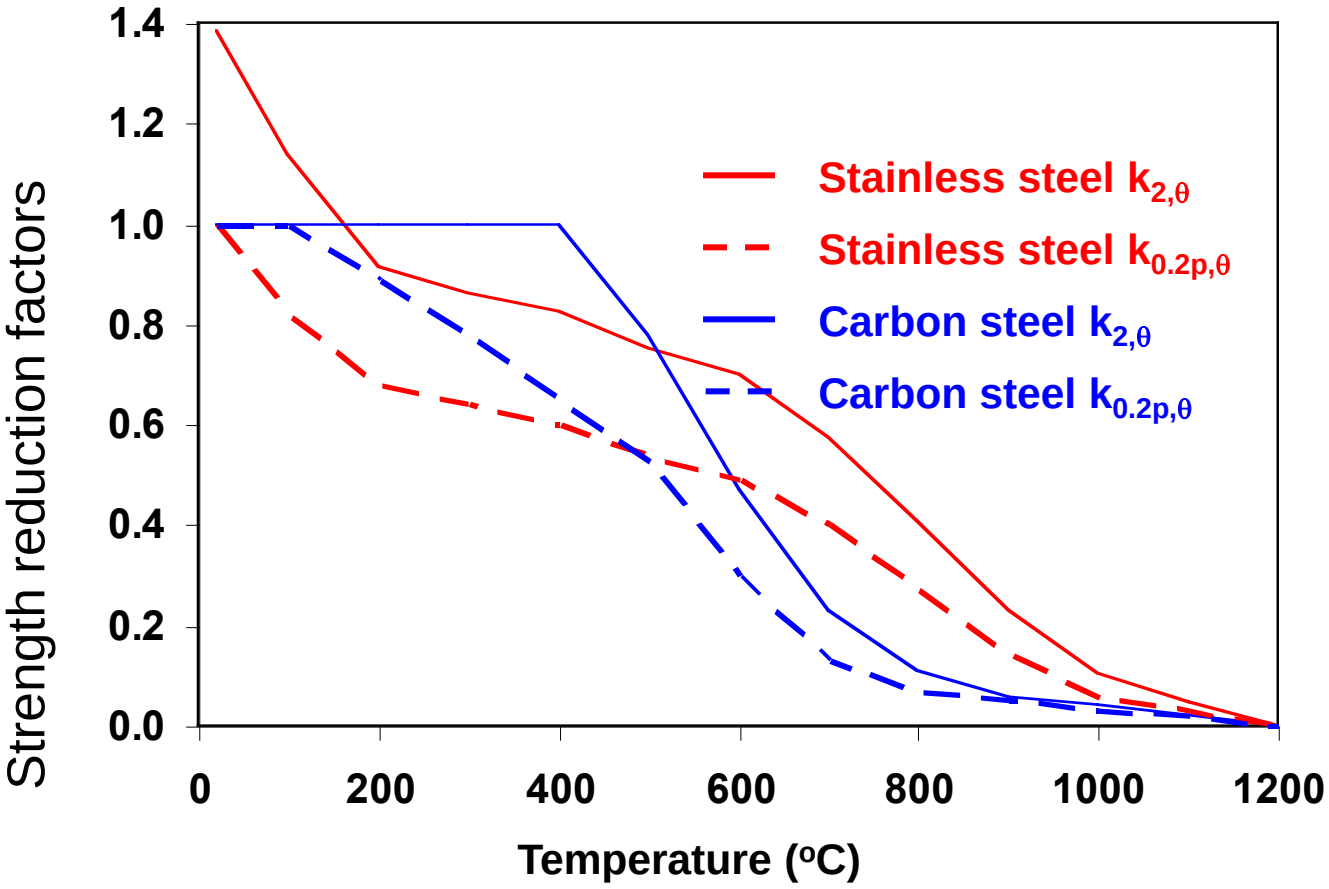
Test: Loaded structural cable supports exposed to 1,000 – 1,050 C (1832-1922ºF) flames

Requirement: Retain structural integrity for 5 minutes

Metal	Result	Comments
Stainless Steel	Passed	Test extended to 45 minutes when gas ran out. No failure occurred. Deflection was 80.5 mm (3.2 inches) after 45 minutes.
Galvanized Steel	Passed	Deflection was 166.5 mm (6.6 inches) after 5 minute test, some molten zinc observed
Aluminum	Failed 26 seconds	Collapsed
Fiberglass	Failed 30 seconds	Collapsed and started to burn, releasing fumes

Fire Testing for Eurocode

Strength Reduction at Elevated Temperature



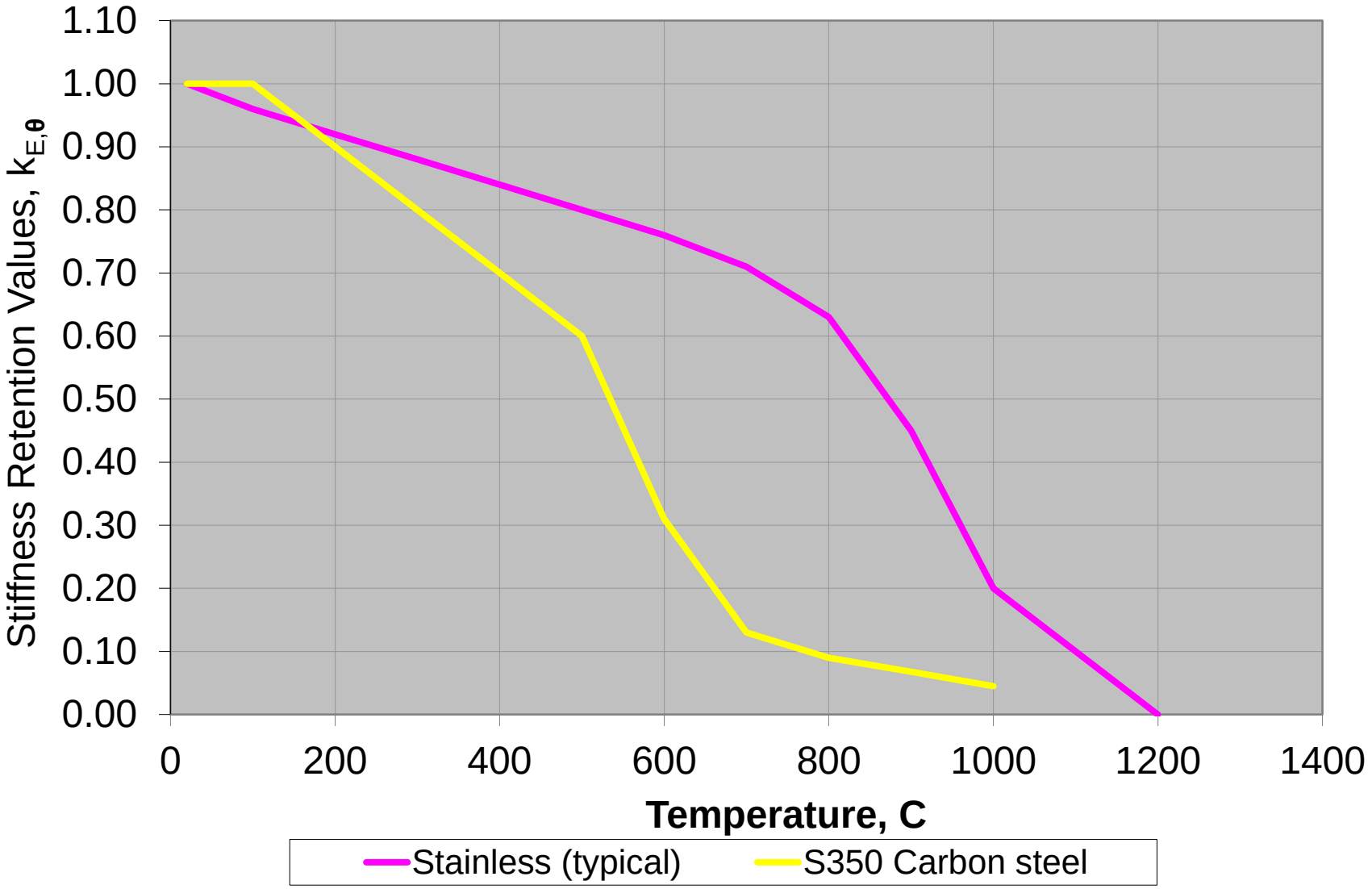
At 800 C (1472 F), stainless steel retains almost four times the strength of carbon steel

$k_{0.2p,q}$ = strength reduction factor at 0.2% proof strain

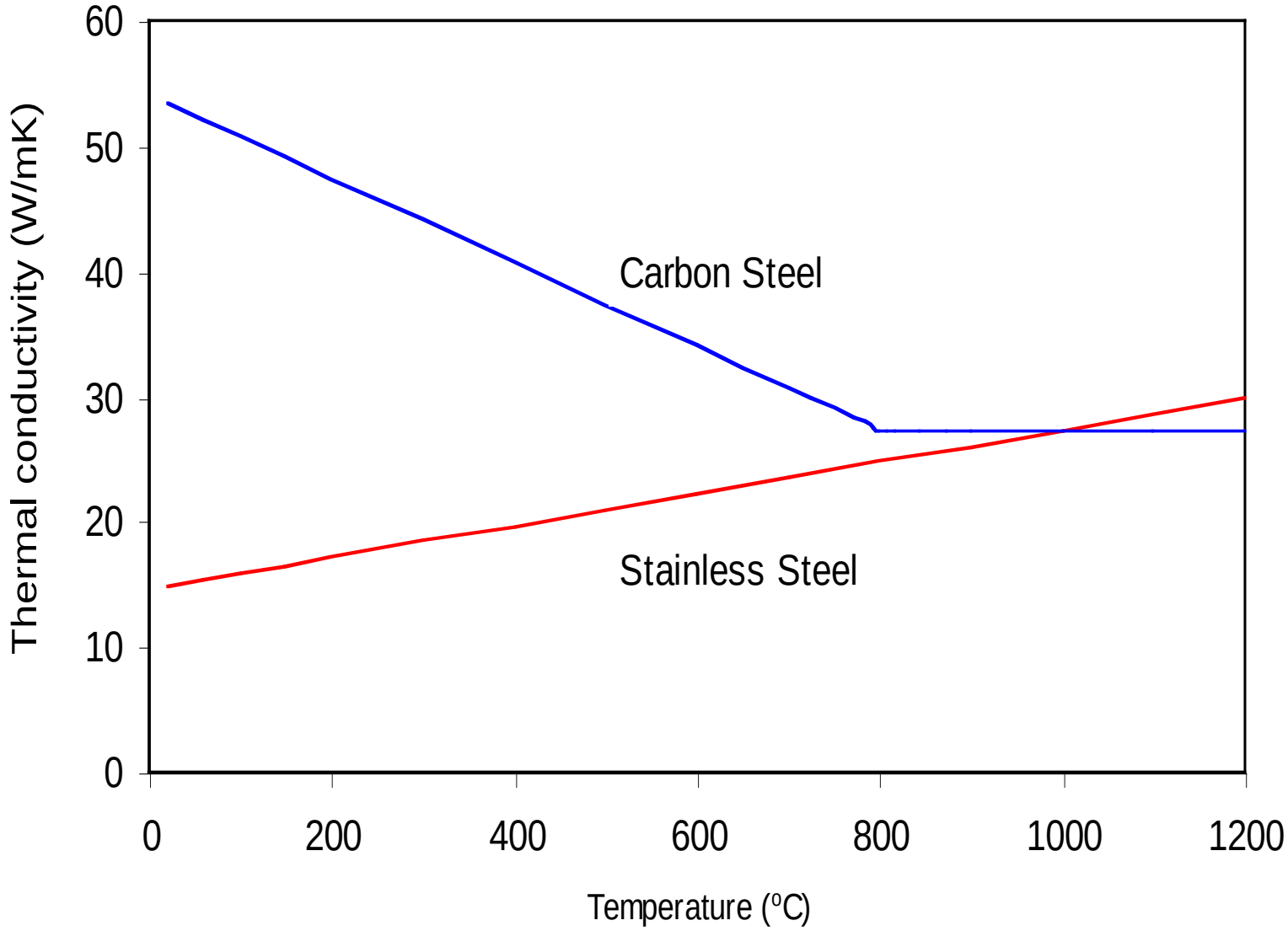
$k_{2,q}$ = strength reduction factor at 2% total strain

Stiffness Retention at Elevated Temperature

7 times the stiffness retention of carbon steel at 800 C (1472 F)



Thermal Conductivity of Carbon and Stainless Steel



Space Frame Roofing Finite Element Analysis

- Tubular structure (1.9” diameter/0.19” wall to 3.5 “ diameter/0.24” wall)
- Various structural knots (intermediate, edge, support) at lattice apexes
- Free span: 35.4 ft
- Module side: 5.9 ft
- Structure width: 11.8 ft
- Roofing load: 184 lbs/ft^2
- Structure weight: 6.9 lbs/ft^2

Critical Times and Temperatures for Space Frame Roof Failure

Steel	Critical time to failure (minutes)	Critical temperature for failure (˚F)
Carbon Steel	10:32	892
Type 304	15:19	1117
Type 316	28:53	1465

Relative to carbon steel

- Type 304 increases the critical time to failure by 45%
- Type 316 increases the critical time to failure by 174%

Relative to Type 304

- Type 316 increases the critical time to failure by 89%

The Helix Bridge, Singapore, 2010

Length: 280m

Design Life: 120 Years

Duplex 2205 650 tons, tube (plate & sheet) and bar

Surface: mirror polish

Type: 5 spans, double helix structure from tubes.

San Diego Harbor Dr. Bridge, 2012

- 2205 is primary structural material
- One of world's longest self-anchored, suspension bridges 168 m (550 ft)
- T. Y. Lin structural design

The Aging Water Infrastructure
Soil & Environment Corrosion Changes

Installation	Material	Expected Life	Failure Point
1880	Cast Iron	120 yrs	2000
1920	Carbon Steel	100 yrs	2020
1945	Ductile Iron	75 yrs	2020
1970	Plastics	60 yrs	2030
2000	Stainless Steel	100 yrs +	2100+

Stainless Steel:
The Modern Plumbing Choice

Stainless Steel has been used successfully for handling potable water since the mid-1960's.

Desalination Equipment

Tanks

Gates

Piping

Tapping Sleeves

Spacers

Couplings

Repair clamps

Desalination equipment

Stainless Steel Water Pipe & Tapping Sleeves

Stainless Steel Water Lines and Tanks Save Water

Which Stainless Steel?

Grade	Cr	Ni	Mo	N
Austenitic				
304(L)	18	8	-	-
316(L)	16	10	2.3	-
Duplex				
2101	21.5	1.5	-	0.22
2304	23	4	-	0.12
2003	20	3	1.6	0.16
2205	22	5	3.0	0.18

Why Stainless Steel?

- **Corrosion Protection** - Coating or cathodic protection is ***not required*** for SS in most locations. A thin chromium-rich oxide film which is self-healing provides corrosion protection for SS.
- **Erosion Corrosion** - SS are much more resistant than steel to erosion-corrosion caused by high flow rates and particulate matter. Handle high velocity and turbulence (pumps) without suffering wall thickness erosion.
- **Coefficient of Friction** - Lower friction compared to cement lined or corroded steel pipes results in less loss of water pressure. Pipe internal diameter can be reduced and pumping cost savings realized.

Why Stainless Steel?

- **Ease of Fabrication** - SS have excellent ductility and can be formed and machined, which permits easy installation of pipelines.

- **Long Pipe Lengths** - SS pipe can be ordered in 20-foot and 40-foot lengths and up to 60-foot in lengths up to 16-inch diameter pipe. DI is available up to 20-foot in length. Number of joints and cost is reduced for long SS pipe strings.

- **Recyclable** - Unlike cement lined and non-metallic pipe, SS are easily recycled and valued for their alloy content. SS pipes have an average recycle content of approximately 60%.

Why Stainless Steel?

- **Low Leakage Rates** - Unlike ductile iron or steel, SS do not suffer from uniform corrosion which results in large perforations and leaks. A corrosion allowance is not required for SS pipe.

- **Hygienic** - SS are basically inert in potable waters due to their protective passive film and maintain water quality and drinking water integrity. SS used for high purity pharmaceutical water and ANSI/NSF drinking waters.

Why Stainless Steel?

- **Environmental Effects**
  - **Temperature** - As operating temperatures decrease, ductile iron, carbon steel and non-metallic pipes decrease in impact strength and become less ductile. Brittle water main failures may result during low temperatures.
  - **UV Resistance** - SS properties are not affected by exposure to UV light as compared to non-metallic pipe.
  - **Soil Corrosion** - SS resist corrosion in most soils and do not require coatings or electrochemical protection systems.

Stainless Steel Standards

- Meets EPA and ANSI/NSF International Standard 61, Annex C
- Acceptable materials in Annex C:
- 304, 304L, 316, 316L, 2205, 2003, 2101, 2304
- Included in the International Building Code

- AWWA C219 - Bolted Sleeve-Type Couplings on Plain end Pipe
- AWWA C220 - Stainless Steel Piping
- AWWA C221 - Fabricated Steel Mechanical Slip-Type Expansion Joints
- AWWA C223 - Tapping Sleeves
- AWWA C226 - Stainless Steel Fittings
- AWWA C606 - Grooved and Shouldered Joints
- AWWA C2BB - Stainless Steel Flanges
- AWWA C2DD - Bolted Split Sleeve Type Couplings

Conclusions

- Stainless steel is a sustainable durable material
- There are endless design possibilities
- It contributes to safety and security
- Evaluate each site carefully & use IMOA and Nickel Institute literature and software to help select an appropriate stainless steel and finish
- If technical questions arise, contact the ISSDA
- In more corrosive environments, have a metallurgical engineer with architecture experience evaluate the site and applications