U.S. Department of Transportation
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# Bridge Security Design

## Overview, Recommended Practice & Future Needs

# Learning Objectives

- Create awareness of highway bridge vulnerability to malicious attacks
- Understand low-probability, high-consequence events and the concept of risk
- Understand ways to reduce risk of damage and human injury
- Review current state-of-the-practice in bridge security and discuss future industry needs

# Webinar Outline

- Why is bridge security important?
- State-of-the-practice in bridge security
  - FHWA Primer on Bridge Security Engineering and Design
  - Anti-Terrorist Planner for Bridges
- Future industry needs

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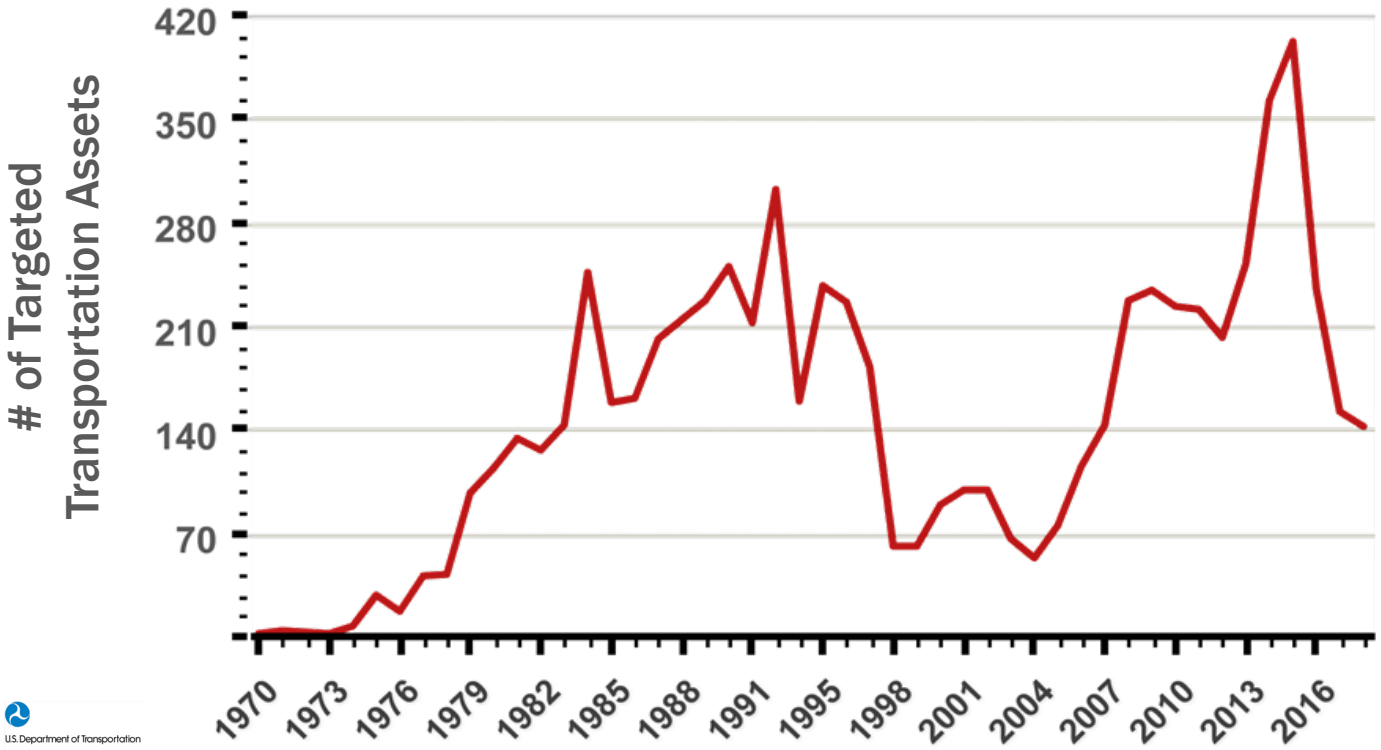
# Why is bridge security important?

# Global Historical Trends

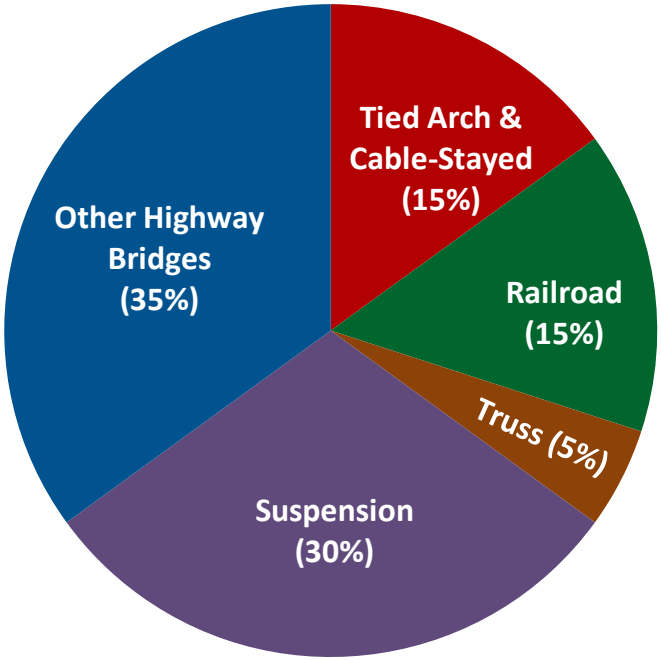
- Documented attacks against transportation infrastructure have increased from less than 100 in 1979 to over 350 in 2015 according to the Global Terrorism Database (GTD)




Data from National Consortium for the Study of Terrorism and Responses to Terrorism, "Global Terrorism Database (GTD)," University of Maryland, 2018

# Global Historical Trends

- Between 1973 and 2019, the Mineta Transportation Institute (MTI) Database includes 310 terrorist attacks specifically targeting vehicle bridges
- Of the attacks in industrialized nations between 1973 and 2001, 58% involved non-iconic structures




Source: Based on data from Jenkins and Gersten, 2001

# Other Factors to Consider

- Low-probability, high-consequence event (risk tolerance)
- We can learn from past non-terrorist related bridge collapses, e.g.:
  - May 2002, **Interstate Hwy 40 Bridge** (Oklahoma; barge impact)
  - September 2001, **Queen Isabella Causeway** (Texas; tugboat impact)
  - August 2007, **Interstate Hwy 35W Bridge** (Minnesota; structural failure)
  - May 1980, **Sunshine Skyway Bridge** (Florida; freighter ship impact)
- Collateral benefits (added value) in enhanced asset security

# Bridges vs. Buildings

- Main structural components are directly exposed to the environment
  - Unlike typical building structures, no frangible envelope
- Highly accessible to the public
  - Very difficult to impose physical standoff
- Little bridge-specific protective design provisions
- Relatively limited structural redundancy

Source: Permission Granted by Wagdy Wassef

Source: Permission Granted by WSP

# Unique Threats

Source: Permission Granted by Eric Williamson

## Man-Made (non-natural) Threats; e.g.,

- Explosive devices
- Thermal/mechanical cutting devices
- Fires
- Vehicle/vessel impact (accidental and malicious)



Source: Permission Granted by U.S. Army Engineer Research and Development Center (ERDC)

# Threat & Vulnerability Risk Assessment (TVRA)

| | |
|---|---|
| **1. Define Design-Basis Threats** | • Conceivable versus practical<br>• Understanding and defining risk tolerance |
| **2. Identify Vulnerable Locations** | • Accessibility<br>• Bridge geometry and bridge component criticality |
| **3. Develop Credible Threat Scenarios** | • Practical threat deployment<br>• Credible attacks |
| **4. Conduct Threat Analysis** | • Derive loading<br>• Calculate damage/response and assess vulnerable members |
| **5. Design Specific Mitigation** | • Passive: Hardening and damage acceptance<br>• Active: Surveillance/Deterrence |

# Example Security Threat Matrix

| | Tower & Piers | Bridge Deck | Stay Cables & Anchorages | Abutments |
|---|---|---|---|---|
| Hand-Emplaced Improvised Explosive Device (IED) | X | | X | X |
| Vehicle-borne IED | X | X | X | X |
| Water-borne IED | X | X | | X |
| Non-Explosive Cutting Device (NECD) | | | X | |
| Exothermic Torch | | | X | |
| Fire | X | X | X | X |
| Impact (Vehicle, Ship, Aircraft) | X | X | X | X |

# An Emerging Threat: Unmanned Aerial Vehicles (UAVs)

## U.S. Government Threat Advisory

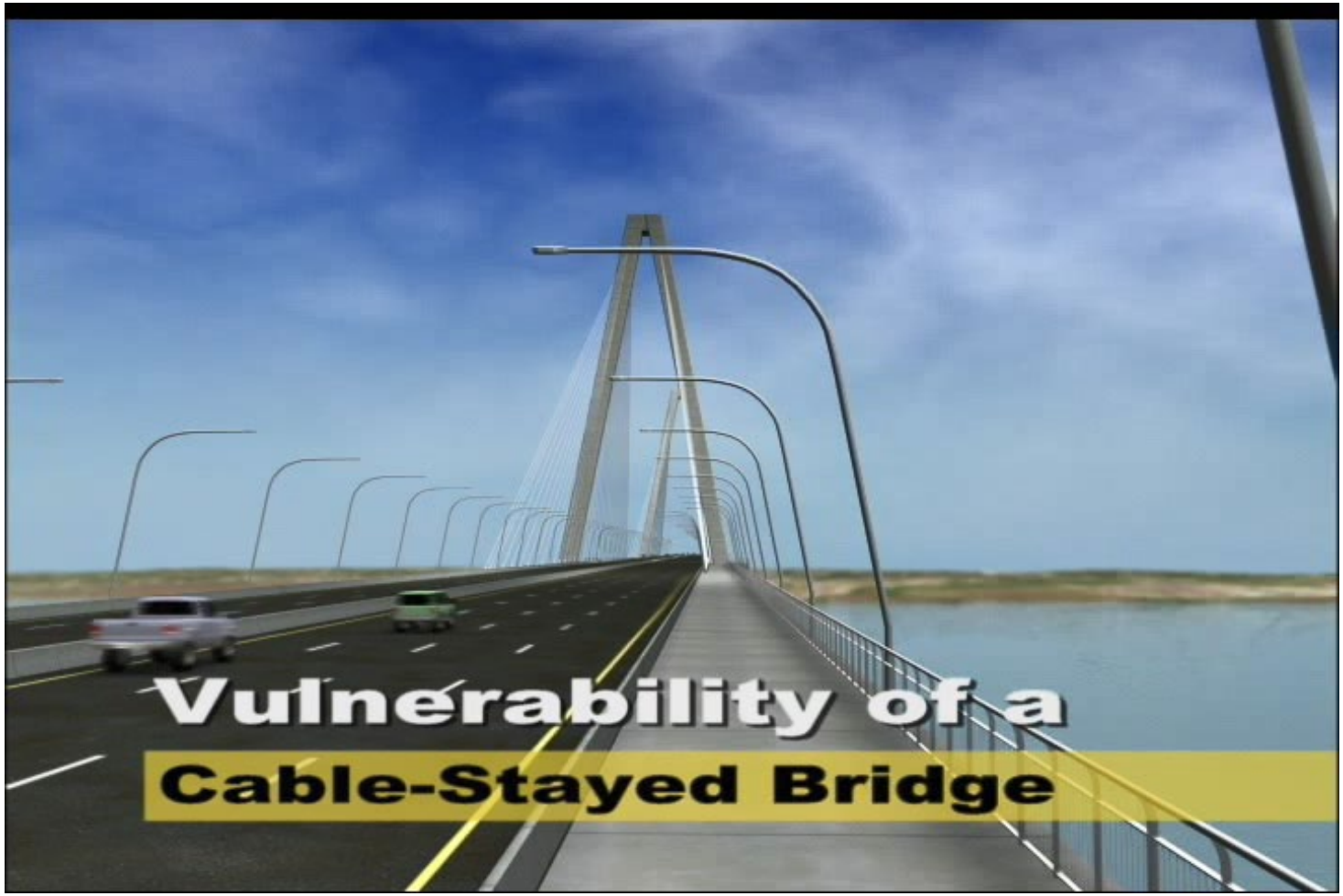
*"Some terrorist groups overseas…pursue new technologies and tactics, such as unmanned aerial systems…"*

*"The current bulletin introduces unmanned aircraft systems potential threats…"*

*"There's been an uptick in terrorist interest using unmanned aerial systems as weapons in the United States…"*

- Homeland Security bulletin warns of weaponized drones and threat to aviation, ABC News; Nov. 9, 2017
- U.S. Department of Homeland Security (DHS) National Terrorism Bulletin issued Nov. 9, 2017
- Terror from skies as Mexican cartel attaches bomb to drone, The Washington Post; Oct. 24, 2017

# The End Game…

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Source: Permission Granted by U.S. Army Engineer Research and Development Center (ERDC)

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# State-of-the-Practice in Bridge Security

FHWA Bridge Security Engineering and Design Knowledge and Resources

Anti-Terrorist Planner for Bridges (ATP-Bridge)

# Bridge Security Reference Documents

*General Documents:*

- American Association of State Highway and Transportation Officials (AASHTO). (2011). *Bridge Security Guidelines*. Washington, D.C.
- Blue Ribbon Panel Report: Recommendations for Bridge & Tunnel Security, 2003
- National Cooperative Highway Research Program (NCHRP) Report 645: Blast-Resistant Highway Bridges: Design and Detailing Guidelines, 2008
- Joint Transportation Research Program (JTRP): Synthesis of Best Practices in Transportation Security
- U.S. Department of Defense: UFC 3-340-02 Structures to Resist the Effects of Accidental Explosions

*Federally Developed Software (available for free):*

- ATP-Bridge – Anti-Terrorist Planner for Bridges
- SBEDS - Single-degree-of-freedom Blast Effects Design Spreadsheet

# Bridge Security Reference Documents

*Vehicle Collision:*

- ASTM International: F 2656-07
- PAS 68: 2013: Impact Test Specifications for Vehicle Security Barrier Systems
- AASHTO Guide Specifications for Protecting Bridge Piers against Vehicular Impact (currently being prepared for publication)
- NCHRP Report 892, Guidelines for shielding Bridge Piers
- FHWA-HIF-18-062: A Performance-Based Approach for Loading Definition of Heavy Vehicle Impact Events

*Vessel Collision:*

- AASHTO Guide Specification for Vessel Collision Design of Highway Bridges 2nd Edition 2009
- Florida Department of Transportation (FDOT) Mathcad software program *Vessel Impact Analysis v3.13*

# Bridge Security Reference Documents

*Fire:*

- *Society of Fire Protection Engineers* (SFPE): Handbook of Fire Protection Engineering

*Stay Cables (Fire):*

- Post-tensioning Institute (PTI): DC45.1-12: Recommendations for Stay-Cable Design, Testing, and Installation

*FHWA Resources:* Source: http://www.fhwa.dot.gov/bridge/security

- Primer on Impact Protection for Critical Transportation Infrastructure (Dec. 2018)
- *Multi-Year Plan for Bridge and Tunnel Security Research, Development, and Deployment (2006)*
- *Blue Ribbon Panel on Bridge and Tunnel Security (2003)*

# Topics of Bridge Security Engineering and Design

1. Security Planning for Highway Bridges
2. Materials Performance
3. Blast Phenomenology
4. Mechanics of Structural Elements
5. Dynamic Response of Structures

# Topics of Bridge Security Engineering and Design (cont'd)

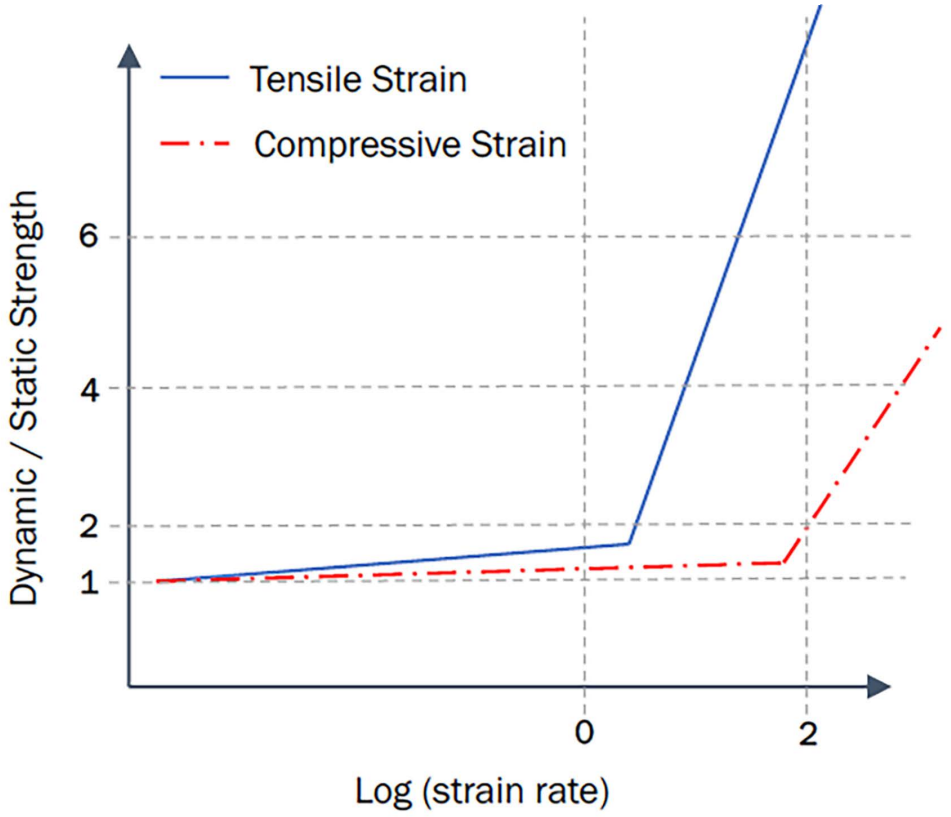
6. Protective Design Best Practices for RC Columns
7. Protective Design Best Practices for Steel Cellular Towers
8. Protective Design Best Practices for RC Towers
9. Protective Design Best Practices for High-Strength Steel Cables
10. Protective Design Best Practices for Other Bridge Components
11. Anti-Terrorist Planner for Bridges (ATP-Bridge) Software

# 1 Security Planning for Highway Bridges

- Threat mitigation strategies
  - Planning & coordination measures
  - Information control measures
  - Site layout measures
  - Access control/deterrent measures
  - Deception measures
- Project coordination (get security folks involved at the outset of a project)
- Additional publicly available bridge security practices

# 2 Materials Performance

- Explosives
  - High explosives
  - Types of explosive charges
  - TNT equivalency
  - Charge shape
- Reinforced concrete & structural steel
  - Strain-rate effects
  - Strength values for design
  - Rate-dependent material models
  - Thermal effects



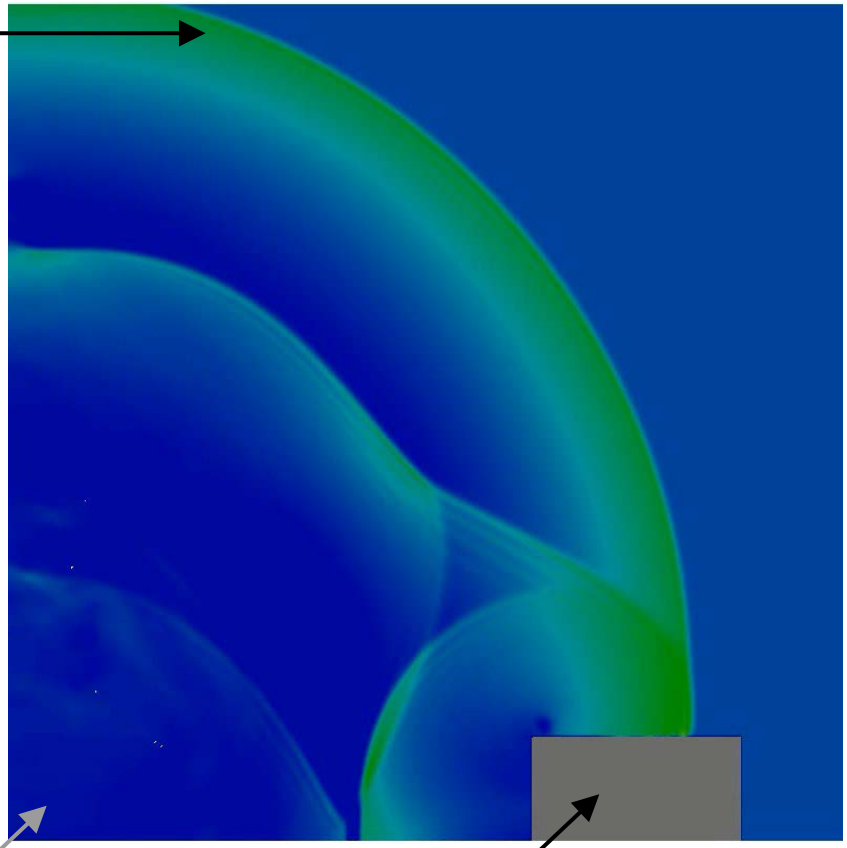

Comparison of concrete dynamic and static behavior

Source: Based on information in: J. W. Tedesco, W. G. McDougal and C. A. Ross, Structural Dynamics: Theory and Application, Menlo Park, CA: Addison Wesley Longman, 1999

# 3 Blast Phenomenology

- Types of explosions
- Shock waves in air
- Far-field behavior of shock waves
- Near-field behavior of shock waves
- Shock wave interaction with bridge components
- Blast load characterization for analysis and design

Source: Permission Granted by Protection Engineering Consultants, LLC



# 4 Mechanics of Structural Elements

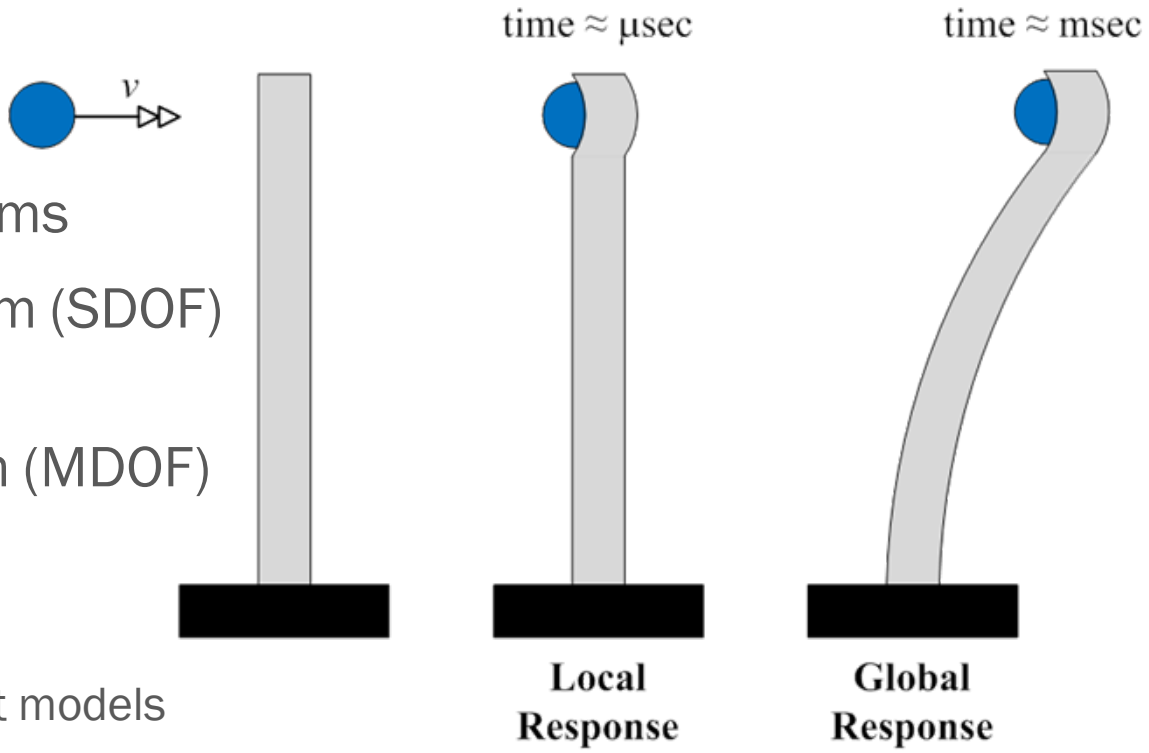
- Conventional RC elements
  - Local response mechanisms (spall/breach)
  - Global response mechanisms
- Prestressed & high-performance concrete elements
  - Prestressed, high-performance, and fiber-reinforced concrete
- Structural steel elements
  - Local response mechanisms (breach)
  - Global response mechanisms
- High-strength steel cables

Source: Permission Granted by Eric Williamson


Source: R.E. Walker et al., 2011 (Permission Granted by U.S. Army Engineer Research and Development Center [ERDC])

# 5 Dynamic Response of Structures

- Dynamic analysis process
- Performance criteria
  - Not apples-to-apples w/ building structures
- Pressure-impulse diagrams
- Single-Degree-of-Freedom (SDOF) analysis
- Multi-Degree-of-Freedom (MDOF) analysis
  - Frame/grillage models
  - High-fidelity finite element models

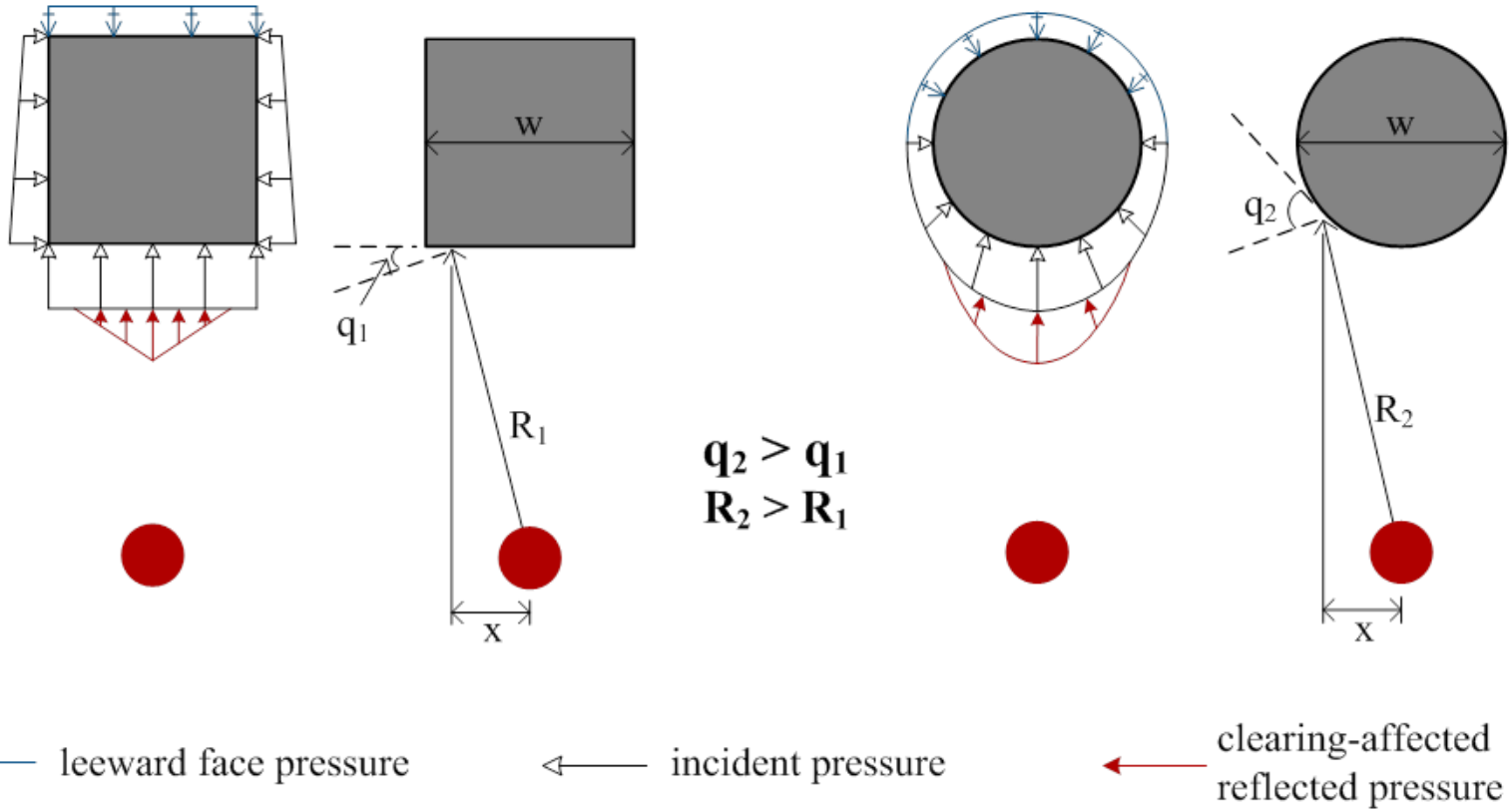



Source: Permission Granted by Eric Sammarco

# Protective Design (PD) Topics

- Design loads
- Failure modes
- Performance criteria
- Design strategies
- Detailing
- Best Practice design procedure
- ATP-Bridge design examples
- Overview of threat mitigation strategies

# 6 PD: Reinforced Concrete Columns

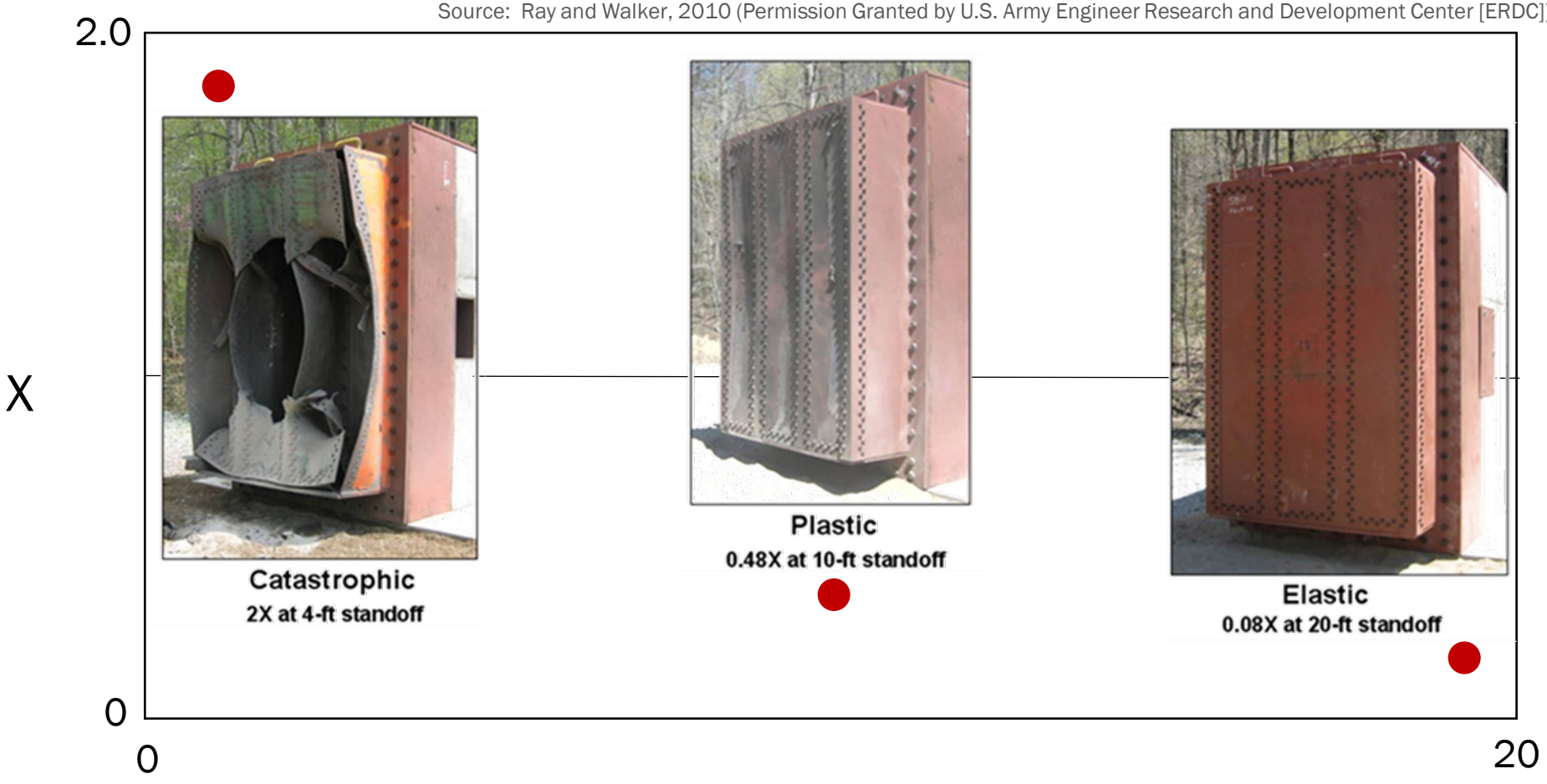





Source: Permission Granted by Eric Sammarco

# 7 PD: Steel Cellular Towers

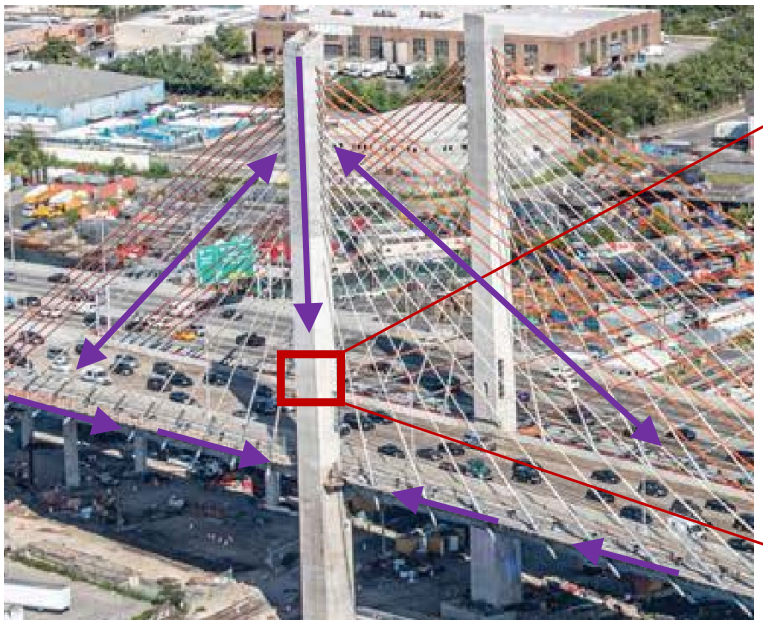
Source: Ray and Walker, 2010 (Permission Granted by U.S. Army Engineer Research and Development Center [ERDC])



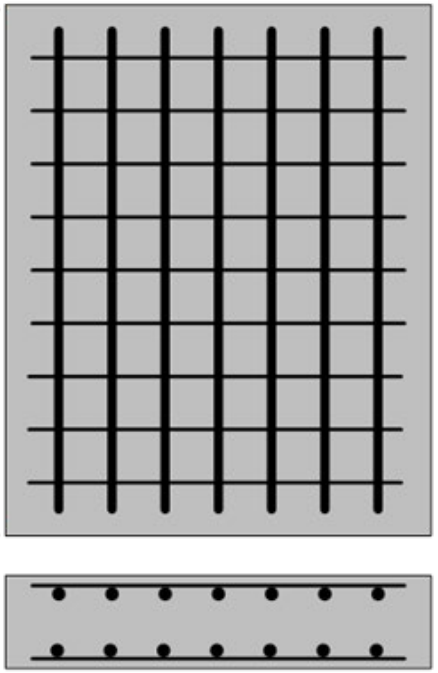
# 8 PD: Reinforced Concrete Towers

## Cable-Induced Axial Compression in Deck and Tower Legs

Source: Permission Granted by WSP



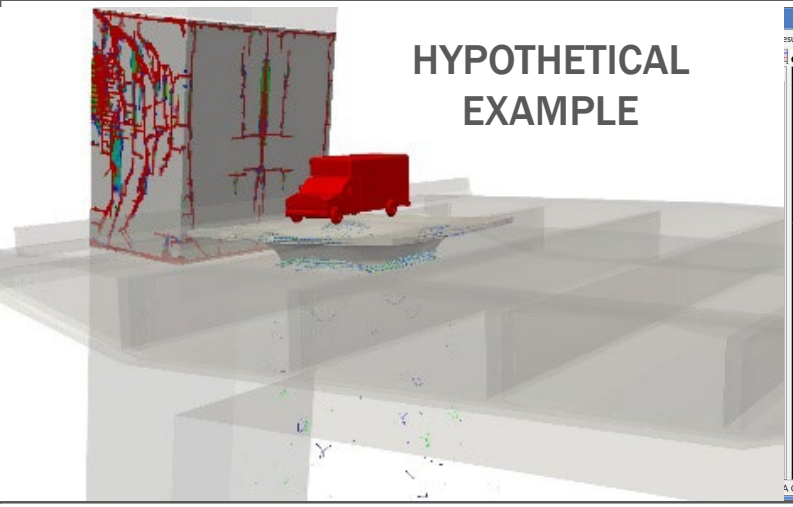
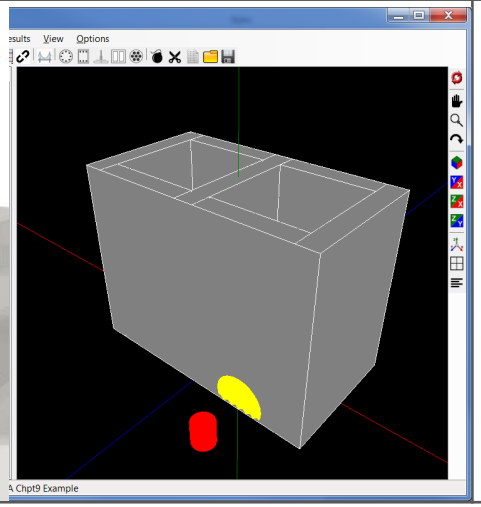
## Orthotropic Rebar Layout



Source: Permission granted by Eric Sammarco

# 8 PD: Reinforced Concrete Towers

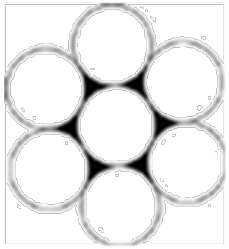
- AASHTO LRFD provisions recommended in NCHRP Report 645
  - Choose a Blast Design Category (BDC) for Design Requirements (AASHTO LRFD Design Article 4.7.6.2) (CFR citation needed here)
  - Scaled Standoff (Z) = R / $W^{1/3}$ R = standoff, W = charge weight

| Z < 1.5, BDC C | 1.5 < Z < 3.0 | Z > 3.0, BDC A |
|---|---|---|
| For a 5,000 lb Explosive Threat $R_x$ = 25ft (more realistic $R_x$ = 5ft, or Z = 0.3) | 25ft < $R_x$ < 51ft | $R_X$ > 51ft |
|     | SDOF /MDOF / Conventional Blast Design | "No additional requirements beyond those for other applicable loads." |

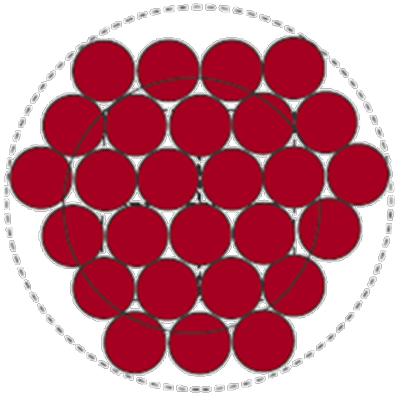
Source: Permission Granted by Protection Engineering Consultants, LLC

Source: Permission Granted by Eric Sammarco

# 9 PD: High-Strength Steel Cables



7- Wire Strand



27- Strand Stay Cable

Post-Test (untensioned)

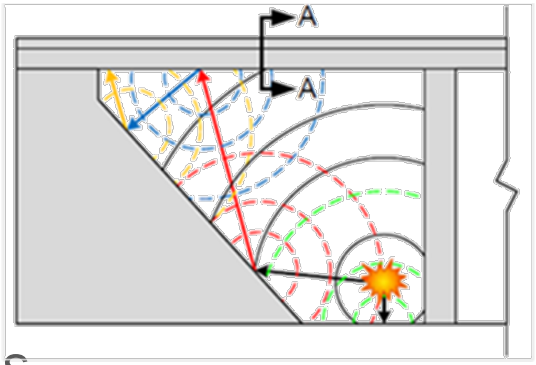
Post-Test (tensioned)

Source: Chiarito, et al. 2011 (Permission Granted by U.S. Army Engineer Research and Development Center [ERDC])

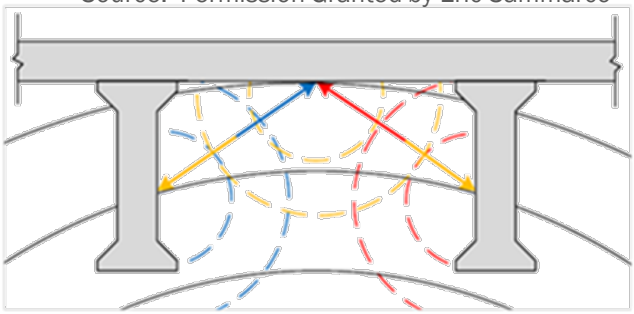
# 10 PD: Other Bridge Components

- Flexural members
- Bridge decks
- Bridge bearings
- Abutments & riprap walls
- Bridges over navigable waterways
- Horizontally curved bridges
- Truss bridges
- Built-up and laced members
- Proprietary protection methods

Source: Permission Granted by Eric Sammarco




Below-Deck Detonation



Section A-A

Incident Wave

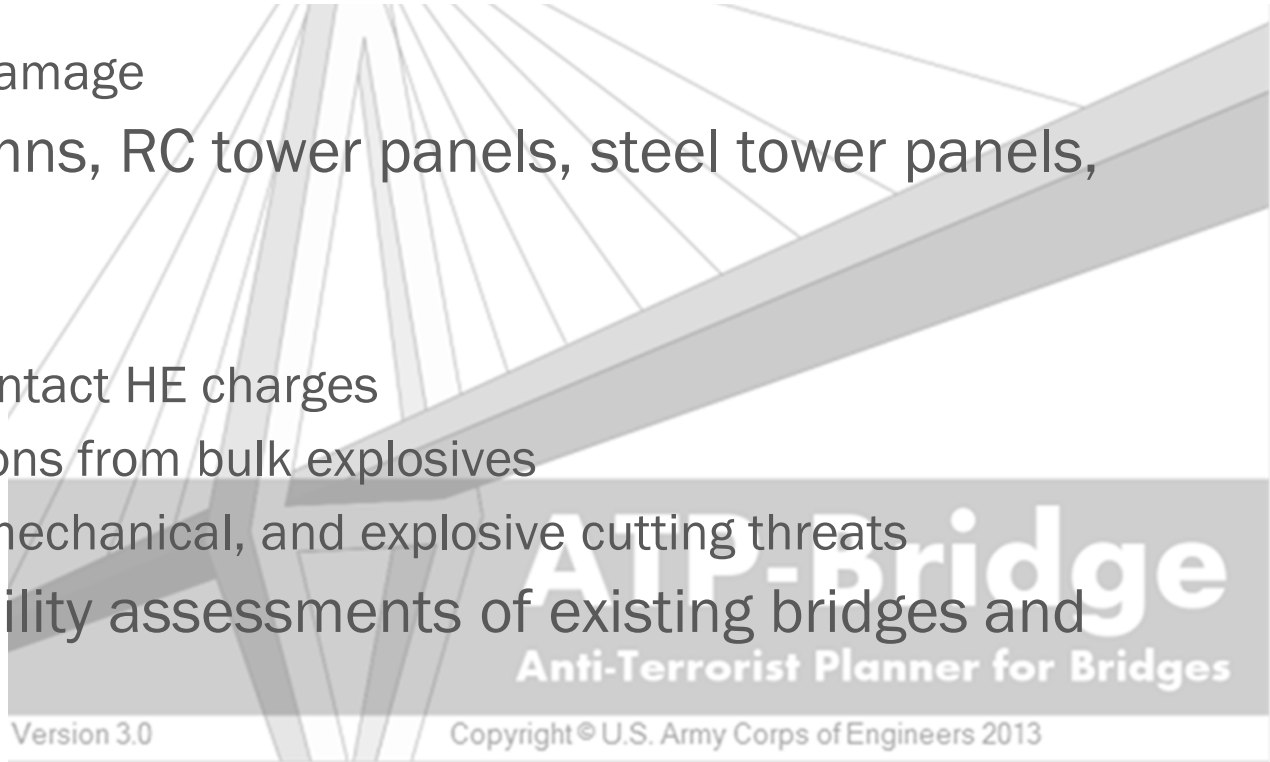
Reflected Wave

Source: Permission Granted by Wagdy Wassef

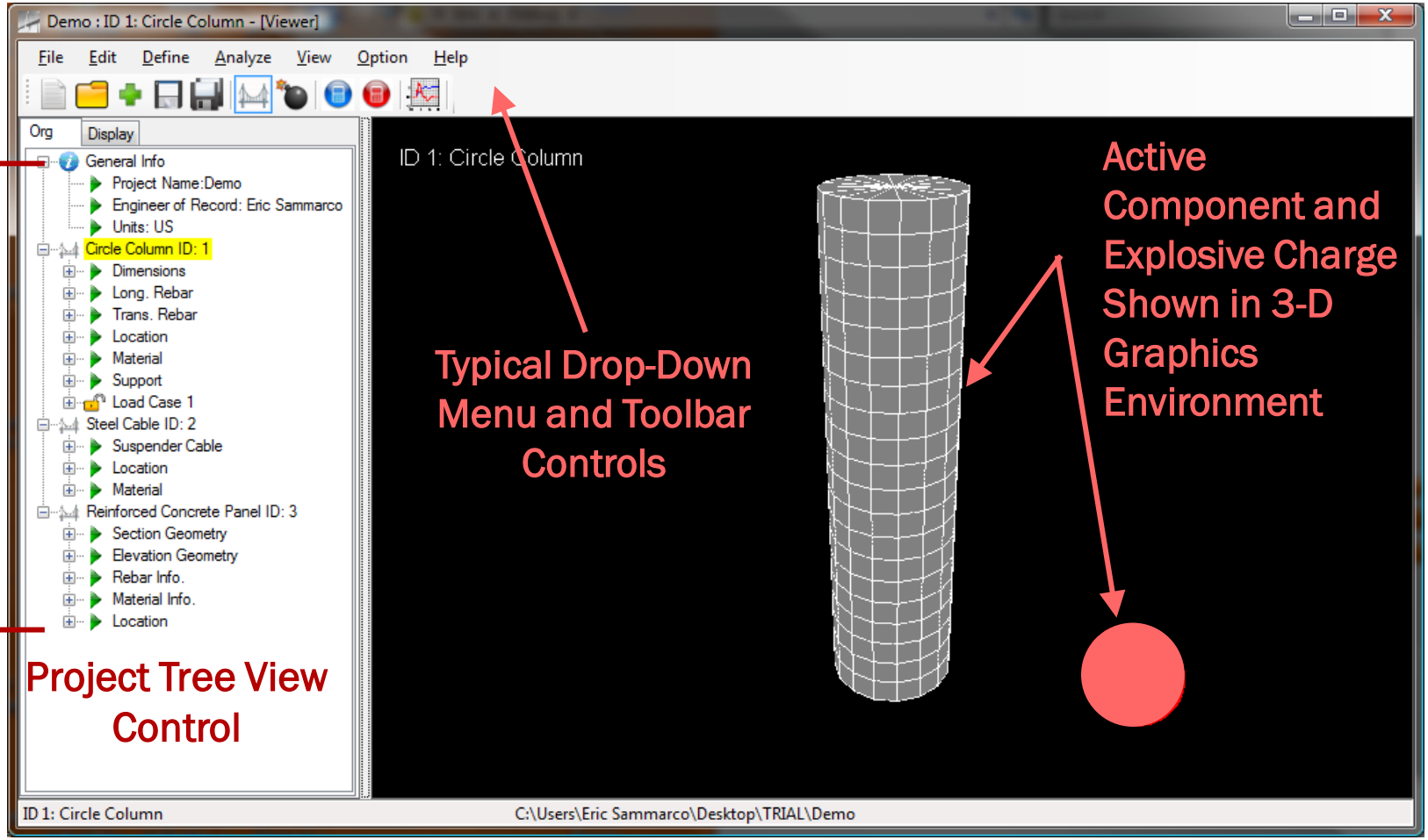
Source: Noriega and Crane, 2013 (Permission Granted by U.S. Army Engineer Research and Development Center [ERDC])

# 11 Anti-Terrorist Planner for Bridges

- Practical, engineering-level software program can:
  - Address a variety of threat scenarios
  - Predict response
  - Predict incurred damage
- Includes: RC columns, RC tower panels, steel tower panels, cables
- Threats
  - Contact & near-contact HE charges
  - Standoff detonations from bulk explosives
  - Various thermal, mechanical, and explosive cutting threats
- Supports vulnerability assessments of existing bridges and of new bridges



# 11 Anti-Terrorism Planner for Bridges




Source: Permission granted by U.S. Army Engineer Research and Development Center [ERDC]

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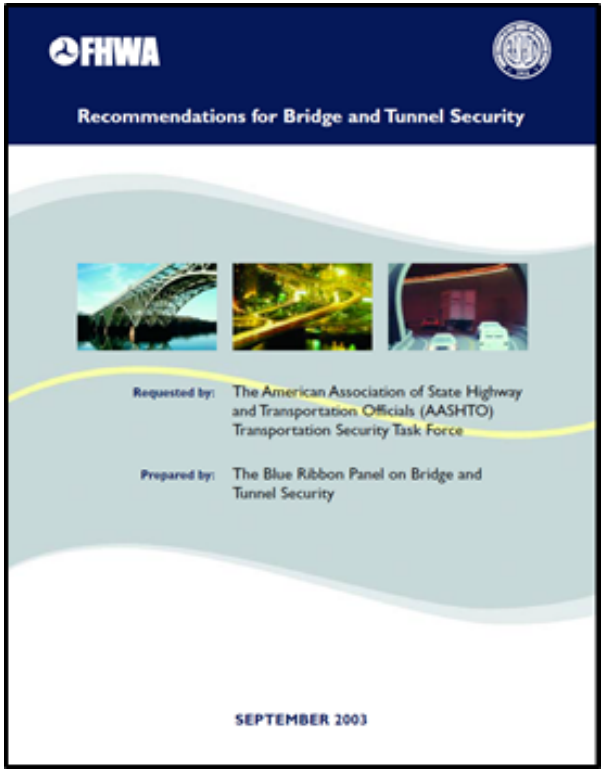
# Future Industry Needs

# Industry Challenges

- Reduce and manage risk of vulnerable transportation infrastructure
- Maintain and secure transportation infrastructure to:
  - support national economic well-being
  - provide freedom of movement
  - serve as a national defense asset
- Since the Blue Ribbon Panel established Security R&D Roadmap:
  - A lot of progress, but…more to do!




Source: FHWA, 2003

Blue Ribbon Panel Report - *Recommendations for Bridge and Tunnel Security*
www.fhwa.dot.gov/bridge/security/brp.pdf

# Industry Challenges

- Quantifying the size and likelihood of ever changing threats
- Varying bridge types and complexity
- Determining vulnerability and levels of accepted performance and risk
- Predicting long-term performance and behavior
- Validating how new materials perform
- Validating solutions for future protection measures
- Detailing retrofits of existing bridges vs. new bridge construction
- Predicting performance change of modified structures (goal is enhanced resiliency; i.e., add value)

# Future Needs for Bridge Security Design: Partners

- Department of Homeland Security (DHS): Science & Technology (S&T), Transportation Security Laboratory (TSL), Transportation Security Administration (TSA)
- USACE: Engineer Research and Development Center (ERDC), Protective Design Center (PDC)
- National Institute of Standards and Technology (NIST)
- Academia: University of Texas at Austin; MCEER (State University of New York at Buffalo); University of Missouri; University of Connecticut, etc.
- Others: TRB, National Cooperative Highway Research Program, industry
- Professional Society Committees (e.g., ASCE-SEI Bridge & Tunnel Security Committee)
- Transportation infrastructure owners and stakeholders

# Future Needs for Bridge Security Design: Non-Natural Hazards

- Credible security threats to highway bridges are non-conventional and challenging to mitigate
- Industry will benefit from standardized methodology for performing a threat, vulnerability, and risk assessment (**TVRA**) centered around **risk tolerance** for the following:
  - **Explosive Threats**: vehicle-borne improvised explosive device (VBEID), hand-emplaced improvised explosive device (HEIED)
  - **Fire**
  - **Non-Explosive Cutting Devices** (NECD)
  - **Impact**: Vehicles, Vessels
  - **Emerging threats** (e.g., drone attacks)

# Future Needs for Bridge Security Design: Tools, R&D, and Goals

- Security Research & State Pooled-Fund Studies, e.g.:
  - Solutions for security retrofits and new protective construction
  - Use of novel materials for protective solutions
  - ATP-Bridge enhancements
  - Material specification language suggestions for owners to use to select security countermeasures
  - Consistent Validation and Verification process for numerical modeling ( to reduce the need for physical testing to support new bridge construction)
  - Consistent procedures for defining design-basis threats/hazards and conducting TVRAs
  - Develop performance criteria specific to highway bridges

**GOAL:** Improve risk management and overall resiliency of our nation's highway bridges in a prioritized and consistent manner.

# Summary

- Security Improves Resiliency and Safety
  - A more secure bridge is also more resilient and safer (asset level)
  - Strengthens networked community (network level)
- The Vision
  - Involve stakeholders; identify knowledge gaps and needs
  - Develop consistent approach to assess/manage risks
  - Establish security measures (Detect, Deny, Deter, Defend) and improve with latest technology
  - Develop and identify best practices of security that improve resiliency

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# Questions?

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