Risk Management for Critical Structures

A Process to Develop Cost-Effective Integrated Solutions for Security Threats

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PEOPLE MOVING PEOPLE

What We're Trying to Prevent

Protecting Critical Facilities

- We know that our facilities may be targets
- But…
  - What do we do to protect a vulnerable transportation system that is so important to the local, national and world economy?

Why Bridge Security Assessment?

- Competing needs for owners and operators
  - Expand capacity
  - Maintain and improve performance
  - Safety and reliability
  - Security

Assessment Goal

- Develop a cost-effective risk management plan for a critical bridge, using a component level analysis to present to management

Methodology

- Developed for a large city owner with many critical facilities
- Developed by a multi-disciplinary team of experts
- Developed to help decide how to best use available funds

Methodology

- We assess relative risk and relative benefit
- What we can do and what we should not do
- Response and recovery plans
- Multi-hazard approach to compliment safety and operations
- Invest scarce resources wisely

Component-Level Risk Management Steps

- Identify the critical bridge
- Assemble a project team
- Compile the threats
- Identify the bridge's components

Component-Level Risk Management Steps

- Quantify occurrence, vulnerability and importance factors
- Calculate the base risk
- Develop a mitigation strategy and recalculate the risk
- Compare risk from baseline to one with mitigation

Risk Equation

- R = O * V * I
  - R = Risk
  - O = Occurrence
  - V = Vulnerability
  - I = Importance

Risk Equation

- Unique to each component for each threat
- $R_{i,j} = O_{i,j} * V_{i,j} * I_j$
  - i = threat
  - j = bridge component

Risk Matrix

	Base Relative Risk				
Bridge Components	VBIED	HEIED	NECD	Impact	Fire
Arch/tie intersection, median	0.25	0.80	0.03	0.00	0.15
Arch/tie intersection, outer	0.41	0.80	0.00	0.00	0.15
Bearings	0.01	0.02	0.00	0.00	0.02
Delta pier, caps	0.02	0.02	0.00	0.00	0.01
Delta pier, filled wall	0.11	0.00	0.00	0.02	0.02
Delta pier, sloped legs	0.21	0.06	0.00	0.06	0.07
Delta pier, tie	0.16	0.12	0.00	0.00	0.05
Floorbeams	0.07	0.18	0.01	0.00	0.04
Hanger connections, median	0.16	0.34	0.17	0.00	0.06
Hanger connections, outer	0.16	0.34	0.17	0.00	0.06
Hangers, median	0.03	0.34	0.35	0.30	0.08
Hangers, outer	0.03	0.34	0.35	0.30	0.08
Rib bracing	0.00	0.11	0.00	0.00	0.03
Steel arch rib, median	0.42	0.78	0.02	0.35	0.19
Steel arch rib, outer	0.42	0.78	0.02	0.35	0.19
Tie girder, median	0.23	0.76	0.03	0.00	0.13
Tie girder, outer	0.39	0.76	0.03	0.00	0.13

Types of Threats

- Non-Explosive
  - Non-Explosive Cutting Device (NECD)
  - Vehicular Impact
  - Fire
- Explosive
  - Vehicle-Borne Improvised Explosive Device (VBIED)
  - Hand-Emplaced Improvised Explosive Device (HEIED)

NECD

- Cut or sever structural members
  - Saws
  - Grinders
  - Torches

Vehicle Impact

Fire

- Cause structural members to lose stiffness and strength
  - Depends on size and duration of fire

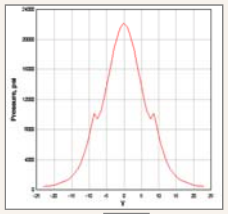
Explosive Devices

Constitute a high percentage of terrorist attacks worldwide

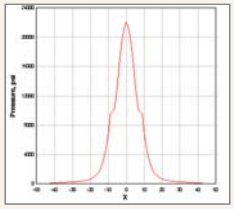
VBIED

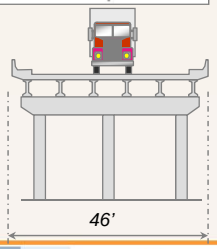
- Historically, the terrorist's weapon of choice
  - Use more explosives
  - Requires no time on target

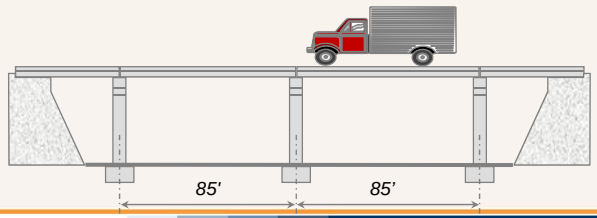
VBIED Characteristics



~ 2000 psi with a few thousand pound truck bomb



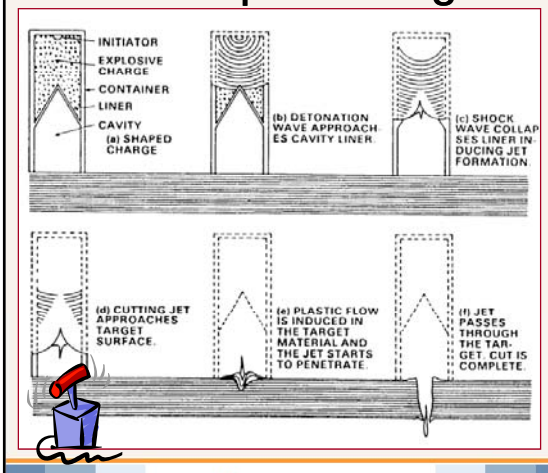




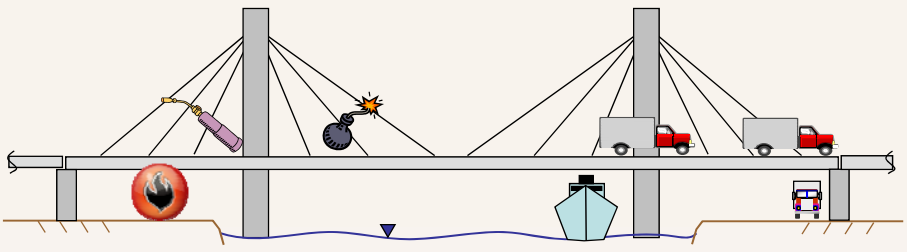
HEIED

- Bulk explosives
  - Military
  - Commercial
  - Home-made
- Shaped charges
  - Conical
  - Linear

HEIED
Shaped Charge Characteristics



Identify Components



Vulnerability
Depends on the Structure Type





Vulnerability
Depends on the Structure Type

- Need to know the collapse mechanism
  - Different for each bridge

Vulnerable Components

- In general
  - Decks
  - Towers
  - Hangers & stays
  - Bearing seats
  - Piers
- Structure specific
  - Deck bridges
  - Cable stay bridges
  - Suspension bridges
  - Truss bridges
  - Movable bridges

Decks

- VBIED
  - Vulnerable in immediate vicinity of blast
  - Larger members are generally very resilient to deck level detonations

Decks

Below-Deck Detonations

- Low-to-water or overpass bridges especially vulnerable
- Water plumes can be very damaging
  - Uplift could be critical
  - Members not designed for upward loadings

Towers

- VBIED
  - Wall on traffic side vulnerable to large bomb in close proximity

Towers

- HEIED
  - Towers are massive and resilient to localized damage
  - Hollow box components vulnerable to internal detonations
    - Access doors typically at roadway level

Towers

- Impact
  - Towers are usually adjacent to the roadway

Hangers & Stays

- VBIED
  - Low vulnerability to airblast , except in immediate vicinity
  - Beware of fragment loadings

Hangers & Stays

- HEIED & NECD
  - Vulnerable to contact charges and cutting devices
  - Successive hangers must be lost for “unzipping” effect

Hangers & Stays

- Fire
  - Does not take long for member to heat up and lose strength

Bearing Seats

- HEIED & VBIED threats could be used against bearing seats to cause localized loss of bearing

Piers

- VBIED
  - Vulnerable to detonations adjacent to pier
  - Steel vulnerable to buckling from airblast distortion

Piers

- HEIED
  - Concrete vulnerable to breaching
  - Steel vulnerable to cutting

Piers

- Impact
  - Vulnerable to land and water based impacts
  - Designed for impact loading?

Girder Bridges

- HEIED
  - Vulnerable to being severed or breached
  - May be difficult to access girders and secure munitions
  - Diaphragms provide load redistribution

Girder Bridges

- Impact
  - No different than what you deal with routinely

Girder Bridges
Box Girders

- Box girders are very vulnerable to internal detonations, even relatively small charges

Cable Stay Bridges
Deck

- VBIED
  - Vulnerable to airblast from large bomb in close proximity
    - Carries horizontal component of cable stays

Suspension Bridges
Main Cables

- VBIED
  - Cables are massive and flexible
  - Resistant to airblast, except for near contact detonation
  - Beware of fragment loadings

Suspension Bridges
Main Cables

- HEIED
  - Vulnerable near anchorages due to access and seclusion
  - Difficult to cut
  - ~50% section loss for collapse,
  - Small amounts of damage difficult to repair

Suspension Bridges
Main Cables in Anchorages

- HEIED & NECD
  - Splayed cables and I-bars vulnerable to cutting charges

Truss Bridges
Panel Members

- VBIED
  - Diagonals and verticals are closest
  - Upper and lower chord more protected
  - Distortion may cause out-of-plane bending/buckling
  - Overstress in tension members

Truss Bridges
Panel Members

- HEIED
  - Diagonals, verticals, and lower chords are most accessible
  - Vulnerable to being severed or distorted
  - Tension members (easiest to cut)
  - Beware of confined spaces

Truss Bridges
Joints

- HEIED
  - Pin connections vulnerable to blow-apart with packed explosives

Movable Bridges

- General Issues
  - Control towers and operator's house vulnerable to intrusion
  - Mechanisms may be most vulnerable in open position
  - Misaligned components make operation impossible

Movable Bridges

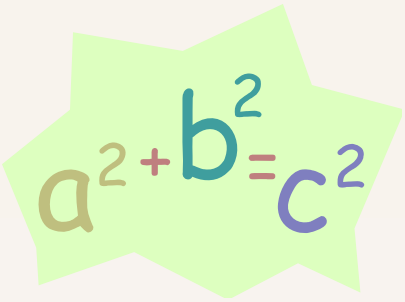
- VBIED & Impact
  - Towers heavily loaded
  - Any distortion disables movement
  - Same vulnerability as other similar structure types

Movable Bridges

- HEIED
  - Lift cables are exposed
  - Lifting mechanism very vulnerable
  - Machinery vulnerable
  - Same vulnerable components as similar bridge types

Risk Equation

- $R_{i,j} = O_{i,j} * V_{i,j} * I_j$
  - R = Risk
  - O = Occurrence
  - V = Vulnerability
  - I = Importance



Occurrence

- $O_{i,j}$ – relative probability of a threat, *i*, actually being used against a given component, *j*
- Attributes
  - General likelihood of threat happening
  - Likelihood of threat being used against component
  - Target attractiveness
  - Access to component

Vulnerability

- $V_{i,j}$ – relative vulnerability of a given component, *j*, given the occurrence of the threat, *i*
  - Software available to help get this information
    - BlastX (Army Corps of Engineers)
    - BEL (FHWA)

Importance

- I_j – measure of component's, *j*, importance to the bridge
- Attributes
  - Structural
  - Historic / symbolic
  - Repair cost
  - Time out of service

Base Relative Risk Discussion

	Base Relative Risk				
Bridge Components	VBIED	HEIED	NECD	Impact	Fire
Tower @ water level	0.10				
Tower @ roadway level	**0.50**	0.19			0.22
Tower @ roadway level (internal)		**0.50**			
Tower @ top (internal)		**0.47**			
Tower (aircraft impact)				**0.48**	
Box girder/deck slab @ tower (main)	**0.46**	0.08			0.19
Box girder/deck slab @ tower (main - internal)		0.19			0.18
Box girder/deck slab @ midspan (main)	0.20	0.04			0.08
Box girder/deck slab @ midspan (main - internal)		0.08			0.08
Box girder/deck slab @ midspan (waterway)	0.02				
Tendon in box girder (main)	0.07	0.29	0.30		
Stay cable	0.18	**0.58**	**0.45**	0.12	0.25
Stay cable @ roadway connection	0.18	**0.58**	**0.45**	0.11	0.25
Stay cable @ saddle (inside tower)		**0.43**	0.06		
Delta frame/strut	0.06	**0.45**	0.06		
Back span pier (#15 and #18)	0.07	0.05			0.05
0					
Box girder/deck slab (approach)	0.11	0.02			0.04
Tendon in box girder (approach)	0.03	0.11	0.11		
Pier (approach)	0.05	0.03			0.04
Box girder/deck slab (approach from land)	0.01				

Mitigation

- Implement measures which are appropriate and effective for a particular risk, yet economical and do not interfere with a structure's operation

Effective Defense

- Prepare to respond and recover
- Deter
- Deny
- Detect
- Defend

Respond and Recover

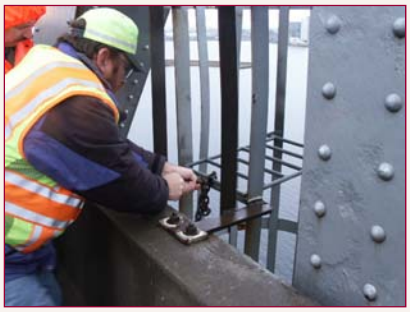
- Develop an incident response plan with local police, fire, and rescue agencies
- Provide training for bridge staff, inspectors, and maintenance personnel
  - Fundamentals of bridge security
  - Recognition of security and terrorist threats, including explosives

Deter

- Increase security patrols
- Install adequate lighting
- Install security signs

Deny Access

- Secure access points
- Plug holes
- Provide fencing and area control



Deny Access
Commendable Practice

Detect

- Capable operations center
  - CCTV
  - Intelligent video
  - Intrusion alarms

Defend

- Standoff
  - On land
  - In water
- Structural hardening
- Fire protection

Defend with Standoff
On Land

Defend with Standoff
In Water

Rock Islands

Dolphins and Fender Systems

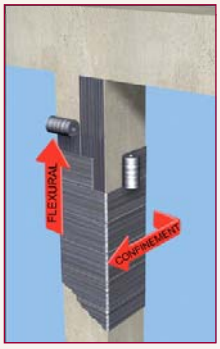
Structural Hardening

- Utilize hardening when sufficient standoff cannot be obtained or is cost prohibitive

Structural Hardening
General Options

- Provide alternate load paths or redundancy
- Reinforce concrete columns
- Increase resistance of steel to cutting
- Add internal diaphragms to cellular members

Structural Hardening
Commendable Practice



Fire Protection

- Apply intumescent paint
- Install fire suppression systems

Defense Priority

- First priority
  - Prepare to respond and recover
- Second priority
  - Deter, deny, detect
- Third priority
  - Defend with standoff
- Fourth priority
  - Defend with structural hardening

Base Relative Risk Review

	Base Relative Risk				
Bridge Components	VBIED	HEIED	NECD	Impact	Fire
Tower @ roadway level	**0.50**	0.19			0.22
Box girder/deck slab @ tower (main)	**0.46**	0.08			0.19
Stay cable	0.18	**0.58**	**0.45**	0.12	0.25
Stay cable @ roadway connection	0.18	**0.58**	**0.45**	0.11	0.25
Box girder (internal)		**0.45**			

Tower @ roadway
VBIED Threats

- Harden tower @ deck to resist VBIED with more than 5,000 lbs
  - VBIED vulnerability factor reduced from 0.50 → 0.30
  - *Could be achieved with additional standoff during a specific threat or elevated threat level, but is not permanent*

Stay Cables & Connections
HEIED & NECD Threats

- Install cable protection system, deck fencing, CCTV and intelligent video
  - HEIED vulnerability factor reduced from 0.95 → 0.70
  - NECD vulnerability factor reduced from 0.75 → 0.50
  - Access to component attribute (occurrence factor) reduced from 1.00 → 0.50

Box Girder (internal)
HEIED Threats

- Secure access into box girder, install intrusion alarms, CCTV, intelligent video
  - Access to component attribute (occurrence factor) reduced from 1.00 → 0.50

Proposed Mitigated Risk

	Base Relative Risk				
Bridge Components	VBIED	HEIED	NECD	Impact	Fire
Tower @ roadway level	0.50	0.19			0.22
Box girder/deck slab @ tower (main)	0.46	0.08			0.19
Stay cable	0.18	0.58	0.45	0.12	0.25
Stay cable @ roadway connection	0.18	0.58	0.45	0.11	0.25
Box girder (internal)		0.45			

	Mitigated Relative Risk				
Bridge Components	VBIED	HEIED	NECD	Impact	Fire
Tower @ roadway level	0.30	0.19			0.22
Box girder/deck slab @ tower (main)	0.46	0.08			0.19
Stay cable	0.18	0.31	0.21	0.12	0.25
Stay cable @ roadway connection	0.18	0.31	0.21	0.11	0.25
Box girder (internal)		0.32			

Benefit – Cost Ratio

- Determine costs for mitigation
- The difference between base risk and mitigated risk is a measure of the Relative Risk Reduction

$$\frac{\text{Benefit}}{\text{Cost}} = \frac{\text{Risk Reduction}}{\text{Mitigation Cost}}$$

Successful Retrofit

Assessment Goal

- Develop a cost-effective risk management plan for a critical bridge, using a component level analysis to present to management

Training Assistance

- First Responder Awareness to Terrorist Threats for Bridges and Tunnels
- Risk Management for Terrorist Threats to Bridges and Tunnels
- Blast Design & Analysis for Bridge Structures

Questions?

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