



NTSB National Transportation Safety Board

Office of Highway Safety

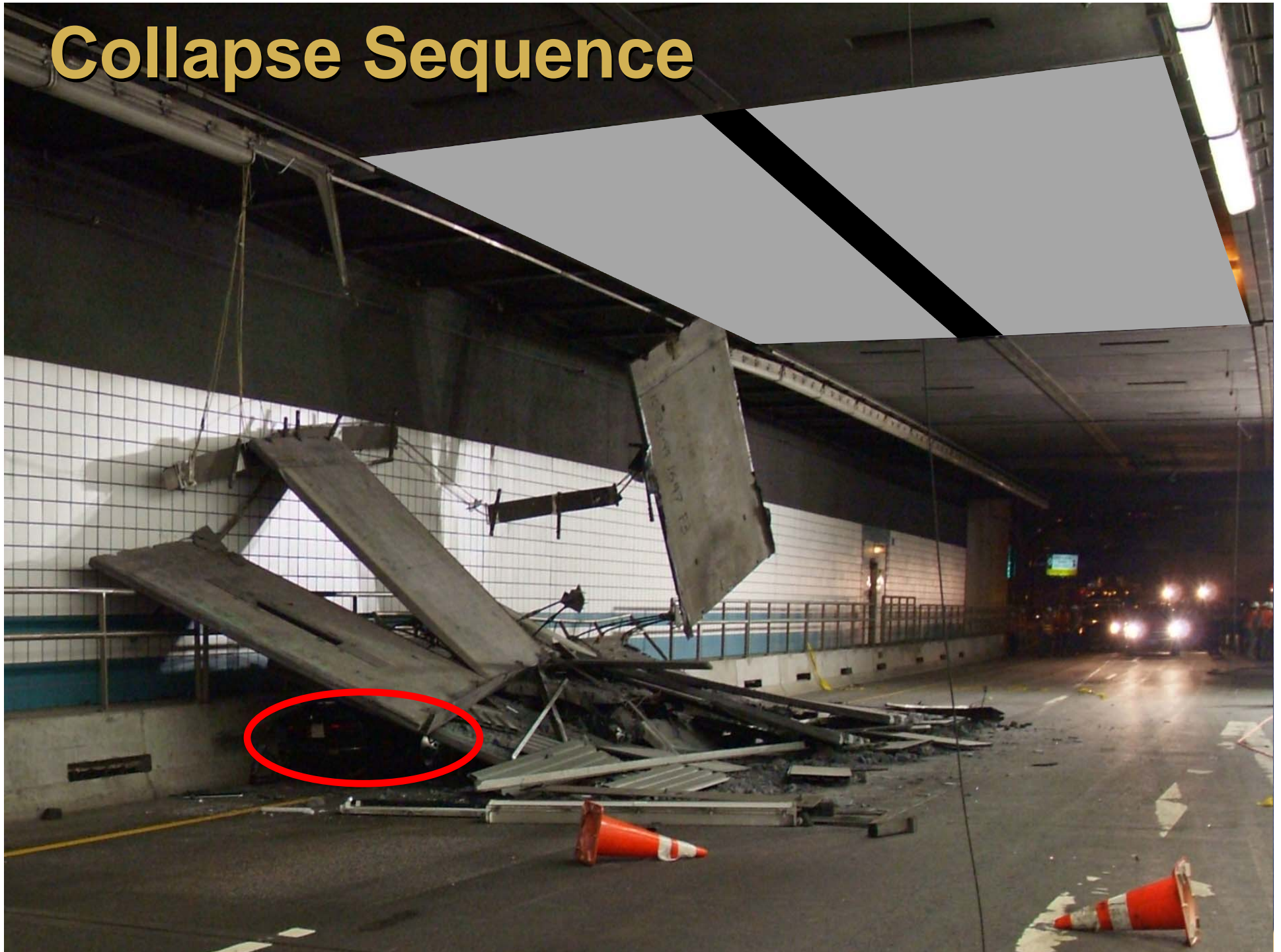
Collapse Sequence and Postaccident Activities

James F. Wildey II

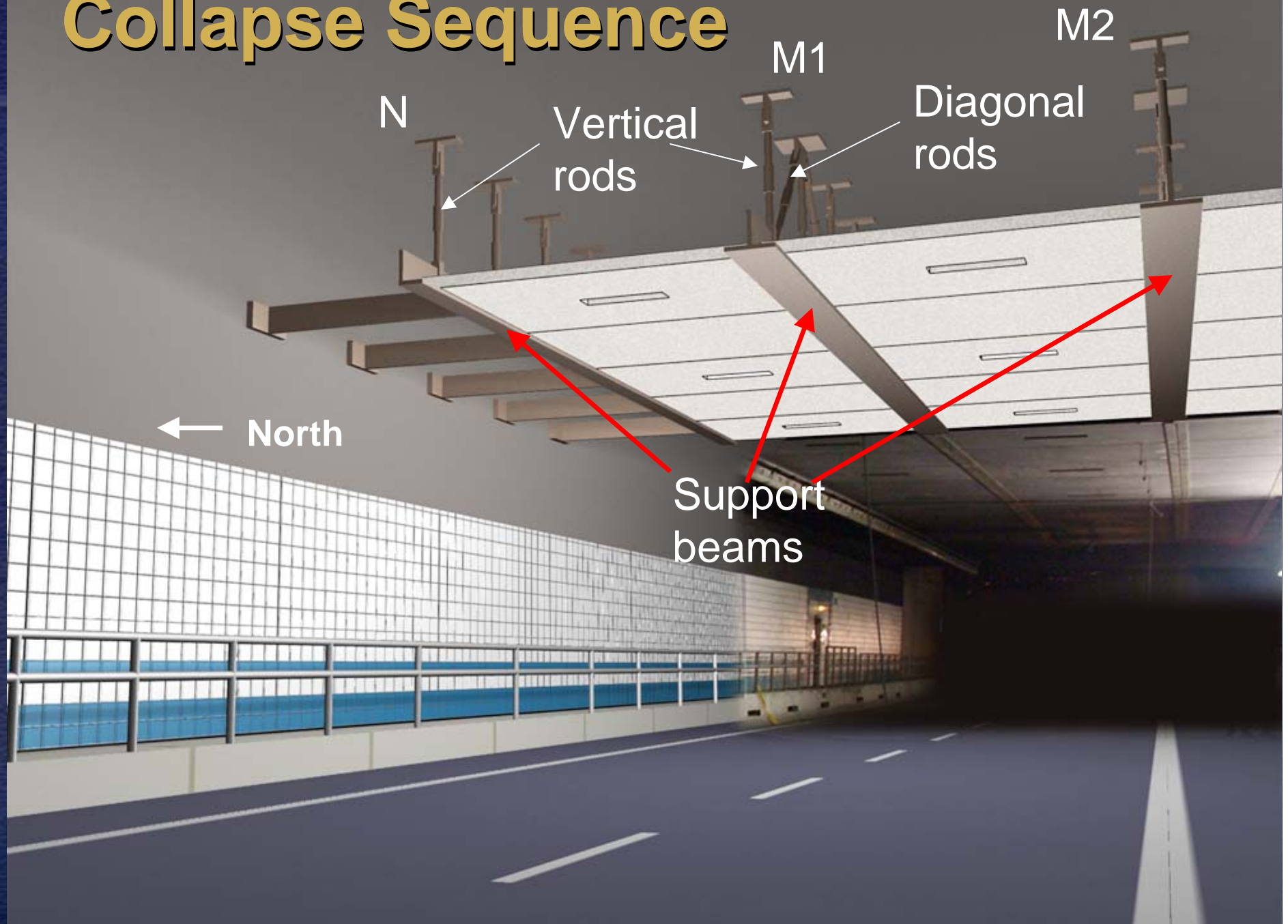
Topics

- On-scene examinations and tests
 - Collapse sequence
 - Measurements of displaced anchors
 - Anchor pull tests
- Examination of adhesive anchors and holes
- Epoxy identification
- Study of installation parameters

Collapse Sequence



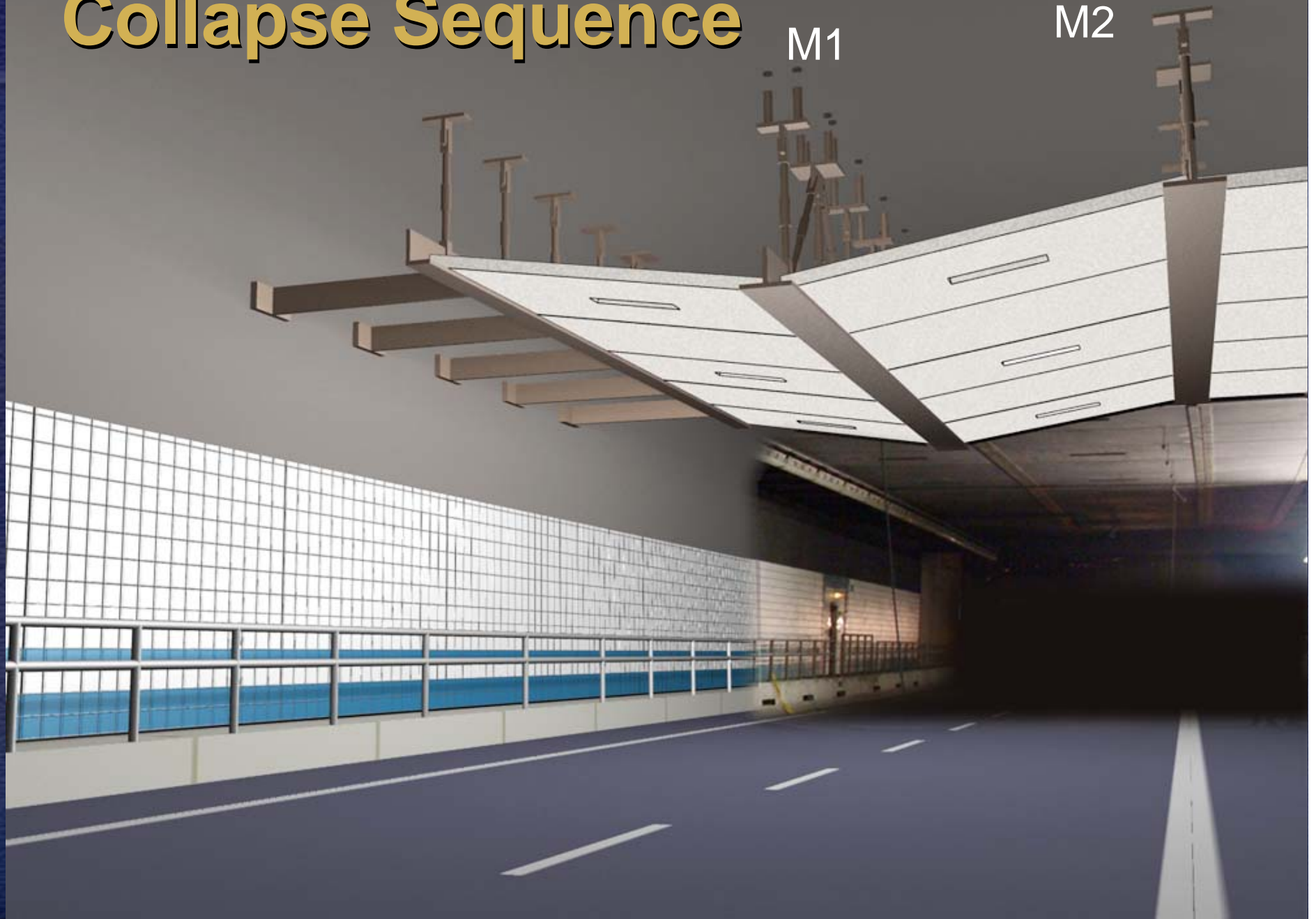
Collapse Sequence



Collapse Sequence

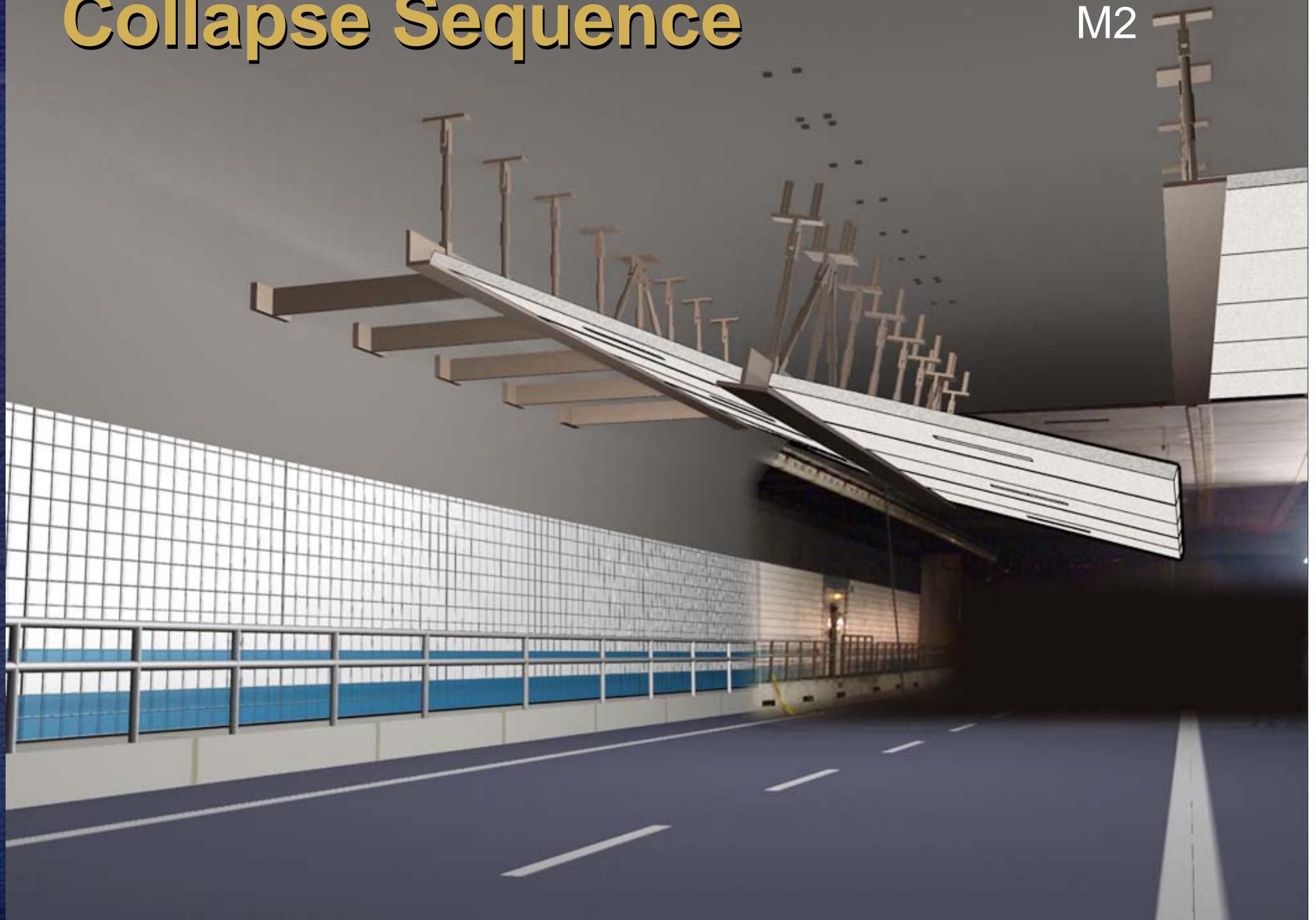
M1

M2

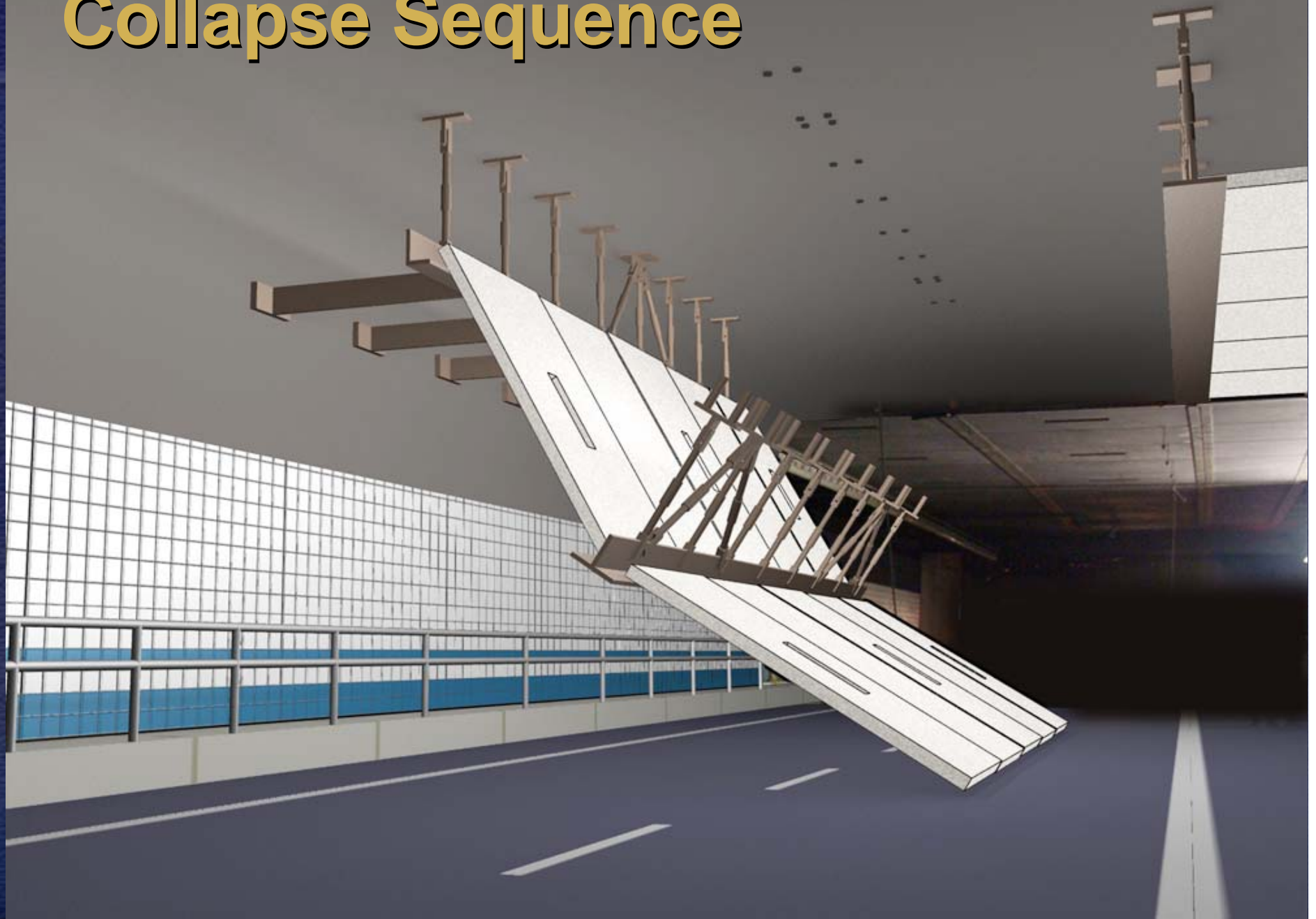


Collapse Sequence

M2

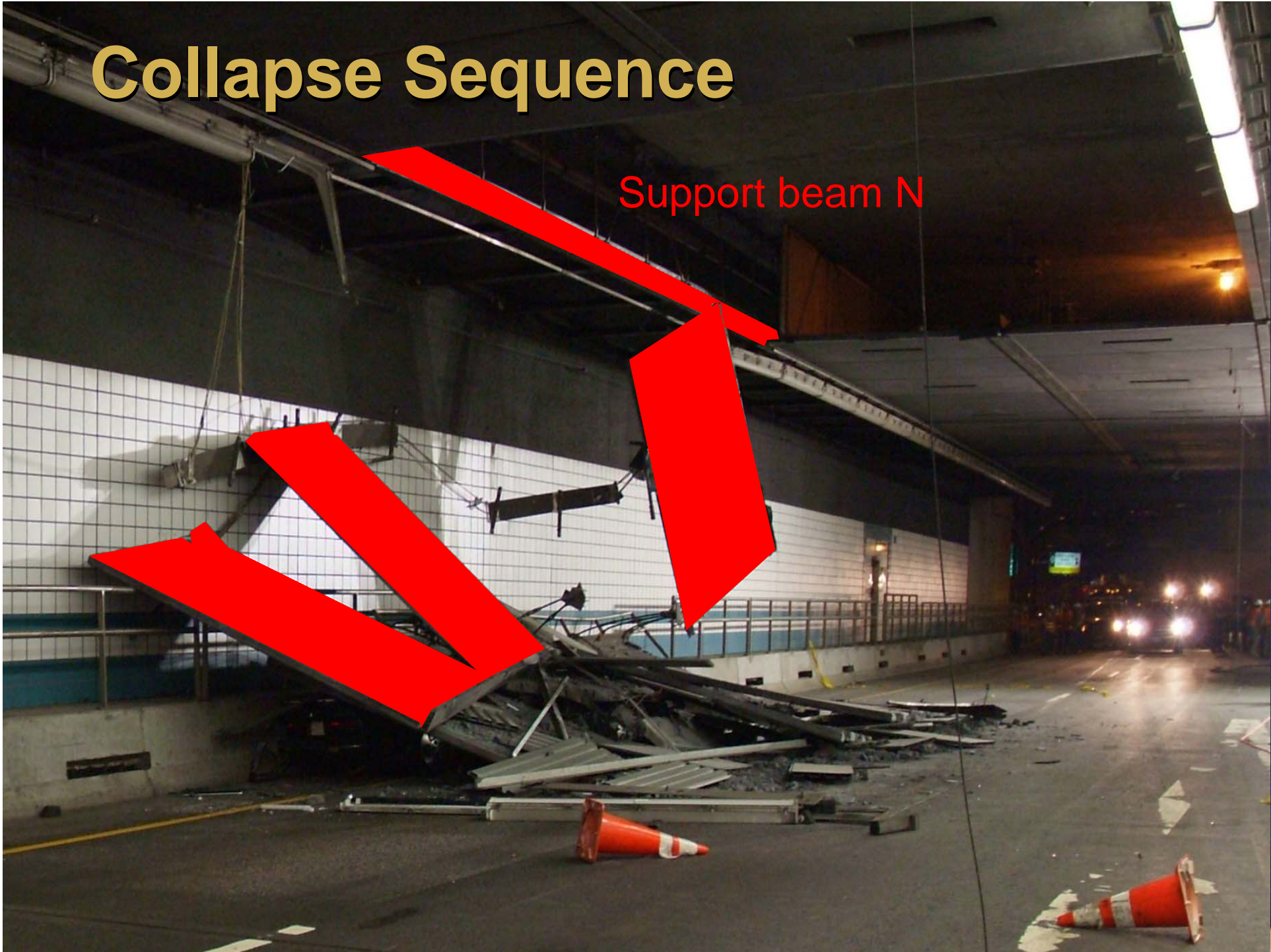


Collapse Sequence



Collapse Sequence

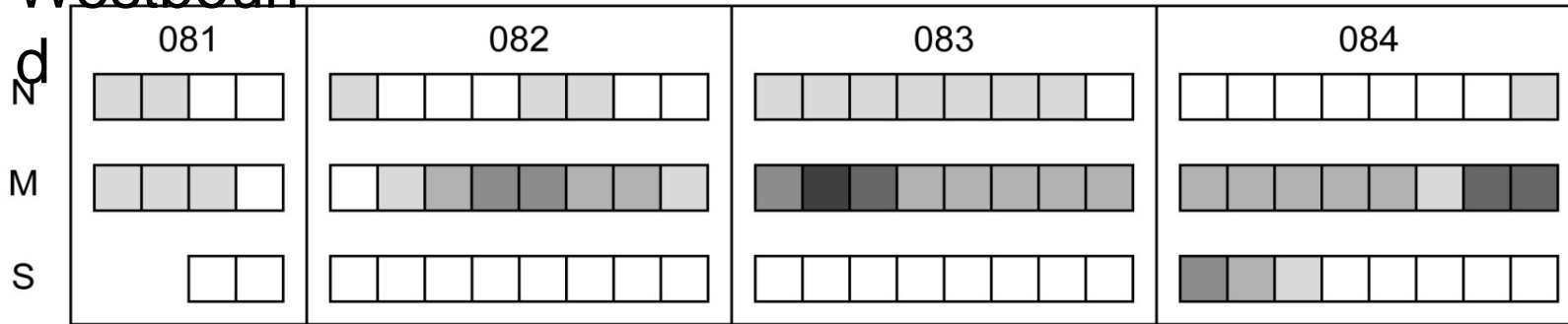
Support beam N



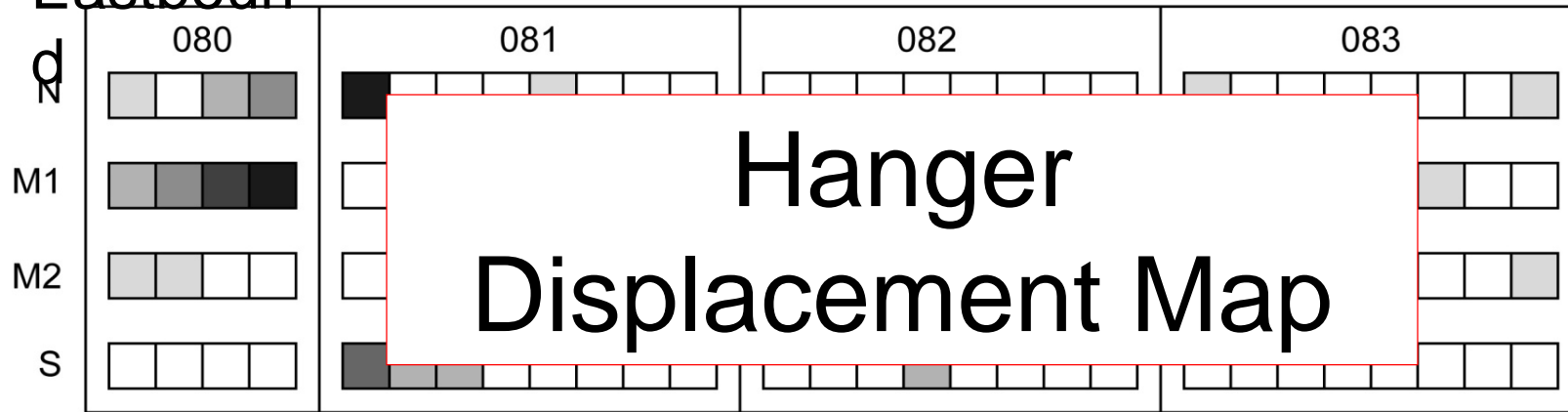
Displaced Anchors



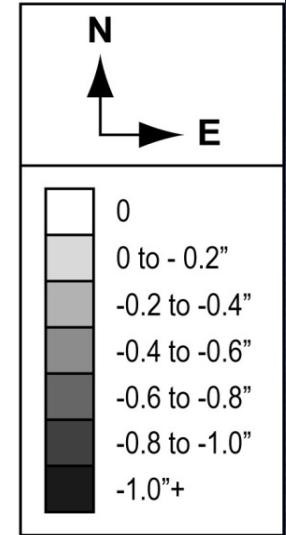
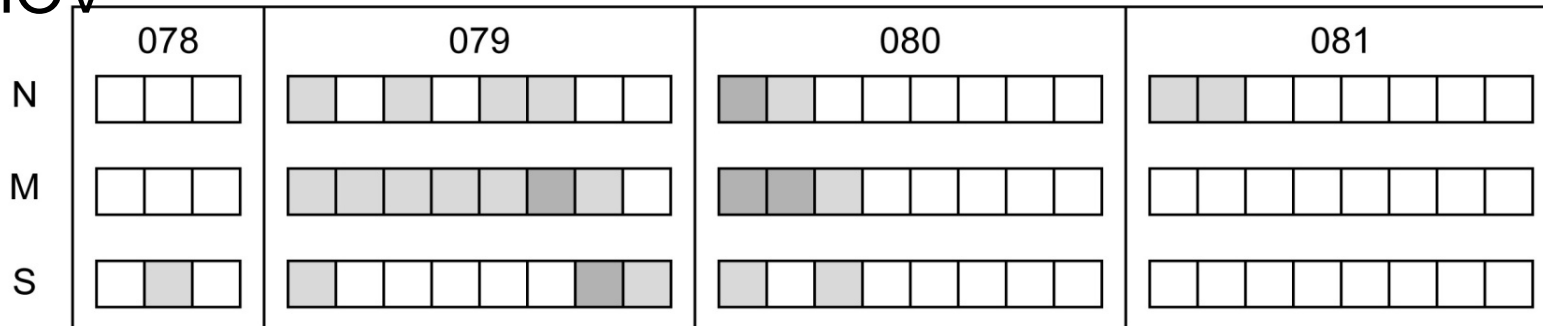
Westbound



Eastbound



HOV



Anchor Pull Tests

- Expected average load capacity: 25,400 pounds
- Load capacity results
 - 14,000 pounds average – anchors with no displacement
 - 7,000 pounds average – displaced anchors

Anchor Pull Tests

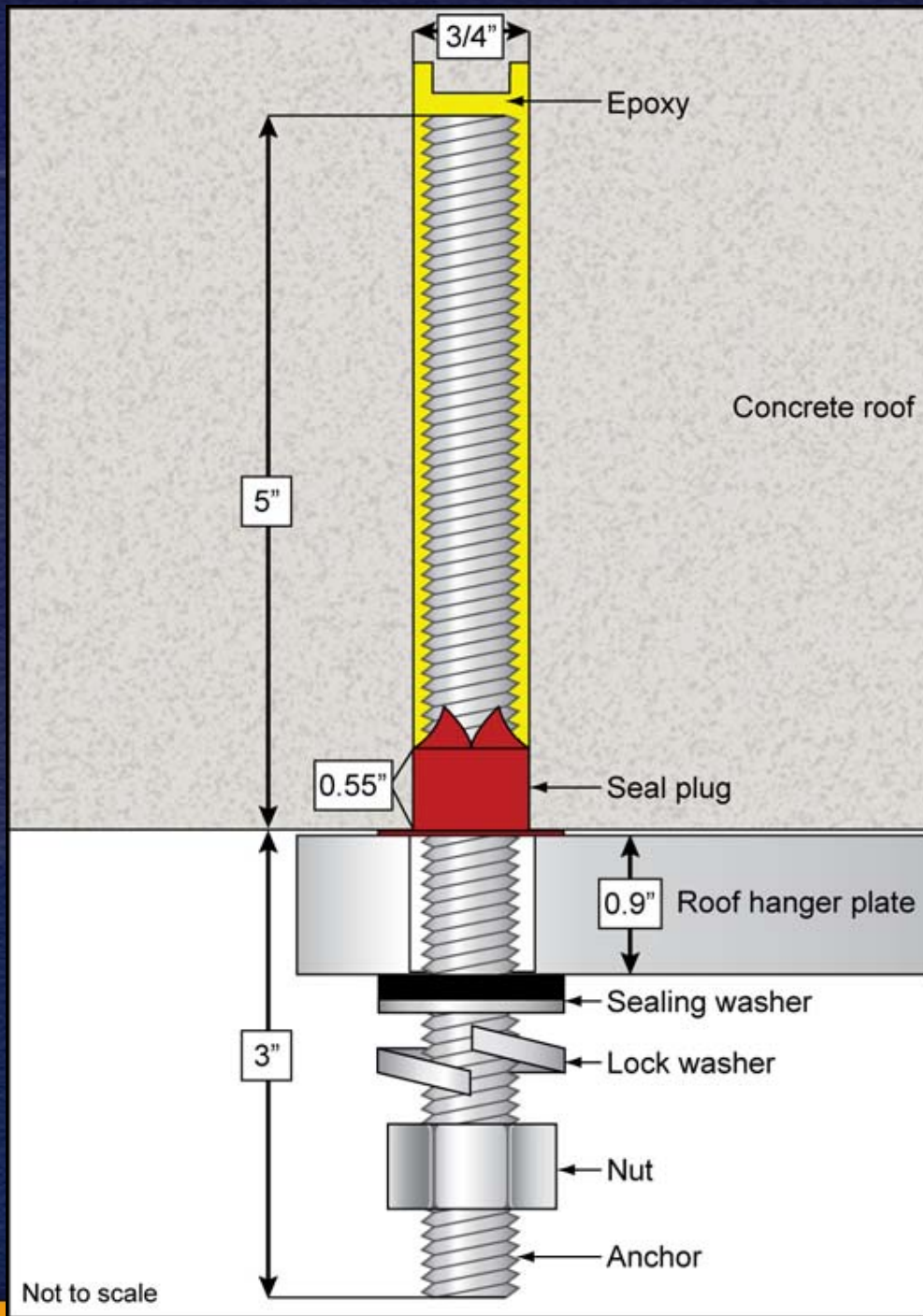
- Expected short-term load capacity
 - not attained or
 - not sustained over time
- Most of the anchors without displacement should have withstood the load if the short-term capacity was maintained over time

Topics

- On-scene examinations and tests
 - Failure sequence
 - Measurements of displaced anchors
 - Anchor pull tests
- **Examination of adhesive anchors and holes**
- Epoxy identification
- Study of installation parameters

Anchor and Hole Examinations

- Anchors from inside and outside the failure area examined
- Anchor holes examined using laser scanning equipment
- Core samples removed and examined



Not to scale

“Good” Installation



Seal
Plug

Epoxy Voids



Seal plug
position

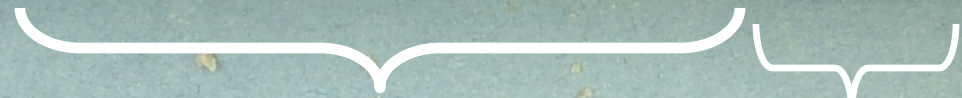
Epoxy Voids

- 19 of 20 failure area anchors had voids
- Void areas might have been larger
- Voids decrease load capacity

Adhesive Failure



Yellowed Epoxy



Yellow discoloration

Seal plug
position

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Dark Brown Epoxy

Topics

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- Examination of adhesive anchors and holes
- **Epoxy identification**
- Study of installation parameters

Epoxy Identification

- Documents indicated that the adhesive was an epoxy from Powers Fasteners
- Powers epoxies are available in two formulations:
 - Standard Set
 - Fast Set
- Initially unknown which formulation was used

Epoxy Identification

- Sika Corporation
Epoxy formulator, distributor, retailer
- Powers
Epoxy distributor, retailer
- Newman Renner Colony
Epoxy retailer
- Modern Continental Construction
Finish installer
- Formulations have not changed

Epoxy Identification

Tests included:

- Fourier transform infrared spectroscopy
- Differential scanning calorimetry
- Thermogravimetric analysis
- Headspace gas chromatography with mass spectroscopy
- X-ray energy dispersive spectroscopy in the scanning electron microscope

Epoxy Identification

Results:

- All samples matched the Powers Fast Set epoxy reference samples
- Samples from the failure area were similar to other typical samples from the tunnels
- Modern Continental used Powers Fast Set epoxy in the D Street Portal
- Brown samples were consistent with epoxy mixed with an excess of hardener

Topics

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- **Study of installation parameters**

Study of Installation Parameters



Parametric Study Results

- “Best practice” capacity over 22,000 pounds
- Parameters NOT degrading capacity:
 - Diamond coring bit (vs. carbide bit)
 - Installation through #11 rebar
 - Excess torque on anchors
 - Shortened epoxy nozzle
 - Excess resin

Parametric Study Results

- Factors reducing load capacity:
 - Excess hardener
 - No cleaning
 - No cleaning or drying (“worst practice”)
 - Voids
 - Difficult to eliminate when installing overhead
 - Fewer voids when installing downward

Testing Summary

- Collapse started with failure of anchors
- Other modules at risk of failure
- Anchor defects present from installation
- Voids difficult to eliminate
- Short-term load capacity above imposed loads
- Epoxy used was Powers Fast Set



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