AUSTRALIAN ENGINEERED FASTENERS AND ANCHORS COUNCIL

AEFAC Australian Engineered Fasteners and Anchors Council

Fasteners to concrete: failures & solutions

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www.aefac.org.au

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DISCLAIMER

These seminar notes have been prepared for general information only and are not an exhaustive statement of all relevant information on the topic. This guidance must not be regarded as a substitute for technical advice provided by a suitably qualified engineer.

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OVERVIEW

- AEFAC
- Safety-critical anchors
- Case study
- Summary and conclusions

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AEFAC

Guidelines for the specification of anchors *(Designers)*

Training & accreditation for installers of anchors *(Contractors)*

Minimum performance & standard specification *(Manufacturers)*

AEFAC

Guideline for field testing & certification of anchors *(Field Engineers)*

Research & Development *(Anchor industry)*

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SAFETY-CRITICAL ANCHORS

"A fastener whose failure may result in collapse or partial collapse of the structure, endanger human life and/or cause considerable economic loss."

Source: www.hillstreetconstruction.com

Source: www.designforconstructionsafety.org

- AS 4100
- ????
- AS 3600

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SAFETY-CRITICAL ANCHORS






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CASE STUDY

17th Bridge, Atlanta, US

Source: 17th Street Bridge Canopy Failure Investigation, WJE Associates

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CASE STUDY

Collapse

- 11.20pm, August 13, 2011
- 58m of the 213m length canopy-fence detached
- Canopy fence came to rest on the 20-lane Interstate Highway 75/85
- Nobody was injured, no vehicles damaged
- No high winds prior to collapse
- Maximum daytime temperatures ~34^{o}C
- Southern aspect received greatest solar exposure

Source: www.11alive.com

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CASE STUDY

Source: www.wsbtv.com

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CASE STUDY

Source: 17th Street Bridge Canopy Failure Investigation, WJE Associates

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CASE STUDY

Failure investigation

- Wiss, Janney, Elstner (WJE) Associates engaged to conduct investigation
  - ✓ Review of design
  - ✓ Field investigation
  - ✓ Laboratory investigation
  - ✓ Site testing
  - ✓ Structural analysis

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CASE STUDY

Description of structure

- 6-lane overpass comprising steel box girders with a cast-in-place r/c concrete deck
- architectural fencing and pedestrian sun-shade canopy on south parapet
- construction completed in 2004

Source: Google Street View

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CASE STUDY

Description of structure

- Canopy-fence frames:
  - ✓ 5.2 – 6.1 m high
  - ✓ 4.0 m overhang
  - ✓ 3.2 m on-centre
  - ✓ built-up steel column and cantilever beam
  - ✓ 2.5 x 2.5 inch (64 mm x 64 mm) tubes and perforated stainless steel sheets forming 'undulating' canopy
  - ✓ Fixed to south parapet via four chemical anchors

Source: www.ajc.com

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CASE STUDY

Review of design

- Very little information on anchors provided
- Design detail specifies:
  - ✓ 4x 7/8 inch (22 mm) diameter epoxy anchors to connect each support frame
  - ✓ Tension capacity of each anchor to be 4 kips (17.8 kN)
  - ✓ Diameter and embedment depth *not* specified
  - ✓ No specification for anchor material or chemical system
  - ✓ Fabrication drawings did not specify chemical anchors
- Georgia Department of Transport 'Qualified Products List 15' (2003) lists chemical anchors approved for standard applications.

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CASE STUDY

Review of design

Table 1. Epoxy Resin Adhesives in GDOT QPL 15 (revised April 18, 2003)

Manufacturer	Trade Name	Mix Ratio (A:B)
Five Star Products, Inc.	RS Anchor Gel	1:1
Futura Companies, Ltd.	Futura Bond 566 R	1:1
ITW Ramset/Red Head	Epcon C6	Cartridge
Prime Resins, Inc.	Prime Rez 1100 High Mod LV	2:1
	Speed Bond #1	1:1
Sika Corporation	Sikadur DOT-SP3	1:1
Superior Epoxies	Dowel Bar Adhesive - 5	Cartridge or 1:1
Symons Corporation	Res-Con 304	Cartridge
Tamms Industries	Duralcrete Fast Set Epoxy Gel	Cartridge or 1:1
Unitex	Pro-Poxy 300 Fast	Cartridge
U.S. Anchor Corp.	Ultrabond 1300	1:1
Weg-It Fastening Systems	Inject-Tite Fast Set	Cartridge
W.R. Meadows of Georgia	Rezi-Weld Gel Paste	Cartridge

**** Some of these products are susceptible to creep.***

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CASE STUDY

LESSON #1
SPECIFY ONE PRODUCT ONLY.

Refer to free technical resources on AEFAC website.

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CASE STUDY

Field investigation

Remaining canopy-fence frames:

- Anchors torch cut for removal
- 112 of 168 anchors had measurable withdrawal: 1.6mm – 44.5mm

Measureable withdrawal.

Torch cut anchors.

Source: 17th Street Bridge Canopy Failure Investigation, WJE Associates

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CASE STUDY

Field investigation

Anchor rods:

- 7/8 inches diameter
- 11 inches long, partially covered in epoxy
  - ✓ All-thread rods, or
  - ✓ 6 inches threaded rod plus 5 inches smooth (unthreaded) bar
- No observed cracking, tearing or distortion of anchor holes in steel frames

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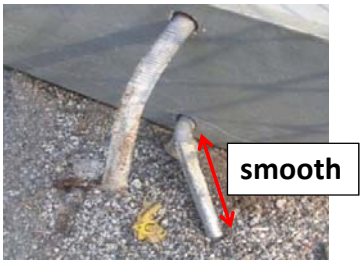
CASE STUDY

Field investigation

- 48/76 failed anchors were available for inspection
- Most anchor failures occurred in chemical product
- A number of failed anchors included smooth metal components
  - ➢ Mechanical interlock not possible
  - ➢ Significantly reduced bond capacity



Anchor rods.

Source: 17th Street Bridge Canopy Failure Investigation, WJE Associates

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CASE STUDY

Field investigation

- Air voids present in the chemical
  - Holes incompletely filled
  - 25mm – 37.5mm voids at rear of most anchor holes
  - Reduced effective embedment depth, reduced bond area
- Wet epoxy material in holes **7 years after placement**.
- Varied colour of epoxy demonstrated ineffective mixing and *entirely* unmixed proportions.

Wet epoxy.

Source: 17th Street Bridge Canopy Failure Investigation, WJE Associates

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CASE STUDY

Laboratory investigation

Chemical anchor analysis:

- Tests performed on samples extracted from inside vacated holes
- Spectroscopical analysis: epoxy resin with calcium carbonate and amorphous silica fillers.
- Thermal analysis: different products used in different holes.
- Nitrogen content analysis: some material was hardener-rich, other was resin-rich.

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CASE STUDY

LESSON #2

INSTALL IT CORRECTLY THE FIRST TIME.

Refer to AEFAC Installer Certification Program.

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CASE STUDY

Laboratory investigation

- Concrete strength = 46.8 MPa
- 6 core samples extracted from south parapet
  - ✓ 4 inch (100mm) samples
  - ✓ 5 samples made over vacated holes
  - ✓ No evidence of oil, grease or other contaminant in anchor holes

Coring

Source: 17th Street Bridge Canopy Failure Investigation, WJE Associates

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CASE STUDY

Site testing

- 5x in-situ tension tests conducted on anchor rods away from failure area
- Maximum load achieved ranged from 46.4 – 93.8 kN
- One anchor failed during test
- Maximum load tested > short-term design load of 4 kips (17.8 kN)

Table 2. Results of In-Situ Load Testing

Anchor Number	Maximum Applied Load (lbs)	
13A	10,436†	(46.4 kN)
33A	17,634‡	(78.4 kN)
33B	21,094‡	(93.8 kN)
34A	20,374‡	(90.6 kN)
41A	15,619‡	(69.5 kN)

† Anchor tested to failure.
‡ Load test stopped prior to failure.

Source: 17th Street Bridge Canopy Failure Investigation, WJE Associates

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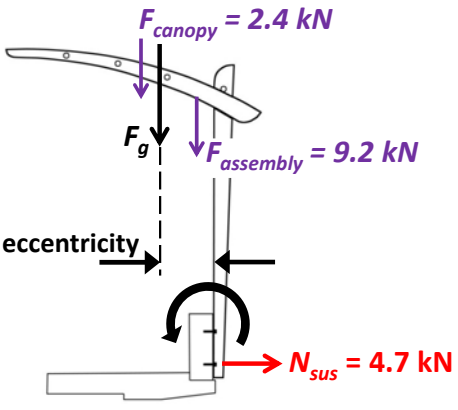
CASE STUDY

Structural analysis – typical frame

- F_g = 11.6 kN
- Eccentricity = 760 mm from face of parapet
- N_{sus} = 4.7 kN
  < short term design load = 17.8 kN

Susceptibility to creep is not related to short-term load!



Typical column-cantilever assembly.

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CASE STUDY

LESSON #3
SPECIFY ACCURATELY AND COMPLETELY.

Refer to upcoming AEFAC Standard.

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CASE STUDY

Source: Google Street View

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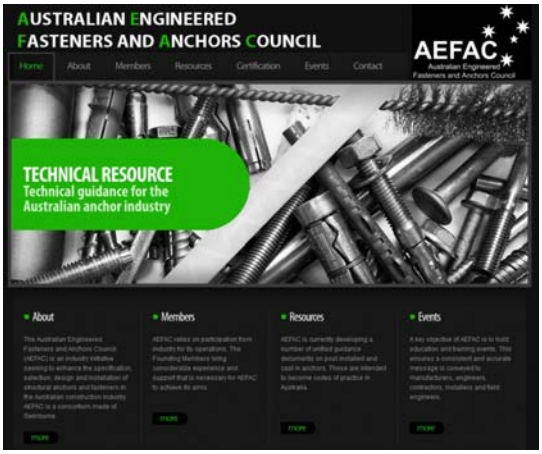
ADDITIONAL RESOURCES

www.aefac.org.au



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CASE STUDY

Conclusions

- Anchors carry the same risks as other types of safety-critical fasteners
- Causes of the failure in the case study were:
  - ✓ Inappropriate specification
  - ✓ Deficient installation
- Solutions created by AEFAC to avoid similar failures in Australia include:
  - ✓ Design according to the upcoming AEFAC Standard
  - ✓ Specify according to technical guidance on the AEFAC website
  - ✓ Install according to the AEFAC Installer Certification Program

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