HOW SAFE ARE ENGINEERING MATERIALS?

What risks are you willing to take?

John Fenwick
Testing? My experience.

- 1965 Friction grip bolt assemblies in fatigue
- 1970-71 TRRL buckling of welded steel plates
- 1977 -79 Relaxation of strand, creep & shrinkage of concrete, welded reo, laminated rubber bearings
- 1980s Strand (Pritchard), concrete ASR(Carse)
- 2000- Reo & strand testing.
- Results often surprising, codes need revising.
Caveat emptor
Let the buyer beware!

- Roman engineering was highly standardized, with good quality control.
- Penalties for non-conformance could be fatal
- Arches in bridges and buildings - designer often stood beneath when falsework removed
- Emphasis on customer responsibility.
- Created very durable structures.
Roman bridge – well selected materials.
The start of “modern” engineering

• Broughton Suspension Bridge - hold down bolt

• Firth of Tay Rail Bridge – wrought & cast iron

• Brooklyn Bridge – hard drawn wire

• Firth of Forth Rail Bridge - steel
Broughton Suspension Bridge 1826

* 44m span Manchester, built by local landowner
* Collapsed under load of 74 marching soldiers, lead by son of bridge builder. 20 injured.
* The single bolt anchoring the suspension chain failed. Cause: badly forged bolt. (No redundancy)
* Inquiry told a distinguished engineer had recommended chain be load tested, but no tests done.
Lessons

• Redundancy is good, the more the better.
• Two bolts good enough? Not in critical cases.
• Four or more—much safer!
• Ultimate redundancy:
  - strand in large concrete bridges,
  - wires in suspension cables.
* Material quality and testing related to redundancy. Less redundancy, more testing.
Firth of Tay Rail Bridge  1878

* Trade wars. German steel banned in UK, cast and wrought iron used.
  • Largest engineering project in UK
  • 72 spans @20m + 13 spans @75m = 2440m.
  • 40m vertical navigation clearance
  • Queen Victoria travelled across it and then knighted designer Thomas Bouch
  • Bouch moved on to design the even bigger Firth of Forth rail bridge
Firth of Tay Rail Bridge 1878
Worst structural disaster in UK history

- Collapsed Dec 1879, when a train crossed in a bad storm. 75 people dead. 13 main spans fell

- Causes: Wind forces not considered, inadequate bracing, poor supervision and poor quality material.

- Results: Bouch disgraced, removed from Forth design. Ban on imports of German steel lifted
Firth of Forth Rail Bridge

• Tay disaster prompted a new set of very cautious design rules
• Wind now included, much more bracing needed
• Reduced stresses, much heavier sections used
• Result: very safe bridge, still in service, but very very expensive.
Firth of Forth Rail Bridge
Brooklyn Bridge 1883

- “Eighth wonder of the world”
- Suspension bridge, 1055m long, 486m main span
- Cables “spun” in situ using hard drawn wire
- “Conflict of interest” Roebling not allowed to use wire from his own wire works
- Sinking caissons very dangerous, Roebling Snr killed, Roebling Jnr gets the “bends” and is bedridden, 30 men die from the bends, wife ends up as site supervisor
Brooklyn Bridge
Material testing

• Most critical component is wire in cables
• Each batch of wire tested by supplier and results given to Roebling (Jnr). Results all good
• Supplier is taking all test samples from one coil which meets specifications
• Fraud discovered after some time when results appear “too good” – little variation!
• Supplier forced to provide extra wires to increase safety factor in cables. High redundancy
Outcomes

• Brooklyn Bridge still in service after 130 years.

• Basic design concepts still the basis for all long span bridges today.

• Fudging test results still as popular as ever.
Other engineering materials – tested?

• Why pick on steel? Common in early bridges
• Feb 2012 edition – Engineers Australia.
• Article on Hunter Expressway NSW
• Consultant awarded $2.3M contract to test concrete on the project.
• This is accepted as normal “good practice”
• What holds the concrete together? Is it tested as thoroughly?
Worlds first all-welded steel bridge

- Belgium 1938- span of 75m across a canal
- Vierendeel truss
- Lower chord snapped on freezing winter day
- Brittle Fracture entered bridge design
- Steel can change from ductile to brittle behavior below a “transition temperature”
- Charpy or Izod testing at various temperatures
Brittle Fracture Solved?

• 13 Liberty ships split in two during WW2, who would want to be a sailor.
• One while tied up at a wharf! At least it made the investigation easier!
• Problem identified again as Brittle Fracture
• By 1954, 60 major structural failures recorded
• More research and testing!
King St Bridge, Melbourne 1961

• Deep welded steel girders, 160 ft spans (49m)
• Flange cover plate end detail led to small crack

• Cracks grew over a year

• On a freezing cold morning in 1962, a truck caused a girder to crack through tension flange and full depth of the web
Results

• Brittle Fracture identified (again?)

• Cracks found at many of the cover plate ends

• Whole bridge strengthened with post-tensioned cables.

• Cost $5 million (about $200m today!)
How did it happen?

• Designed and specified by a consortium set up for this sole purpose, and then disbanded.
• Steel for girders specified to BS 968, which included notch ductility tests.
• Test specimens failed, BHP said steel OK
• “Compromise” was to keep testing till a test passed, (even though 6 or 7 had failed) and then pass the batch of steel.
• And the result became history.
King St Bridge
Aircraft Design

• WW2  Timber and cloth to riveted aluminium
• Huge research and testing programs
• Sound barrier and jet planes
• Comet first commercial jet liner – 3 crash.
• Full scale testing shows fatigue cracks at window corners caused catastrophic failure
• Full scale testing became part of design
• Early 1960s, major projects cancelled
Stiffened Steel Box Girders

- Tacoma Narrows 1944, too flexible in torsion
- Heavy stiffening trusses used 1950s
- 1967 Freeman Fox use aerofoil steel box on Severn Suspension Bridge – much cheaper
- Airplane designers had moved into bridges and alum wing design charts used for boxes
- Welded steel quite different to riveted alum
- Huge scale change, no full scale tests. So!
The great steel box girder disaster!

- 1970 Four of the largest steel box girders collapsed during construction in Milford Haven, Melbourne, Vienna and Koblenz
- Subsequent testing showed large inbuilt compressive forces due to weld shrinkage
- Multiple interacting buckling modes in designs
- Merrison rules made designs very expensive
- Steel box girders lost popularity
Strand Testing - Relaxation

- 1977 Houghton Highway. Alternate strand offered at cost saving. Conforms to spec?
- Test rig set up at UQ. Steaming tests on site.
- Strand passed tests.
- More testing of concrete, strand for Gateway
- Pritchard found about 50% of overseas suppliers did not conform
- Two more test rigs made, more testing
Processing strand for Low Relax

- Strand runs around twin rolls at high speed.
- Heated to 400 degrees C.
- Quenched to room temp.
- Hydraulic ram tensions strand.

**LOW RELAXATION PROCESS REQUIRES HIGH LEVELS OF CONTROL**
**ANY ERRORS AND STRAND HAS HIGHER RELAXATION, FROM 3% UP TO 20% AND WILL NOT MEET AS4672**
Relaxation test

ALTERNATIVE LEVER MACHINES NOT ACCURATE ENOUGH!!!

ERRORS
- Strand slips in wedges
- King wire slips
- Rig too Flexible
- Temperature variations
- Rate of loading

RESULTS
Plot Relaxation vs. Time
- Straight line in log – log format
- Linear regression plots – R squared = 0.99+
- Line slope constant to 2 significant figures
RELAXATION PLOTS

Linear Regression $R^2 = 0.993$

EXTRAPOLATE TO LIFE OF STRUCTURE
HOW TO FUDGE A RELAXATION TEST

• Supply an old test result for new batch
  BUT when caught,
• Manufacture a new test result from old one
  BUT it will have low R squared, wrong slope
• Re-tension strand to reduce end relax loss
• Load strand over extended time.
• Test at lower temperature
Lesson?

• It is difficult to pick falsified test results even if you know all the technical details!

• As an engineer on site, you have no chance.
Do you really want to take the risk?

• She’ll be right mate! Or
• Set up your own testing system and try to outwit your nice cheap suppliers, or
• Let an expert do the checking for you and simply specify an ACRS certified supplier?
• Oh, and just remember to check they actually are certified, and the product is ACRS tagged!
Reinforcement – what could go wrong?

• Most good suppliers just meet the specified characteristic yield specified in AS4671
• It’s very competitive, and no one gives free extras these days
• A high yield usually means lower ductility, not a good thing!
• There are plenty of good suppliers, and some very bad ones. Can you tell the difference.
Properties

YIELD STRESS MPa

500 550 600

BRITTLE ductile
ELONGATION

NUMBER OF TESTS

YIELD AND DUCTILITY CLOSELY LINKED. CONTROLLING BOTH TAKES SKILL
TEST CERTIFICATES.

• On their own, they provide no guarantee of product quality.
• The Australian 6 Nov 2012 “Scam shuts nukes sites” safety equipment with false certificates.
• “Steel connector failures – forged certificates” CROSS report 254 July 2012; refers to steel products, aviation spare parts etc with false certificates
• A necessary but not sufficient condition.
WHATS THE SOLUTION?  ACRS

• Industry based product certification body
• Not for profit, “customers” in the majority.
• Assessments done by experts (retired metallurgists with 30+yrs of testing experience
• 3 way testing checks records, test methods and product conformance to AS. LTQ checked
ACRS

- Cost to supplier: 30 cents per ton + audit fee
- Cost to customer: time taken to check ACRS
- Over 40 suppliers (150+ sites) certified
- Is it an absolute guarantee? NO! The only absolute guarantee is for customer to test every batch of product with own experts.
- Does it provide a high level of assurance product conforms at low cost? YES!
- What risks do you, personally, want to take?
THANKYOU

• ANY QUESTIONS?
The Australian Steel Institute

“Sustaining Australian Steelwork quality and public safety in a global market place “
We are concerned!

The Australian Steel market has become global. But….It does not have the checks and balances of other countries

- Our standards are often “informative” not “normative”.
- Our western equivalents have third party product certification (over 20 countries)
- Our equivalents have fabricator prequalification and accreditation.
Why Fabricator Prequalification?

- Europe, Canada, USA and a range of other countries have a mandatory fabricator certification system for major works. Australia does not for both local or overseas steelwork.

- TMR and RMS have recognised this deficiency through experience.

- NZ is in the process due to a significant sporting arena failure.
Why are we concerned?

- The ASI compliance program is based around ensuring that designers and clients get the design they create and clients get the product they pay for.
- ...Unfortunately this is not always the case.
TMR Structural steel review

- TMR Bus station situation: 300 tonnes of steel, 19 countries and 32 steel mills

- ...the extent of structural steel material, bolts and fabrication quality problems has increased significantly in recent years. It is noted that in this time period there has also been a change in sourcing from overseas.”
Why is Compliance important?

- Australian Standards are intertwined & interdependent
- Reduces real risk of material substitution &/or misrepresentation
- Reduces risks of failure, delays, waste &/or injury
- Provides confidence in end result
- Protects reputation & integrity
- A key ingredient in safety

Design Standards: AS 4100, AS 5100

Material Standards AS/NZS 1163, 3678, 3679

PROJECT DELIVERY: Cost, Safety, Quality
FABRICATION and COATING STANDARDS eg AS/NZS 1554, 2312 etc

Design Standards Structural Bridges eg AS 4100, AS 5100

Material Standards Tube, Sections, Plate, Bolts

PROJECT DESIGN

PROJECT DELIVERY

Cost, Safety, Risk Performance
## EXAMPLE
welding of structural steel to design standard
AS4100

<table>
<thead>
<tr>
<th>Spec</th>
<th>Requirement</th>
<th>Why</th>
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<tbody>
<tr>
<td>AS/NZS 1554 sect 2.1</td>
<td>Steel compliance with AS or AS/NZS standards or testing with full certification</td>
<td>To determine correct welding consumables (weldability group numbers to AS/NZS 1554.1)</td>
</tr>
<tr>
<td>AS/NZS 1554.1 sect 4.1</td>
<td>Create procedure qualification record and welding procedure specification to be available for examination</td>
<td>To ensure traceability of correct set up</td>
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<tr>
<td>AS/NZS 1554.1 sect 4.12.2.2 eg AS/NZS 2980 and ISO 9606-1</td>
<td>Use qualified welders</td>
<td>Ensure skill level appropriate</td>
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<tr>
<td>AS/NZS 1554.1 sect 4.12.1</td>
<td>Welding carried out under supervision of qualified welding supervisor</td>
<td>Adequate management supervision</td>
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<tr>
<td>AS/NZS 1554.1 sect 7</td>
<td>Inspection reports to engineers spec</td>
<td>Certification</td>
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<tr>
<td>AS/NZS 1554.1 sect 7.2</td>
<td>Inspector must be qualified</td>
<td>To IIW, WTIA or CBIP</td>
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</table>
Australian Current Marketplace

- What we get
  
  PROJECT DELIVERY:
  Cost, Time

- What we need
  
  PROJECT DELIVERY:
  Cost, Time, Safety, Compliance
ASI Position

1. Supports design and compliance with Australian Standards
2. Supports third party product certification
1. Supports Fabricator Prequalification
Non Conforming Test Certificate

Should reference AS/NZS 3679.1 - 2010

Certification not valid as there's no ILAC logo or reference

Only 5 (vs. 13) listed
MISSING INFORMATION:
- No ILAC Accredited Testing laboratory listed
- No Product Steelmaking Process indentified
- No length, bundle or pack identifier
- No heat number provided
- No chemical analysis type (L or P) listed
- Not all required 13 elements listed
- No material acknowledgement or signatory statements
ISSUES
Pressures the Designer faces

• Back fitting foreign material standards into AS4100
• Acceptance of materials that do not have compliant test certificates
• Rectification of steelwork
Why 3rd Party Accreditation

**WHY**

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**TEST CERTIFICATE**

- **Customer:** BLUESCOPE DISTRIBUTION ELECTRONIC TRADING CLAYTON VIC 3169
- **Supplier:** BLUESCOPE STEEL (AUS) PTY LTD PORT KEMBLA, N.S.W., AUSTRALIA.
- **Cost Order No:** 20020388

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**CHEMICAL ANALYSIS**

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<th>Cr</th>
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**MECHANICAL TESTING**

**Tensile A2139**

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**ITEMS COVERED BY THIS CERTIFICATE**

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**COMMENTS**

This test certificate is issued subject to the Uncertainty of Results statement set out on BlueScope Steel's Website www.bluetestedcertificates.com. In order to rely upon this certificate, you must adhere to the Uncertainty of Results statement. This product is supplied in accordance with the requirements of AS:2011 sampling and chemical analysis and performed in accordance with BlueScope Steel's procedure EN-607-2005 SC. MECHANICAL TESTING HAS BEEN PERFORMED ON SAMPLES SUPPLIED BY THE RELEVANT PRODUCTION DEPARTMENT. HEAT TREATMENT - PRODUCT AS ROLLED.

**MECHANICAL COMMENTS**

TEST PIECE LOCATION: LOCG TGF=Transverse Quarter Front End
TEST CATEGORY (SCA) E-Bars
DIA PET LENGTH (mm) A=0.65 * square root of the original cross-sectional area of the test piece.
• The ASI encourages all major construction projects to have an effective fabricator prequalification and assessment system in place to minimise risk.
Workplace Health and Safety Act 2011

• The new harmonised Work, Health and Safety Act 2011 puts significant shared responsibility on all parties in the construction value chain, specifically including manufacturers, importers, suppliers, designers and constructors. Penalties can be both civil and criminal.
Workplace Health and Safety
Act 2011

The ASI opinion is that material and product compliance is a necessary component of the solution.

ie

“….a requirement that “officers” exercise “due diligence” to ensure “compliance”….WHS masterclass
This Means

On advisement the ASI views this to mean....

The responsible officer must takes steps to ensure the steel quality, fabrication including welding and bolting must be compliant to the relevant standards to ensure the construction is safe.

The responsible person may include the contractor, designer, importer... for example
ACCC Product Safety - a guide to testing

• 1. Source products from reputable manufacturers/suppliers who have an established reputation for supplying products that are tested to comply with equivalent or higher regulatory requirements.

• 2. Ask for documentary evidence of compliance from third-party product-testing or product certification agencies.
IS THIS OVERKILL?

Role of the ASI
Why is compliance important
Warning sounded on cheap Chinese import

Shoddy steel road risk

SHODDY Chinese steel may be putting the lives of Victorian road users at risk.
| TN001 | **High Strength structural bolt assemblies to AS/NZS 1252** *(PDF) (44 Kb)* Version 3, Feb 2012. Author: T.J. Hogan |
| TN002 | **Issues with temporary bracing of steel structures** *(PDF) (156 Kb)* Version 2, Feb 2011. Author: T.J. Hogan |
| TN003 | **Design of eccentrically loaded bracing cleats** *(PDF) (82 Kb)* Version 1, Jun 2010. Author: T.J. Hogan |
| TN004 | **Design properties for crane runway beams** *(PDF) (355 Kb)* Version 2, Sep 2010. Author: T.J. Hogan |
| TN005 | **Guidelines for designing to AS 4100 when imported materials are involved** *(PDF) (47 Kb)* Version 3, Feb 2012. Author: T.J. Hogan |
| TN006 | **Update for 'Design of structural steel hollow section connections - volume 1: Design models'** *(PDF) (84 Kb)* Version 2, Jun 2011. Authors: T.J. Hogan and A.A. Syam |
| TN007 | **Compliance issues and steel structures** *(PDF) (42 Kb)* Version 2, Feb 2012. Author: T.J. Hogan |
| TN008 | **Welding consumables and design of welds in AS 4100-1998 with amendment 1, 2012** *(PDF) (43 Kb)* Version 1, Feb 2012. Author: T.J. Hogan |
| TN009 | **Documentation of structural steel** *(PDF) (74 Kb)* Version 1, Apr 2012, Author: T.J. Hogan |
| TN010 | **Third-party steel product certification** *(PDF) (78 Kb)* Version 1, Jul 2012. Authors: T.J. Hogan and P.W. Key |
Significance of Notifications

- Industry advisory notices are deemed as being notification to industry and therefore are presumed as being in the public arena and can be used in court.
Failure, Injury, Death, Risk, Rectification, Delays

Safety & Risk Avoidance

Compliance
- 3rd Party Certification
- Fabricator Prequal
- Build with Standards

Awareness
- Seminars
- Technotes
- Publications
Summary Recommendations

• Design and enforce compliance to Australian Standards where appropriate.
• Ensure test certificates and marking of product are checked.
• Call for third party product certification on steel.
• Call for prequalified and inspected fabricators.

These actions reduce the risk and liability for you on your project.