Instrumented Impact Testing: Force and Energy Scales/Targets

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Introduction

- **Independent targets for absorbed energy**
  - US (NIST), EU (IRMM), Japan (NRLM)...soon China, Brazil, Korea...
  - Each target uses an independent certification system
  - Bias between targets

- **Need a new target for absorbed energy**
  - Reduce bias between targets
  - Link certification systems
Role of Instrumented Impact Testing

- increased traceability to SI units
- Independent test method
Independent measures of absorbed energy

- Area under force – displacement curve
  - Measured using an instrumented striker
  - Verified/Calibrated
    - Force (static, with load cell)
    - Force (dynamic, with indirect verification specimen)
    - Time or length
    - Energy (sometimes calibrated/corrected using encoder reading)
  - Traceable to test method, SI units, and energy scale/encoder

- Loss in energy (absorbed by fracture)
  - Measured by dial or encoder
  - Verified/Calibrated
    - Energy direct (potential energy, velocity, geometry, losses due to air resistance, bearing friction, pointer friction)...SI
    - Energy indirect (losses due to vibration of frame & pendulum, shock to foundation)
  - Traceable to test method, SI units, and verification specimens
Role of Instrumented Impact Testing

Questions

– Are the energy losses for instrumented impact tests
  • the same?
  • apparent in the data?
– Can we use instrumented impact tests results to
  • define bias between “regional absorbed energy targets”?
  • provide better or complementary traceability for users?

Details

– Mechanical work
  • \( dW = dFdl \), where \( F \) is force on the body, and \( l \) is displacement (path);
– Kinetic energy
  • \( E = \frac{1}{2}mv^2 \), where \( m \) is mass, and \( v \) is velocity
– Potential Energy
  • \( E_p = mgh \), where \( m \) is mass, \( g = 9.81 \text{ m/s}^2 \), and \( dh \) is the change in elevation
Outline of Talk

• Material Tested (dynamic force specimen)
• Results (machine variables & specimen position)
• Results (bias between 2 machines using same striker)
• Discussion
Test Material
Dynamic Force Specimens

Low Energy

- Max force = 32.97 ± 0.75 kN (±2.3 %)
  - expanded uncertainty of 1.84 kN (5.6 %)
  - 95 % uncertainty interval of ±6 %

High Energy

- Max force = 24.06 ± 0.28 kN (±1.2 %)
  - expanded uncertainty of 0.70 kN (2.9 %)
  - 95 % uncertainty interval of ±3 %

- Super-high Energy
  - Not certified for dynamic force
Machine Variables & Specimen Position

Test Matrix

- Low and High verification specimens used (~ 15 J, and ~ 100 J)
- Super-high verification specimens used (~ 240 J)
  - used only when looking at the effect of foundation bolts
- Tests were performed on an instrumented machine with 407.6 J capacity
- The instrumented striker 8 mm radius of the striking edge
- Tests were conducted at 21°C (in most cases)

<table>
<thead>
<tr>
<th>Variable considered</th>
<th>Low energy</th>
<th>High energy</th>
<th>Super-high energy</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>RT -40°C</td>
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<tr>
<td>Reference tests</td>
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<tr>
<td>Loose foundation bolts</td>
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<tr>
<td>Loose anvil bolts</td>
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<tr>
<td>Loose striker bolts</td>
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<td>COP position changed</td>
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<tr>
<td>Lateral specimen offset</td>
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<td>-</td>
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<tr>
<td>Specimen/anvils distance</td>
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<tr>
<td>TOTAL</td>
<td>44</td>
<td>10</td>
<td>43</td>
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</tbody>
</table>
Machine Variables & Specimen Position

Results

Test machine variables and specimen positioning for low-energy (RT and -40°C)
Machine Variables & Specimen Position

Results

Test machine variables and specimen positioning for high and super-high energy
Test machine variables and specimen positioning for high and super-high energy.
Statistical Significance of the Various Machine Parameters Based on the t-test Results.

<table>
<thead>
<tr>
<th>Test machine variable</th>
<th>Test parameter</th>
<th>Low-energy specimens (RT)</th>
<th>Low-energy specimens (-40°C)</th>
<th>High-energy specimens</th>
<th>Super-high energy specimens</th>
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<tr>
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<td>KV</td>
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<td>$W_t$</td>
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<tr>
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<td>KV</td>
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<td>Anvil bolts</td>
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<td>COP position</td>
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<tr>
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<td>KV</td>
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<td>NS</td>
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</tbody>
</table>
Machine Variables & Specimen Position

Summary of Results

Specimen Position,

- Moving the samples away from the anvils has more effect than sideways displacement
  - effects visible on test record
  - particularly significant when distance exceeded 0.5 mm
  - Low energy specimens more affected than high energy
  - Losing data due to mis-triggering increased

- Lateral offset of the sample affected forces more than energies, but the consequences were not very significant.
Machine Variables & Specimen Position

Summary of Results

Machine Variables

– Typically increased maximum forces & energies
  • Not simple result of post-impact vibration (energy) losses
  • Exception for COP/COS (Fm decreased)
– Unbolting pendulum from foundation had least influence
– Variations due to bolting were moderate (< 5%)
– Variation at high energy typically less than at low energy
– Effects not particularly evident nor systematic
Machine Variables & Specimen Position

Overview

- Machine variables on instrumented Charpy test results
  - Typically < 5% change for machines variables
  - Can be > 10% change for specimen position variables

- Force data more sensitive to variables than energy
  - Instrumented tests detect effects not noted by encoder alone

- Considered the effect of one variable at a time here
  - Synergetic effects between two or more variables could be more easily detected from either the instrumented test record, the absorb energy value or both.
Bias, Materials and Machines

• Same Specimens as in previous study
  – 25 to 27 specimens tested for each energy level on each machine

• Charpy machines used in study
  – Mach #2
    • capacity of 358.5 J,
    • impact velocity of 5.12 m/s,
    • hammer mass 27.287kg
  – Mach #3
    • capacity of 407.7 J,
    • impact velocity of 5.47 m/s,
    • hammer mass 27.287kg
  – Same machine manufacturer

• Instrumented striker
  – 8 mm radius
| Parameter | Energy level | Test machine | N  | Mean value | Stand. dev. | P        | Result t-test (difference is…)
<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
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</thead>
<tbody>
<tr>
<td>$F_{gy}$ (kN)</td>
<td>High</td>
<td>2 3 25</td>
<td>20.61 20.86</td>
<td>0.128 0.084</td>
<td>&lt; 0.0001</td>
<td>Extremely significant</td>
<td></td>
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<tr>
<td></td>
<td>Super-High</td>
<td>2 3 25</td>
<td>20.32 20.63</td>
<td>0.190 0.221</td>
<td>&lt; 0.0001</td>
<td>Extremely significant</td>
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<tr>
<td></td>
<td>Low</td>
<td>2 3 25</td>
<td>32.62 32.13</td>
<td>0.394 0.713</td>
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<tr>
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<td>High</td>
<td>2 3 25</td>
<td>24.28 24.44</td>
<td>0.078 0.094</td>
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<tr>
<td></td>
<td>Super-High</td>
<td>2 3 25</td>
<td>25.57 25.71</td>
<td>0.072 0.062</td>
<td>&lt; 0.0001</td>
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<tr>
<td>$F_m$ (kN)</td>
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<td>2 3 25</td>
<td>18.46 18.52</td>
<td>0.626 0.412</td>
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<tr>
<td></td>
<td>High</td>
<td>2 3 25</td>
<td>102.76 104.69</td>
<td>2.539 2.407</td>
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<td>Super-High</td>
<td>2 3 25</td>
<td>220.80 222.89</td>
<td>3.928 4.298</td>
<td>0.0777</td>
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<tr>
<td>$W_t$ (J)</td>
<td>Low</td>
<td>2 3 25</td>
<td>19.14 19.65</td>
<td>0.777 0.474</td>
<td>0.0058</td>
<td>Very significant</td>
<td></td>
</tr>
<tr>
<td></td>
<td>High</td>
<td>2 3 25</td>
<td>107.95 109.19</td>
<td>3.314 3.132</td>
<td>0.1778</td>
<td>Not significant</td>
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</tr>
<tr>
<td></td>
<td>Super-High</td>
<td>2 3 25</td>
<td>239.33 239.60</td>
<td>5.560 6.514</td>
<td>0.8686</td>
<td>Not significant</td>
<td></td>
</tr>
<tr>
<td>KV (J)</td>
<td>Low</td>
<td>2 3 27</td>
<td>19.14 19.65</td>
<td>0.777 0.474</td>
<td>0.0058</td>
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<td>Not significant</td>
<td></td>
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</tbody>
</table>
Bias, Results
Absorbed Energy

• Bias between machines consistent
  – About 3% to 7% (for both KV & Wt)
  – Absorbed energy for machine #2 < #3

• Magnitude of Bias, depends on measurement method
  – Wt ≥ KV
    • Equal for low energy (0.3 %)
    • Increase from 1 % (KV) to 2 % (Wt) for high energy
    • Increase from 0.1 % (KV) to 1 % (Wt) for super-high energy

• SD of dial energy (KV) > SD instrumented (Wt)
  • KV may have vibration loss which vary from test to test for KV

• SD of energy values > SD Force values
Bias, Results

Force

- Differences more significant for force than energy

- Generally (1 exception)
  - Machine #3 > machine #2
  - Assuming that the most significant design difference between the machines is the impact speed
    - higher rate may promote early fracture for brittle materials
    - higher crack resistance for ductile materials.
### Bias, Results

<table>
<thead>
<tr>
<th>Striker</th>
<th>N</th>
<th>KV Average (J)</th>
<th>Abs. standard deviation (J)</th>
<th>Rel. standard deviation (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-instrumented</td>
<td>25</td>
<td>246.58</td>
<td>10.248</td>
<td>4.16</td>
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<tr>
<td>Instrumented</td>
<td>25</td>
<td>239.33</td>
<td>5.560</td>
<td>2.32</td>
</tr>
</tbody>
</table>

Differences in KV (Dial) for the same machine,
- 2 different strikers
- for the super-high energy specimens (about 3 % difference)
  - striker had an effect on absorbed energies measured by the encoder
  - stiffness lower for instrumented striker (with cavities)
Discussion
Use of Instrumented testing to improve target for Absorbed Energy

• Use of identical striker removes variables
  – Need standardization for reference machines
• Force measurements indicate static calibration robust (force scale)
• Lower SD for instrumented tests
• Sensitivity of Force to machine variables
• Independent measurement methods
Thank You
Results

Statistical significance of loosening the machine bolts evaluated using an unpaired $t$-test (95% confidence level).

The degree of statistical significance depends on the value of the two-tailed probability, $P$, using a threshold value 0.05, as follows:

- $P > 0.05$ $\Rightarrow$ not significant
- $< P < 0.05$ $\Rightarrow$ significant
- $< P < 0.01$ $\Rightarrow$ very significant
- $P < 0.001$ $\Rightarrow$ extremely significant

For specimen position, no statistical analysis performed, due to the limited number of data for each condition (from 2 to 4).