Testing Large Structures in the Field

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Large Structure Test Issues

- Need to test in the field
- Large input forces required
- Limited choices for boundary conditions
- Natural excitation sources cannot be removed
- May not be able to take out of service
To review a trajectory in the evolution of field testing of large structures as driven by Tom Carne and his colleagues.

- **Step relaxation testing** – Can input large yet controlled forces
  - Vertical Axis Wind Turbine – non-rotating
  - Vertical Axis Wind Turbine - rotating

- **Support system modelling** – Allows a wider range of support conditions
  - STARS launch system

- **Natural excitation analysis** – Uses the natural environment for excitation
  - Vertical Axis Wind Turbines – non-rotating
  - Vertical Axis Wind Turbines – rotating
  - Other applications – HAWT's, Trucks, STARS, Space Shuttle

- **Hybrid force reconstruction** – Augments test data with analytical data
  - Space Shuttle Rollout Stack
Making Step Relaxation Testing Viable

Raw Step Relaxation Force does not convert to frequency domain in a usable form

Apply high pass filtering to both the input force and the responses

Filtered Step Relaxation Force converts to frequency domain well
Step Relaxation Testing – E’ole Wind Turbine

110 Meter Tall Turbine Structure in the Field
Very Windy Site
Step Relaxation Device - E’OLE

Step Relaxation

10,000 pounds on blade

30,000 pounds on tower

Release < 0.1 seconds
Attaching cable for Step Input
Free Support to Match Flight Conditions
Hydroset and pulley block weighted several thousands pounds and were modeled as a double pendulum.
Reconciliation Performed with B.C. Model
Model Match for STARS Shell Modes

Test/Analysis Correlation Using System Identification Techniques

STARS First Stage Shell Modes

<table>
<thead>
<tr>
<th>FEM₀</th>
<th>FEMₙ</th>
<th>Test</th>
<th>Δ₀ %</th>
<th>Δₙ %</th>
<th>Mode</th>
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</thead>
<tbody>
<tr>
<td>35.8</td>
<td>39.9</td>
<td>39.7</td>
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<td>41.5</td>
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## Early Assessment of Natural Excitation Input

<table>
<thead>
<tr>
<th>MODE SHAPE DESCRIPTION</th>
<th>STEP RELAXATION (Hz)</th>
<th>WIND EXCITATION (Hz)</th>
<th>FINITE ELEMENT MODEL (Hz)</th>
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<tbody>
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<td>0.63</td>
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<td>SECOND TOWER IN-PLANE</td>
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<td>THIRD TOWER OUT-OF-PLANE</td>
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</table>
Making Natural Excitation Work

- Natural Excitation used on E’OLE and other turbines
- E’OLE test published ’88 IMAC and M.A. journal
- Formalized approach in ’92 IMAC & Oct.95 journal
- Called this NExT:
  - 1. Acquire response data -- long time histories
  - 2. Calculate auto & cross-correlation functions
    - Showed that correlation fcns sum of decaying sinusoids
    - Reference dofs
  - 3. Time domain modal id algorithm to estimate
    - Poly-Reference and ERA
  - 4. Extract mode shapes
- NExT used on rotating systems (VAWT & HAWT)
- Applied to flight systems (STARS and Space Shuttle)
Rotating 34-Meter VAWT Using NExT

[Diagram showing 34-meter test bed frequencies with various labels such as 2B, 3Fs, 3Pr, 3Fa, 2Pr, 1To, 2Fs, 2Fa, 1Tt, 1B, and 1F, plotted against turbine rotation rate in RPM.]
Space Shuttle Roll-Out Numbers

Space Shuttle Elements:

- Orbiter (Orb) – 250,000 lbs
- External Tank (ET) – 65,000 lbs
- Solid Rocket Boosters (SRBs) – $3 \times 10^6$ lbs
- Mobile Launch Platform (MLP) – $8 \times 10^6$ lbs
- Crawler Transporter (CT) – $1 \times 10^6$ lbs
- Total – $12 \times 10^6$ lbs

Historical Roll-out Speed - .9 mph
Constrained Roll-out Speed - .8 mph
Desired Roll-Out Speed – 1.0 mph
Max CT Speed – 2.0 mph

Roll-out found to possess narrow-band excitation which drives system dynamics
Hybrid Approach Developed for Shuttle Stack

- **Measured data at .8, .9, and 1.0 mph from STS-115:**
  - MLP, SRB, and Orbiter sensors used;
  - CT, SSME, and wireless sensors not used; and
  - Six bad channels removed (2 on HDP’s, 3 on SRB, 1 on Orb.).

- **Model from Shuttle Modeling and Integration Group:**
  - CT, MLP, and SRB models used for past roll-out work;
  - ET shell model developed by DCI, Inc.;
  - Cargo Hi-Fi Orbiter model with Lo-Fi SSME models; and
  - Node at undeformed C.G. and RBE3’s to MLP/CT interfaces;

- **SWAT Forces and Moments Calculated:**
  - Sum of Weighted Accelerations Technique (SWAT)
  - 29 modes (including 6 rigid body) to 6.17 Hz; and
  - 400 seconds of data at 64 samples/second used.
Hybrid Approach Developed for Shuttle Stack

- SWAT forces time-shifted to estimate other speeds:
  - Assumes that the frequency content changes slowly with speed;
  - Assumes that the magnitude changes slowly with speed; and

  \[ \text{New Time Vector} = (\text{Original CT Speed} / \text{New CT Speed}) \times \text{Original Time Vector}. \]

- .8 mph SWAT forces generated .76, .78, .82, and .84 mph forces.
- .9 mph SWAT forces generated .86, .88, .92, and .94 mph forces.
- 1.0 mph SWAT forces generated .96, .98, 1.02, and 1.04 mph forces.
- Forces used to drive the vehicle model at the C.G.
- 15 NASTRAN transient solutions produced.
- RMS and PSD data plotted as a function of CT speed.
Source of Roll-Out Harmonic Forces

Roller Spacing = 30 inches

1 mph = 17.6 in/sec = .59 roller crossings/sec
(source of the .59 family of harmonics)

Shoe Spacing = 18 inches

1 mph = 17.6 in/sec = .98 shoe crossings/sec
(source of the .98 family of harmonics)
Frequency Sensitivity for Orbiter Tail

ACCEL 54 ORBITER TAIL  
CHAN=85:87  GRID=50821250 [X Direction ((in/sec^2)^2)/Hz]

Y Direction ((in/sec^2)^2)/Hz

Z Direction ((in/sec^2)^2)/Hz

Y Direction ((in/sec^2)^2)/Hz

Speed (mph)

Frequency (Hz)
Conclusions

- Testing large structures in the field creates unique challenges.

- Several critical developments have been covered:
  - Step Relaxation Testing has been developed into a useful technique to apply large forces to operational systems by appropriate windowing;
  - Capability for large structures testing with free support conditions has been expanded by implementing modeling of the support structure;
  - Natural excitation has been developed as a viable approach to testing large structures in the field; and
  - A hybrid approach as been developed to allow forces to be estimated in operating structures.

- These developments have greatly increased the ability to extract information from large structures.
References


References


