Seismic Analysis of Overhead Cranes for Nuclear Industry

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- Who We Are?
- Our Products
- Overview of Seismic Analysis
- Case Study – 1 (Coupled Building/Crane Seismic Analysis)
- Case Study – 2 (Time History Seismic Analysis)
Who We Are

- Konecranes – Leading Lifting Equipment Manufacturer
  - SuperSafe™ single failure proof cranes
  - Polar cranes,
  - Over head fuel handling cranes
  - Turbine maintenance cranes
  - Gantry cranes
  - Remotely operated top running cranes
  - Jib cranes
  - Cask transfer machines

- QA
  - NUREG 0554
  - NUREG 0612
  - ASME NOG-1
  - ASME NUM-1

- More on www.konecranes.com
Finite Element Analysis of Overhead Cranes

- Finite Element Modeling
- Modal Analysis
- Linear Response Spectrum Analysis
- Time History Analysis
Simplified Finite Element Model

- A simplified model with only beam elements for bridge/trolley
- Global frequencies
- Useful at the conceptual design phase
- Not very useful for trolley stress analysis during seismic excitation
Detailed Finite Element Modeling

Bridge
- **BEAM188**
  - Warping $T = GJ\theta' - EC_{w}\theta'''$
- **Lateral Torsional Buckling**

\[
F_{cr} = \frac{C_{b} \cdot \pi^{2} \cdot E}{\left( \frac{L_b}{r_{ts}} \right)^{2}} \sqrt{1 + \frac{0.0781 - c}{8} \left( \frac{L_b}{r_{ts}} \right)^{2}}
\]

Rope
- **COMBIN14**
  - Simple Pendulum $f := \frac{1}{2\pi} \sqrt{\frac{g}{L}}$

Trolley
- **SHELL181**
Modal Analysis

- Natural Frequencies (0-33Hz)
- Mass Participation Factors (> 90%)
- Required for response spectrum analysis and time history analysis
- Coupled with building or decoupled from building
  - If $Rm < 0.01$, decoupling can be done for any $Rf$.
  - If $0.01 \leq Rm \leq 0.1$, decoupling can be done if $Rf \leq 0.8$ or if $Rf \geq 1.25$.
  - If $Rm \geq 0.1$, or $0.8 \leq Rf \leq 1.25$, an approximate model of the runway system shall be included with the crane model.
- Dynamic characteristics vary with bridge, trolley and hook positions
Seismic Analysis

- **Response Spectrum Analysis**
  - Linear
  - Requires Frequency vs. Acceleration
  - Maximum Response
  - Computationally Efficient

- **Time History Analysis**
  - Can be Nonlinear
  - Requires Time vs. Acceleration
  - Time Consuming
  - Accurate
Input Excitation

- Curve of frequency vs. acceleration
- Typically Acceleration Spectrum
- Three curves (EW, NS and Vertical)
- Various curves for different damping
- Operational Basis Earthquake (OBE)
  Safe Shutdown Earthquake (SSE)
- Crane Rail Level for decoupled

Acceleration Spectrum

Acceleration Time History
Linear Response Spectrum Analysis

- **Perform Modal Analysis**
  - No need to expand modes

- **Perform SPRS Analysis**
  - Input Spectrum
  - Excitation Direction
  - Missing Mass

- **Expand Modes**
  - Expand modes with significant Mode Participation Factors

- **Combine Modes**
  - Modes combined based on the modal coefficients to get total response
  - SRSS/Grouping etc., methods
Total Response

• Results to be combined
  – Response of the structure due to Static Load
  – Response of the structure due to EW Excitation
  – Response of the structure due to NS Excitation
  – Response of the structure due to Vertical Excitation

• Total Response

\[ \sigma = |\sigma_{st}| + \sqrt{\sum_{j=1}^{3} \sigma_j^2} \]

– \( \sigma_{st} \) is the static stress
– \( \sigma_j \) is the seismic stress obtained due to excitation in direction \( j \)
Total Response – Contd.

```
/POST1
FILE,'SPECTRUM1','RST'
SUMTYP,COMP
/INP,SPECTRUM1,MCOM
LCWRITE,10
FILE,'SPECTRUM2','RST'
SUMTYP,COMP
/INP,SPECTRUM2,MCOM
LCWRITE,20
FILE,'SPECTRUM3','RST'
SUMTYP,COMP
/INP,SPECTRUM3,MCOM
LCWRITE,30
FILE,'STATIC','RST'
LCWRITE,40
SUMTYP,COMP
LCABS,ALL,1
LCOPER,ZERO
LCOPER,ADD,10
LCOPER,SQUARE
LCOPER,ADD,20,MULT,20
LCOPER,ADD,30,MULT,30
LCOPER,SQRT
LCOPER,ADD,40
LCWRITE,5
```

! Spectrum analysis results
! Add component stresses
! Obtain seismic response based on mode coeff.
! Write the combined results
! Static analysis results
! Perform absolute addition
! Add in an SRSS sense
! Add the static results
Batch Execution

- **Number of analysis is more**
  - 5 Bridge Positions, 5 Trolley Positions, 3 Hook Positions, 3 Directions and 2 Excitations
  - 450 analyses. Not to forget the total response computation.

- **ANSYS supports Tcl/Tk scripting**
  - Setup the db files
  - Setup the spectrum macros
  - Identify the output location
Batch Execution – Contd.

```tcl
set DbDir "C:\\Puagzh\\SEISMIC\\COUPLEDMODELS\\T1"
set ScriptDir "C:\\Puagzh\\SEISMIC\\SCRIPTS"
set OpDir "C:\\Puagzh\\SEISMIC\\OP"

set craneconfigs [ glob [ file join $DbDir "*.*.db"] ]
set spectrum [ glob [ file join $ScriptDir "Spectrum *.*.mac"] ]
foreach cc $craneconfigs {
    set LC_Folder [ file root [ file tail $cc ] ]
    # Create Modal analysis folder and perform modal analysis
    set ModalFolder [ file join $OpDir "$LC_Folder Modal" ]
    file mkdir $ModalFolder
    file copy $cc $ModalFolder
    file rename [ file join $ModalFolder [ file tail $cc ] ] \ 
    [ file join $ModalFolder "${LC_Folder}_Modal.db" ]
    file copy [ file join $ScriptDir modal.mac ] $ModalFolder

    # Perform modal analysis here
    ans_sendcommand "/Cwd,$ModalFolder"
    ans_sendcommand /filename,"${LC_Folder}_Modal,1"
    ans_sendcommand resume,"${LC_Folder}_Modal.db"
    catch { file rename modalResults.out ${LC_Folder}_ModalResults.out }

    # Create Static analysis folder and perform static analysis
    set StaticFolder [ file join $OpDir "$LC_Folder Static" ]
    file mkdir $StaticFolder
    file copy $cc $StaticFolder
    file rename [ file join $StaticFolder [ file tail $cc ] ] \ 
    [ file join $StaticFolder "${LC_Folder}_Static.db" ]
    file copy [ file join $ScriptDir static.mac ] $StaticFolder

    # Perform static analysis here
    ans_sendcommand "/Cwd,$StaticFolder"
    catch { ans_sendcommand /filename,"${LC_Folder}_Static,1" }
    ans_sendcommand resume,"${LC_Folder}_Static.db"
    catch { ans_sendcommand /input,static,mac" }
    set StaticFiles2Del { page tmp err stat PCS mntr emat esav log }
    foreach extn $StaticFiles2Del {
        catch { file delete "${LC_Folder}_Static.$extn" }
    }
```
Post Processing – Stress Plots

Stress Plot - Bridge

Stress Plot - Trolley
# Post Processing – Mass Participation Factors

<table>
<thead>
<tr>
<th>Configuration</th>
<th>NS</th>
<th>Vertical</th>
<th>EW</th>
<th>NS (%)</th>
<th>Vertical (%)</th>
<th>EW (%)</th>
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</table>
### Table 9-33: Trolley Wheel Loads - Bridge Position P

<table>
<thead>
<tr>
<th>Configuration</th>
<th>Location</th>
<th>Seismic Loads</th>
<th>Static Loads</th>
<th>Uplift</th>
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<td>FY (lbf)</td>
<td>FZ (lbf)</td>
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<td>16888</td>
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</tbody>
</table>
Post Processing – Accelerations

- Evaluation of Trolley and Bridge Mounted Components
- Accelerations (in terms of G)

<table>
<thead>
<tr>
<th>Components</th>
<th>E-W</th>
<th>N-S</th>
<th>Vert. Up</th>
<th>Vert Down</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main Hoist</td>
<td>3.63</td>
<td>1.32</td>
<td>1.4</td>
<td>3.4</td>
</tr>
<tr>
<td>Aux Hoist</td>
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<td>1.32</td>
<td>1.4</td>
<td>3.4</td>
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<td>Bridge Mounted</td>
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<td>Seismic Restraints</td>
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</table>

Acceleration Plot
Time History Analysis

- Create large mass at the BC
  - Typically (M=MassX1E6)
- Perform Modal Analysis
  - Compare the frequencies (1, 2)
- Time history analysis
  - Mode superposition
  - Damping
  - Integration time step
  - Transient effects
  - Apply Force at the base (GXM)
  - If the excitations are not statistically independent, cannot combine the input acceleration
  - Expand results
Animations – Comparing Frequencies
Post Processing

- Scan through each time step
- Identify the maximum stress in a particular node for a particular excitation
- Perform step 2 for all nodes and 3 excitations
- Combine the maximum value identified for each node.
- Add the seismic results with the static solution.

```plaintext
/post1
lcooper,zero
lcdefi,5,1,1
lcase,5
*get, noSteps, active, 0, set, nset, last, 1
*do, 1, 1, noSteps|
   lcdefi, 6, 1, 1
   lcooper, abmx, 6
*endo
lwrite, 5
```
Post Processing – Comparison

- Comparison on Time History (TH) and Response Spectrum (RS) stress results

<table>
<thead>
<tr>
<th>Single Crane Application</th>
<th>Cross Sectional Normal Stresses on the Girt Plate (ksi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location</td>
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<tr>
<td>Combination</td>
<td>RS</td>
</tr>
<tr>
<td>SUM with EW</td>
<td>31.5</td>
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<tr>
<td>SUM with NS</td>
<td>32.3</td>
</tr>
</tbody>
</table>

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Summary

• Both the response spectrum and time history analysis results are comparable
• Large models for several load cases are successfully analyzed for seismic conditions
• Tcl/Tk interaction with ANSYS helps in managing the load cases efficiently
• Load combination helps in managing the results file size