DYNAMIC DESIGN AND ANALYSIS METHOD DDAM AND MODAL EFFECTIVE MASS

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AGENDA

- **MODAL EFFECTIVE MASS THEORY**
- DDAM BACKGROUND.
- SIMPLE DDAM ANALYSIS
- MODAL DATABASE USAGE
- BRACKET DDAM ANALYSIS – CHASING MODAL EFFECTIVE MASS
- MODESET USAGE
- RACK EXAMPLE
- ENGINE DECK CRADLE - LARGE SCALE ANALYSIS
- DDAM STRESSES

Modal Effective Mass Theory

- Eigenvectors in a Normal Modes Analysis are independent of each other and are arbitrarily scaled.
- Until we apply some type of loading – either transient or frequency response, then it is difficult to predict which modes will play a dominant part in a structure.
- One way we can help predict what are the important modes is to use a technique called Modal Effective Mass.
- Linear combinations of Eigenvectors can be assembled to make arbitrary shapes.
  - Shape to be made is a Rigid Body Vector in the direction of response we are interested in.
- The Rigid Body Vector is D_R so that $D_r = \sum \Phi \varepsilon$ where ε is a vector of scaling factors on the eigenvectors Φ, i.e. a set of Participation Factors.

Modal Effective Mass Theory (Continued)

- Pre Multiply by $\Phi^T M$:

$$\Phi^T M D_R = \Phi^T M \Phi \{\varepsilon\}$$

$$\Phi^T M D_R = M_{ii} \{\varepsilon\}$$

- Where M_{ii} is the diagonal matrix of generalized masses for each mode *I.*
- The term $\Phi^T M D_R$ is commonly known as the Participation Factor.
- The scaling factor ε_i is then a scaling on the generalized mass M_{ii} to achieve the Participation Factor.
- We can also define a 'rigid body' mass M_r in a similar way to a generalized mass as

$$M_r = D_R^T M D_R$$

- But

$$D_R = \Phi \{\varepsilon\}$$

- So

$$M_r = \varepsilon^T \Phi^T M \Phi \varepsilon = \varepsilon^T M_{ii} \varepsilon$$

Modal Effective Mass Theory (Continued)

- So the contribution which each mode provides to the rigid body mass M_r is

$$\varepsilon_i^2 M_{ii}$$

  as M_{ii} is a diagonal matrix.

- This is known as the Modal Effective Mass.
- If we Mass Normalize then $\Phi^T M \Phi = [I]$ so participation Factor is ε, Modal Effective Mass is ε^2.
- The modal effective weight is modal effective mass factored by g in the appropriate units.

Applications In Industry

- The values calculated are used by different industries in different ways:
  - Civil Engineering seismic analysis:
    - The contribution from each mode is assessed as a percentage and the total is summed.
    - Any shortfall from 100% is classified as ‘missing mass’.
    - If the missing mass is significant then it may indicate errors in the analysis, typically insufficient modes being used in a modal method.
    - ‘Missing mass’ is often characterized as higher frequency body type loading and can be simulated by applying a 1g inertia load in the appropriate direction, factored by the % missing mass, added as a static load. This is done outside NASTRAN.
  - Naval Shock Analysis:
    - For DDAM Analysis a criterion of 80% Effective Mass is applied in each direction to decide whether sufficient modes have been used.

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Dynamic Design Analysis Method (DDAM) Background

- Shipboard machinery and equipment must be designed to operate under severe conditions of shock loading due to underwater explosion of bombs, torpedoes and mines.

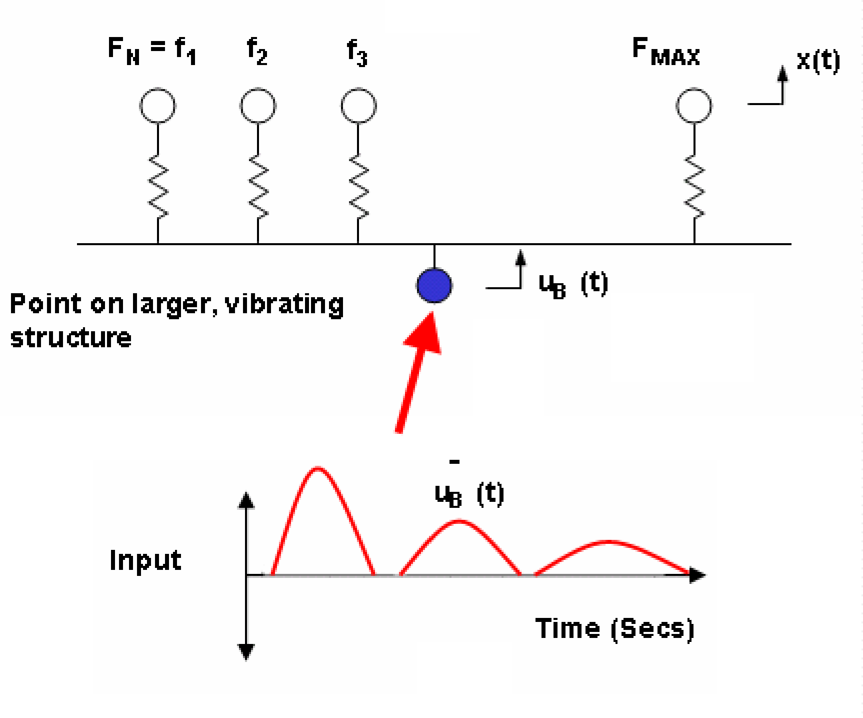
- The severe nature of the transient motion of the ship's hull due to these external forces transmits shock loading to onboard equipment.

- Since WW2, the US Navy has carried out an extensive program of trials and analysis to assure the capability of equipment to survive shock loading due to adjacent underwater explosions.

- DDAM was evolved to replace the original static 'g' loading analysis with a more realistic shock spectrum environment.

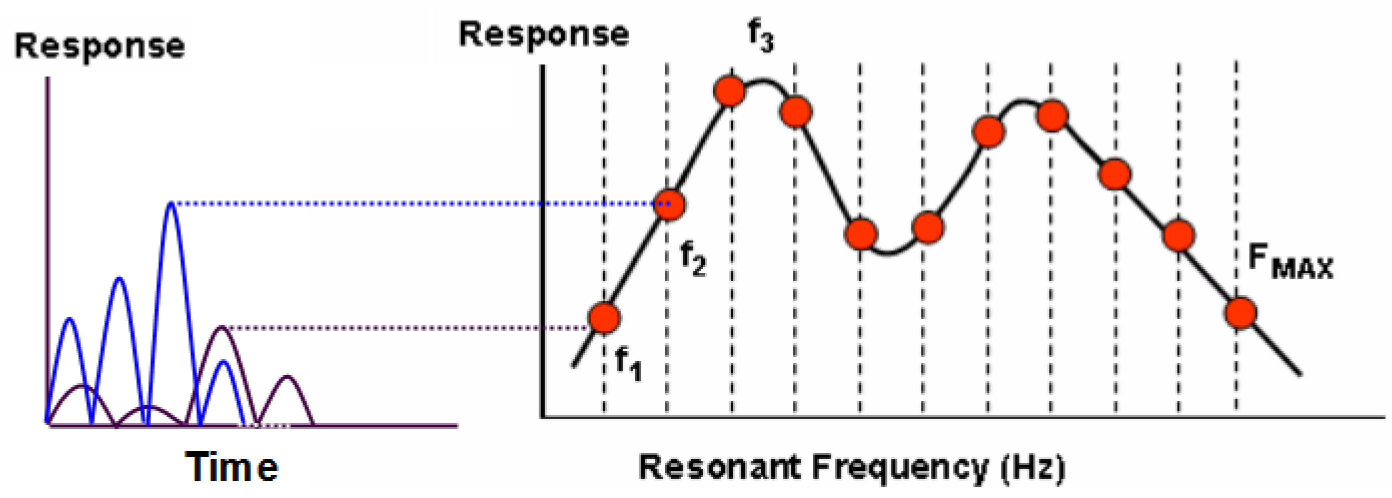
DDAM Background (Continued)

- Shock spectrum analysis calculates the maximum response of a series of simple spring-mass systems at a location, each with a tuned frequency, to a transient input.



DDAM Background (Continued)

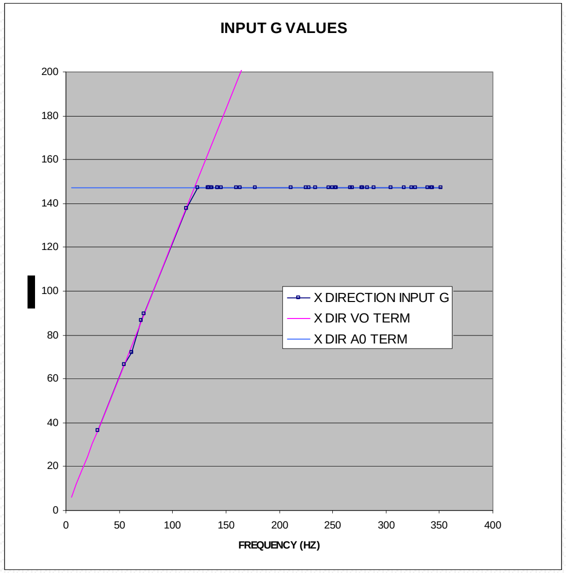
- The overall plot of maximum response plotted against frequency is called a response spectrum.
- The response spectrum is then used to evaluate the peak responses of equipment at the location



DDAM Background (Continued)

- DDAM shock spectrum analysis does not require the two stage approach of conventional shock spectrum methods, generation and application.

- The shock spectrum is implicit in the user supplied velocity and acceleration values and coefficients.



- The NEiNASTRAN implementation of DDAM requires only one analysis in which the implied shock spectrum is evaluated and the peak responses are calculated.

DDAM Background (Continued)

- There is an interaction between the equipment being shock loaded and its structure. This change in spectrum is often called the spectrum-dip effect. It is similar to soil structure interaction in seismic analysis, where the free field accelerations are greater than those with a very heavy structure present.

- In the analysis of shipboard equipment the spectrum-dip effect has a pronounced effect on the shock spectra that an individual equipment may experience. The coefficients included in the DDAM analysis allow for the influence of equipment location and orientation. The spectrum is also reduced to account for the mass of the equipment.

- In a conventional shock spectra analysis no interaction is assumed between the base structure and the component.

Dynamic Design Analysis (DDAM) Procedure

- The first step in the DDAM procedure is to calculate the natural frequencies of the system.

- The Eigenvalues (Natural frequencies) and Eigenvectors (Mode Shapes) are extracted using the Lanczos or Subspace eigensolver.

- The Participation Factors and Modal Effective Weight are calculated for each Mode and each direction (x, y and z) automatically.

DDAM Analysis Procedure (Continued)

- Once the Modal Effective Weight and Frequency are known for each mode, the shock spectrum INPUT acceleration can be calculated (each modal frequency in each direction).
- The ship type, orientation and spectrum-dip effect on the input acceleration are included via the coefficients defined on the DDAMDAT entry.
    - The peak acceleration input for each mode can be derived from the user defined Acceleration Coefficients, Velocity Coefficients or Minimum Acceleration.
    - The criteria used are reported in the output.
- The shock responses are calculated until the target Effective weight is reached, or until all modes are exhausted.
- The peak velocities and displacements at each mode are derived from the accelerations.
- All other output quantities such as Stress and Force can be derived from the peak displacements.

DDAM Analysis (Continued)

Input Acceleration calculation

The user supplied velocity, acceleration, and weighting factors are used to compute the velocity and acceleration spectra which serves as the input for response/shock spectrum analysis. The formulas for a SURFACE ship with HULL or SHELL mounted equipment are given by:

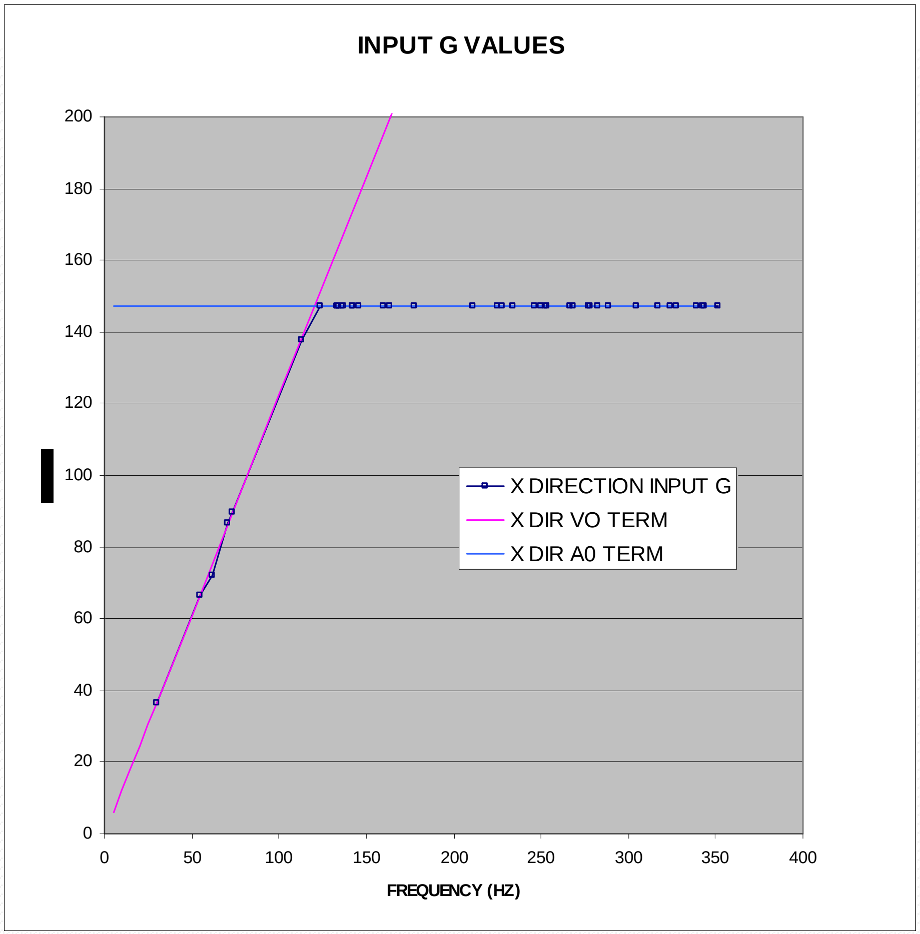
$$V_0 = VF_i \frac{VA(VB+M)}{(VC+M)} \qquad A_0 = AF_i \frac{AA(AB+M)}{(AC+M)}$$

For all other ship types and mounting locations the formulas are:

$$V_0 = VF_i \frac{VA(VB+M)}{(VC+M)} \qquad A_0 = AF_i \frac{AA(AB+M)(AC+M)}{(AD+M)^2}$$

Where M is the modal weight in kips calculated internally for that mode.

Input Acceleration calculation



$$V_0 = VF_i \frac{VA(VB+M)}{(VC+M)}$$

$$A_{eq} = V_0 * F_i$$

$$A_0 = AF_i \frac{AA(AB+M)}{(AC+M)}$$

DDAM Analysis (Continued)

Input Acceleration calculation (Cont)

- Coefficients are confidential
- Beware Units:

M is weight in KIPS

V is in Ft/sec

A is in g units (acceleration due to gravity)

Coefficients have no units

DDAM Analysis (Continued)

Hypothetical naval shock spectra
Surface Ship, Hull mounted equipment

$$V_0 = VF_i \frac{VA(VB+M)}{(VC+M)} \qquad A_0 = AF_i \frac{AA(AB+M)}{(AC+M)}$$

M = 40 kips (40,000 lb)

Vanilla Coefficients

AF1 = 1.0
AA = 50.0
AB = 40.0
AC = 10.0

VF1 = 1.0
VA = 4.0
VB = 30.0
VC = 10.0

V0 = 5.6 ft/s
A0 = 80.0 g

(After Scavuzzo and Pusey ; Naval Shock Analysis and Design SAVIAC 2002)

DDAM Analysis (Continued)

Hypothetical naval shock spectra
Surface Ship, Hull mounted equipment

V0 = 5.6 ft/s

This must be converted to equivalent acceleration:

$$A_{eq} = \frac{V * \text{Modal Frequency (rad/s)}}{g} \quad g = 32.2 \text{ ft/s}^2$$

If Modal Frequency = 62.83 rad/s (10Hz) A_{eq} = 10.9 g

A0 is larger so A_{eq} is used (VELOCITY DRIVEN)

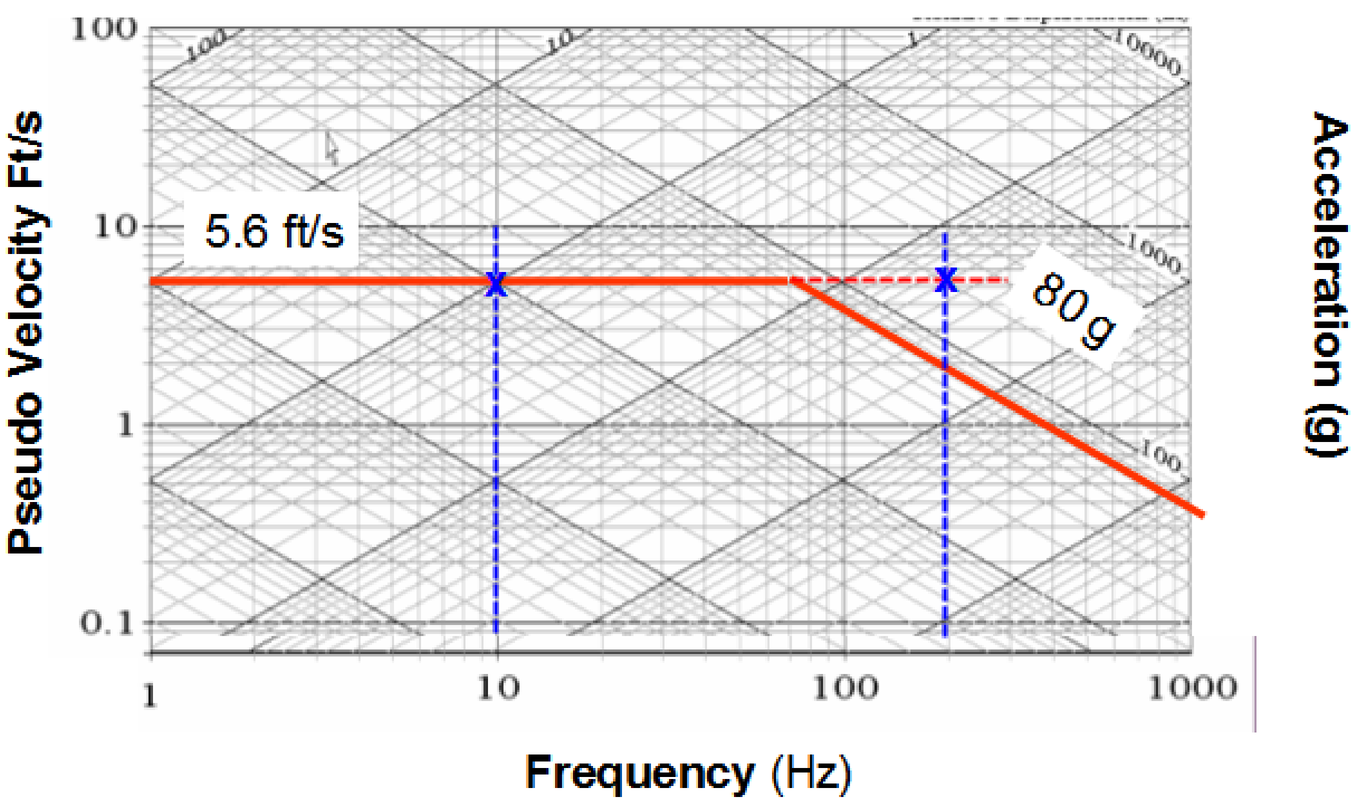
If Modal Frequency = 1256 rad/s (200Hz) A_{eq} = 218 g

A_{eq} is larger so A0 is used (ACCELERATION DRIVEN)

(After Scavuzzo and Pusey ; Naval Shock Analysis and Design SAVIAC 2002)

DDAM Analysis (Continued)

Hypothetical naval shock spectra



(After Scavuzzo and Pusey ; Naval Shock Analysis and Design SAVIAC 2002)

DDAM Analysis (Continued)

Hypothetical naval shock spectra
Surface Ship, Hull mounted equipment

Consider two extremes:

1. Modal Mass is very low

   A0 = 200 g
   V0 = 12 ft/s

2. Modal Mass is very high

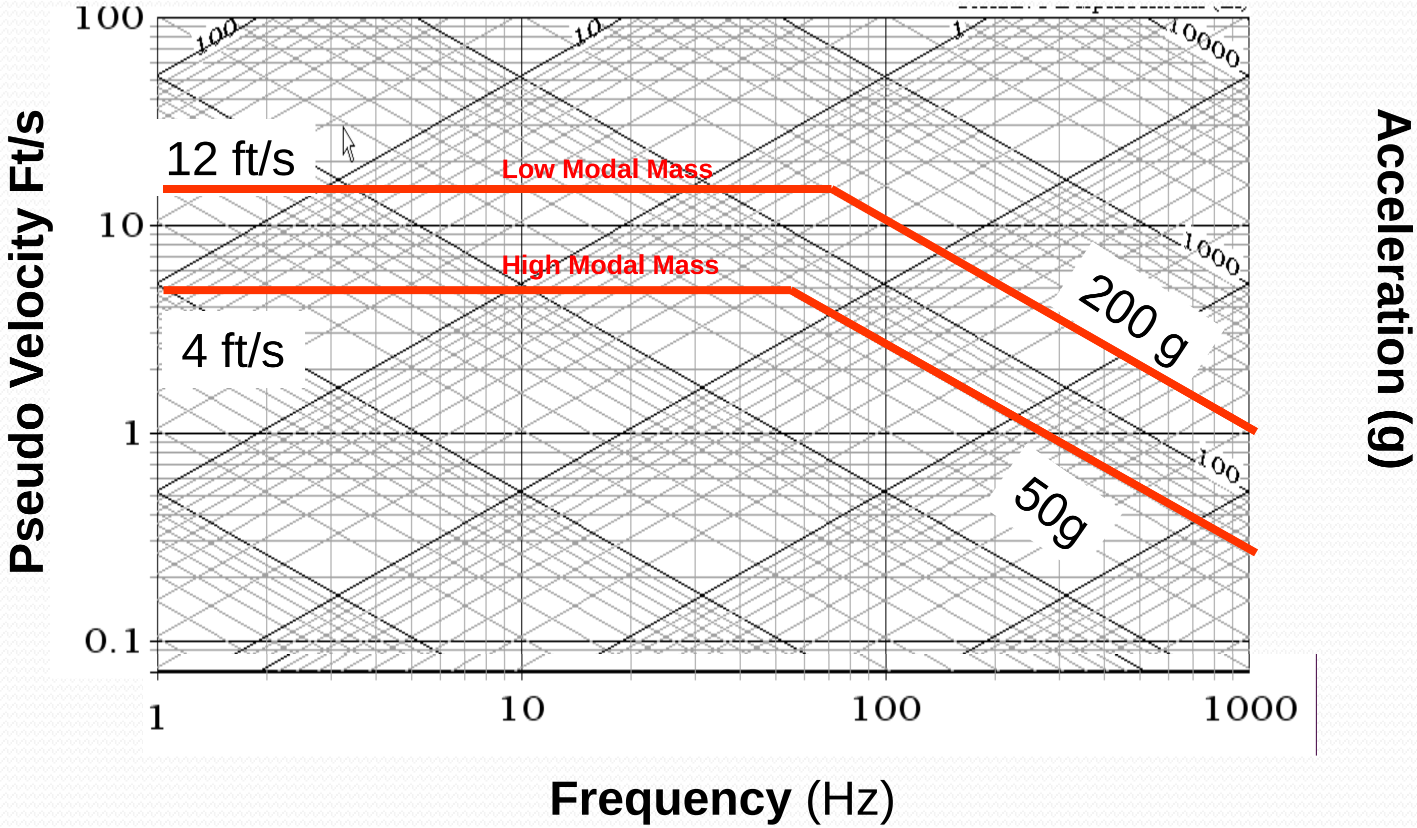
   A0 = 50 g
   V0 = 4 ft/s

Input Acceleration will be in this range, dependent on Modal Mass

(After Scavuzzo and Pusey ; Naval Shock Analysis and Design SAVIAC 2002)

DDAM Analysis (Continued)

Hypothetical naval shock spectra



(After Scavuzzo and Pusey ; Naval Shock Analysis and Design SAVIAC 2002)

DDAM Analysis Procedure (Continued)

The shock response for each mode is computed as follows:

$$\Gamma_{ia} = \S_{ia} P_a \frac{A_a}{\varpi_a^2}$$

where:

ϖ_a = *Natural frequency for a th mode*
P_a = *Participation factor*
A_a = *Shock spectrum acceleration*
$\S_{ia}$ = *i th response for a th mode*
Γ_{ia} = *Scaled response (stress, force, displacement)*

DDAM Analysis Procedure (Continued)

The scaled responses are summed using the Navy Research Lab (NRL) method.

The NRL method estimates the maximum response by taking the response for the mode that exhibits the largest response and adding the square root of the sum of the squares of the response of the other modes. It is assumed that the peak responses are not in phase and the values are not added in an absolute manner.

However, note that for a term with only two strongly dominant modes these responses are effectively added in an absolute manner

$$\Gamma_{iNRL} = |\Gamma_{iMAX}| + \sqrt{\Gamma^2_{iRSS} - \Gamma^2_{iMAX}}$$

where:

$$\Gamma_{iRSS} = \sqrt{\Sigma_a \Gamma_{ia}{}^2}$$

$$\Gamma_{iMAX} = \textit{Maximum of } \Gamma_{ia}$$

$$\Gamma_{ia} = i^{th} \textit{ scaled shock response } a^{th} \textit{ mode}$$

DDAM Analysis

Dynamic Design Analysis (DDAM) Summary

- A form of shock spectrum analysis
- User supplied shock coefficients
- Performs Shock excitation calculations
- Generates Shock Spectrum data
- Applies modal summation techniques
- Optional Modal cutoff percentage
- Modes ordered by Participation Factor or Mode Number

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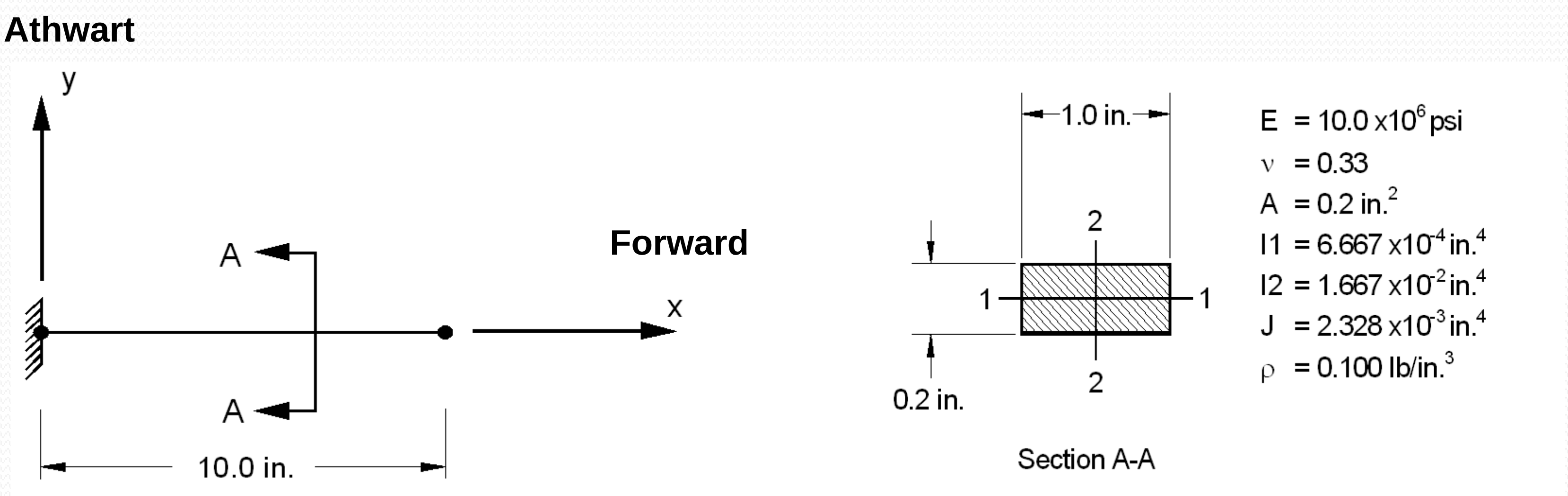
DDAM Analysis (Continued)

DDAM Example

As an example we will use the cantilever beam shown.

It is desired to find the response of the beam when subjected to the specified DDAM shock environment.



DDAM Analysis (Continued)

DDAM Example

```
$
$ MODAL SOLUTION.
$
SOL MODAL
CEND
$
TITLE = INSTALLATION TEST CASE
SUBTITLE = DDAM ANALYSIS OF A 3-D CANTILEVER BEAM
$
DISPLACEMENT = ALL
VELOCITY = ALL
ACCELERATION = ALL
STRESS = ALL
$
SUBCASE 1
SPC = 1
METHOD = 1
DDAM = 1
$
BEGIN BULK
```

- The analysis is set up like a typical normal modes analysis with the exception of the **DDAM** Case Control command and **DDAMDAT** Bulk Data entry.
- The **DDAM** command initiates a shock spectrum solution sequence and references the **DDAMDAT** entry.
- Note that only one Subcase is defined, but multiple input directions can be applied on the DDAMDAT entry, each spawning a Subcase automatically.

DDAM Analysis (Continued)

DDAM Example

```
$
$ DDAM COEFFICIENTS AND ANALYSIS PARAMETERS.
$
DDAMDAT,  1,  0.25,  0.5,  1.,  0.25,  0.5,  1.,  10.,
,  20.,  50.,  10.,  37.5,  6.,  ,  SURFACE,  DECK,
,  123,  1,  3,  386.4,  6.,  80.
```

coefficients on velocity and accelerations

The sequence shock directions are applied

Definition of Fore-Aft and vertical components

Weight-mass conversion factor

Min. acceleration. If computed value less than this then Min. value is used

Target Effective Mass

Type of ship, Position of component

- The **DDAMDAT** entry contains the shock environment in coefficient form and the analysis control settings.
- The analysis control settings specify shock directions and their labels and the modal mass cutoff percentage at which shock excitation calculations cease.
- In our example analysis all three shock directions are requested though only the results of the third (vertical direction) will be presented.

DDAM Analysis (Cont.)

DDAM Example

- User supplied shock coefficients on the DDAMDAT entry

1	2	3	4	5	6	7	8	9	10
DDAMDAT	SID	VF1	VF2	VF3	AF1	AF2	AF3	*VA*	
	VB	*VC*	*AA*	*AB*	*AC*	*AD*	STYPE	LTYPE	
	DIRSEQ	FADIR	VDIR	GCF	MINACC	CUTOFF	MTYPE		

DDAMDAT	10	0.25	0.5	1.0	0.25	0.50	1.0	*10.0*	
	20.0	*50.0*	*10.0*	*45.5*	*6.5*	*15.0*	SURFACE	HULL	
			3	1		100.0			

- VFi and AFi are directional coefficients
- *Ax* and *Vx* are non-directional coefficients

DDAM Analysis (Continued)

DDAM Example

```
$
$ DDAM COEFFICIENTS AND ANALYSIS PARAMETERS.
$
DDAMDAT,  1,  0.25,  0.5,  1.,  0.25,  0.5,  1., 10.,
,  20.,  50.,  10.,  37.5,  6.,  ,  SURFACE,  DECK,
,  123,  1,  3,  386.4,  6.,  80.
```

The sequence shock directions are applied

Directional Coefficients

Definition of Fore-Aft and vertical components

- NEiNASTRAN does not update the coefficient order, to avoid storing this data in the code
- The user must re-order as appropriate

DDAM Analysis (Continued)

DDAM Example

The user supplied velocity, acceleration, and weighting factors are used to compute the velocity and acceleration spectra which serves as the input for response/shock spectrum analysis. The formulas for a SURFACE ship with HULL or SHELL mounted equipment are given by:

$$V_0 = VF_i \frac{VA(VB+M)}{(VC+M)} \qquad A_0 = AF_i \frac{AA(AB+M)}{(AC+M)}$$

For all other ship types and mounting locations the formulas are:

$$V_0 = VF_i \frac{VA(VB+M)}{(VC+M)} \qquad A_0 = AF_i \frac{AA(AB+M)(AC+M)}{(AD+M)^2}$$

Where M is the modal weight in kips calculated internally for that mode.

DDAM Analysis (Continued)

- The acceleration term to be used in the shock factor calculation is assessed from the minimum values of the direct acceleration and the acceleration derived from the velocity.
- If accelerations generated are less than MINACC, the MINACC value will be used.
- The source of the acceleration is reported in the output.
- The modal mass cutoff percentage is percentage of total mass at which modal processing ceases.
  - DDAM analysis requires that only a percentage (typically 80%) of the total modal mass needs to be included in the NRL sum.
- The material type specified in the MTYPE field only affects the output labels and is not used in the analysis.
  - The character variable PLASTIC does not indicate or initiate nonlinear analysis.

DDAM Analysis (Continued)

DDAM Example

R E A L   E I G E N V A L U E S

MODE NUMBER	EIGENVALUE	RADIANS	CYCLES	GENERALIZED MASS	GENERALIZED STIFFNESS	ORTHOGONALITY LOSS	ERROR MEASURE
1	1.576987E+05	3.971130E+02	6.320250E+01	1.000000E+00	1.576987E+05	0.000000E+00	1.227248E-14
2	3.943060E+06	1.985714E+03	3.160362E+02	1.000000E+00	3.943060E+06	1.155646E-14	2.955895E-14
3	6.037523E+06	2.457137E+03	3.910655E+02	1.000000E+00	6.037523E+06	1.688713E-15	8.159152E-16
4	4.616942E+07	6.794808E+03	1.081427E+03	1.000000E+00	4.616942E+07	1.782905E-14	2.261833E-16
5	1.509607E+08	1.228661E+04	1.955474E+03	1.000000E+00	1.509607E+08	3.964347E-16	3.785877E-15
6	1.724843E+08	1.313333E+04	2.090234E+03	1.000000E+00	1.724843E+08	2.377492E-16	1.090117E-16
7	4.574813E+08	2.138881E+04	3.404135E+03	1.000000E+00	4.574813E+08	1.310584E-15	8.413792E-17
8	9.514420E+08	3.084545E+04	4.909206E+03	1.000000E+00	9.514420E+08	2.255649E-28	2.619714E-15
9	9.864355E+08	3.140757E+04	4.998670E+03	1.000000E+00	9.864355E+08	1.676146E-28	1.797256E-16
10	1.154409E+09	3.397659E+04	5.407542E+03	1.000000E+00	1.154409E+09	5.764565E-17	1.163198E-15
11	1.839977E+09	4.289495E+04	6.826943E+03	1.000000E+00	1.839977E+09	1.976612E-16	3.595590E-14
12	3.045140E+09	5.518279E+04	8.782614E+03	1.000000E+00	3.045140E+09	7.285839E-17	3.824739E-12
13	4.312754E+09	6.567156E+04	1.045195E+04	1.000000E+00	4.312754E+09	2.561294E-16	3.568461E-11
14	4.468211E+09	6.684468E+04	1.063866E+04	1.000000E+00	4.468211E+09	1.517765E-16	1.616015E-10
15	5.695423E+09	7.546803E+04	1.201111E+04	1.000000E+00	5.695423E+09	1.257675E-17	6.912539E-10
16	8.422989E+09	9.177684E+04	1.460674E+04	1.000000E+00	8.422989E+09	4.477803E-19	1.857973E-15
17	1.143875E+10	1.069521E+05	1.702195E+04	1.000000E+00	1.143875E+10	1.422968E-19	7.019080E-08
18	2.263472E+10	1.504484E+05	2.394460E+04	1.000000E+00	2.263472E+10	3.950147E-19	7.909201E-16
19	2.466459E+10	1.570496E+05	2.499522E+04	1.000000E+00	2.466459E+10	2.002828E-17	9.592725E-06
20	4.219548E+10	2.054154E+05	3.269287E+04	1.000000E+00	4.219548E+10	1.442139E-18	5.547834E-16

- We have requested a normal modes analysis with 20 modes recovered.
- The range is 63Hz to 32,693Hz.
- We would expect that the higher modes will be insignificant in the shock response.

DDAM Analysis (Continued)

DDAM Example

```
 D D A M   A N A L Y S I S   D A T A   D E F I N I T I O N

DDAM DATA SET      = 1

SHIP TYPE          = SURFACE
MOUNTING LOCATION  = DECK
MATERIAL TYPE      = ELASTIC
SUMMATION METHOD   = NRL

TOTAL MASS         = 5.176000E-04
TOTAL WEIGHT       = 2.000006E-01
CONVERSION FACTOR  = 3.864000E+02
```

The listing shows a summary of the user specified analysis control settings

DDAM Analysis (Continued)

VERTICAL (Z) DIRECTED SHOCK SUBCASE 3

M O D A L E F F E C T I V E W E I G H T

MODE NUMBER	CYCLES	PARTICIPATION FACTOR	MODAL WEIGHT	MODAL PERCENT	CUMULATIVE WEIGHT	CUMULATIVE PERCENT
2	3.160362E+02	-1.777455E-02	1.220771E-01	61.0383	1.220771E-01	61.0383
5	1.955474E+03	9.873827E-03	3.767108E-02	18.8355	1.597482E-01	79.8738
10	5.407542E+03	5.776554E-03	1.289362E-02	6.4468	1.726418E-01	86.3206

MASS AVAILABLE = 92.8737 PERCENT
MASS USED = 86.3206 PERCENT

- This listing shows part of the output for Subcase 3, the vertical shock loading.
- Shows the significant individual and cumulative modal weights through the calculated frequencies.
- In our case we have achieved the target modal weight of 80% after 10 modes, i.e. 5408 Hz. Note that we were very close to target after 5 modes (1955 Hz).
- All 20 modes contribute 92.9% weight.
- The cumulative modal weight should be checked in each shock direction to verify the required percentage is achieved.
- Failure to meet the required modal weight requires either increasing the number of desired modes or the frequency range on the EIGRL Bulk Data entry and rerunning the model.

DDAM Analysis (Continued)

DDAM Example

```
VERTICAL (Z) DIRECTED SHOCK                                        SUBCASE 3

                                              P E A K   M O D A L   R E S P O N S E

      MODE      DISPLACEMENT          VELOCITY          ACCELERATION
     NUMBER
        2       3.580498E-05       7.109844E-02       1.411812E+02
        5       1.579561E-06       1.940745E-02       2.384517E+02
       10       1.208442E-07       4.105872E-03       1.395035E+02
```

Peak Modal Response is reported as: peak displacement, velocity and acceleration for each significant mode.

DDAM Analysis (Continued)

DDAM Example

VERTICAL (Z) DIRECTED SHOCK SUBCASE 3

M O D A L R E A C T I O N

MODE NUMBER	CYCLES	PARTICIPATION FACTOR	RESPONSE ACCELERATION	RESPONSE REACTION	INPUT ACCELERATION	INPUT SOURCE
2	3.160362E+02	-1.777455E-02	1.411812E+02	-2.509431E+00	2.055612E+01	VELOCITY
5	1.955474E+03	9.873827E-03	2.384517E+02	2.354430E+00	6.249967E+01	ACCELERATION
10	5.407542E+03	5.776554E-03	1.395035E+02	8.058497E-01	6.249989E+01	ACCELERATION

- **Input Acceleration** = input acceleration in g units derived from DDAMDAT coefficients
- **Source** = the criteria that gave highest input acceleration
  - acceleration – directly from acceleration coefficients
  - velocity – derived from velocity coefficients
  - minimum g – derived from defined minimum g level
- **Participation Factor** (PFACTOR) determines the contribution of each mode
- **Response Acceleration** = peak modal accel = input accel * PFACTOR in fundamental units
- **Response Reaction** = total dynamic forces on the masses = PFACTOR * peak modal accel

DDAM Analysis (Continued)

DDAM Example

VERTICAL (Z) DIRECTED SHOCK SUBCASE 3

T O T A L B A S E R E A C T I O N

COMPONENT	MAXIMUM MODE	REACTION	SRSS	NRL SUM
1	8	0.000000E+00	0.000000E+00	0.000000E+00
2	1	0.000000E+00	0.000000E+00	0.000000E+00
3	2	2.509431E+00	2.488521E+00	4.997952E+00
4	0	0.000000E+00	0.000000E+00	0.000000E+00
5	2	1.831502E+01	5.077361E+00	2.339238E+01
6	1	0.000000E+00	0.000000E+00	0.000000E+00

For each direction:

- Reaction = Mode with maximum dynamic force and value of the force
- SRSS = The SRSS of contributions of the remainder of the modes in that direction
- NRL SUM = The NRL summation of the Peak reaction and the SRSS of the remainder in each direction

DDAM Analysis (Continued)

DDAM Example

VERTICAL (Z) DIRECTED SHOCK SUBCASE 3

D I S P L A C E M E N T   V E C T O R

GRID ID	COORDINATE ID	T1	T2	T3	R1	R2	R3
2	0	0.000000E+00	0.000000E+00	6.518836E-05	0.000000E+00	1.254091E-04	0.000000E+00
3	0	0.000000E+00	0.000000E+00	2.410175E-04	0.000000E+00	2.214736E-04	0.000000E+00
4	0	0.000000E+00	0.000000E+00	4.988605E-04	0.000000E+00	2.900596E-04	0.000000E+00
5	0	0.000000E+00	0.000000E+00	8.126876E-04	0.000000E+00	3.349217E-04	0.000000E+00
- - -							
10	0	0.000000E+00	0.000000E+00	2.771175E-03	0.000000E+00	4.969525E-04	0.000000E+00
11	0	0.000000E+00	0.000000E+00	3.269731E-03	0.000000E+00	4.996089E-04	0.000000E+00

MAXIMUM DISPLACEMENT MAGNITUDE = 3.269731E-03 AT GRID 11

MAXIMUM ROTATION MAGNITUDE = 4.996089E-04 AT GRID 11

Peak displacements are calculated from the peak accelerations and combined using the NRL method

DDAM Analysis (Continued)

DDAM Example

VERTICAL (Z) DIRECTED SHOCK SUBCASE 3

F O R C E S I N B A R E L E M E N T S

ELEMENT ID	DISTANCE	BENDING MOMENT PLANE 1	BENDING MOMENT PLANE 2	SHEAR FORCE PLANE 1	SHEAR FORCE PLANE 2	AXIAL FORCE	TORQUE
1	0.0000	1.874176E-14	2.339238E+01	1.019053E-14	4.997952E+00	0.000000E+00	0.000000E+00
	0.0000	9.916143E-15	1.843065E+01	1.019053E-14	4.997952E+00	0.000000E+00	0.000000E+00
2	0.0000	9.525158E-15	1.842811E+01	8.604592E-15	4.851512E+00	0.000000E+00	0.000000E+00
	0.0000	2.826726E-15	1.386419E+01	8.604592E-15	4.851512E+00	0.000000E+00	0.000000E+00
- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -
9	0.0000	9.467554E-15	2.981920E+00	5.254982E-15	2.021816E+00	0.000000E+00	0.000000E+00
	0.0000	4.301747E-15	9.762868E-01	5.254982E-15	2.021816E+00	0.000000E+00	0.000000E+00
10	0.0000	4.076723E-15	9.660734E-01	4.114474E-15	9.606903E-01	0.000000E+00	0.000000E+00
	0.0000	0.000000E+00	5.994315E-03	4.114474E-15	9.606903E-01	0.000000E+00	0.000000E+00

Forces are calculated in a similar manner

DDAM Analysis (Continued)

VERTICAL (Z) DIRECTED SHOCK SUBCASE 3

S T R E S S E S   I N   B A R   E L E M E N T S

ELEMENT ID	DISTANCE	SX-C	SX-D	SX-E	SX-F	AXIAL	SX-MAX	SX-MIN
1	0.0000	7.016311E+02	7.016311E+02	7.016311E+02	7.016311E+02	0.000000E+00	7.016311E+02	7.016311E+02
	0.0000	5.528090E+02	5.528090E+02	5.528090E+02	5.528090E+02	0.000000E+00	5.528090E+02	5.528090E+02
2	0.0000	5.527326E+02	5.527326E+02	5.527326E+02	5.527326E+02	0.000000E+00	5.527326E+02	5.527326E+02
	0.0000	4.158424E+02	4.158424E+02	4.158424E+02	4.158424E+02	0.000000E+00	4.158424E+02	4.158424E+02
- - -								
9	0.0000	8.943972E+01	8.943972E+01	8.943972E+01	8.943972E+01	0.000000E+00	8.943972E+01	8.943972E+01
	0.0000	2.928275E+01	2.928275E+01	2.928275E+01	2.928275E+01	0.000000E+00	2.928275E+01	2.928275E+01
10	0.0000	2.897641E+01	2.897641E+01	2.897641E+01	2.897641E+01	0.000000E+00	2.897641E+01	2.897641E+01
	0.0000	1.797935E-01	1.797935E-01	1.797935E-01	1.797935E-01	0.000000E+00	1.797935E-01	1.797935E-01

MAXIMUM BAR ELEMENT TOTAL STRESS = 7.016311E+02 AT ELEMENT 1

MINIMUM BAR ELEMENT TOTAL STRESS = 2.897641E+01 AT ELEMENT 10

Stresses are calculated in a similar manner

DDAM Analysis (Continued)

Summary of analysis (vertical shock only)

- Mass of 5.176000E-04 slugs, weight of 0.2 lbs
- 20 Modes were extracted, from 63Hz to 32,693Hz
- All 20 Modes provided 92.9% effective mass
- Mode 1 –10 provided 86.3% effective mass, with a cutoff of 80%
- Ranking of modal effective mass

  Mode 2 61.0%

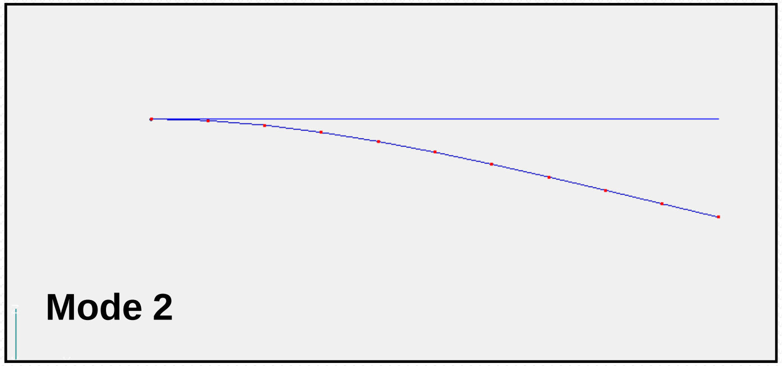
  Mode 5 18.8%

  Mode 10 6.4%

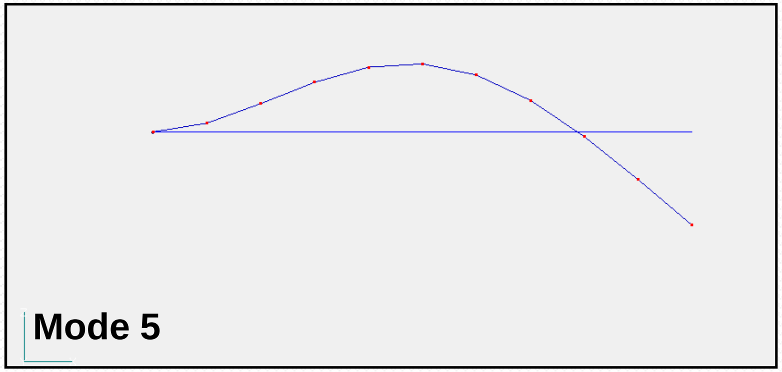
Mode	Frequency	Input Accelerations	Peak Output Acceleration	Total Dynamic Response
2	216Hz	20.6g	141.2 in/s^2	-2.51 lbf
5	196Hz	62.5g	238.5 in/s^2	2.35 lbf
10	541Hz	62.5g	139.5 in/s^2	0.81 lbf

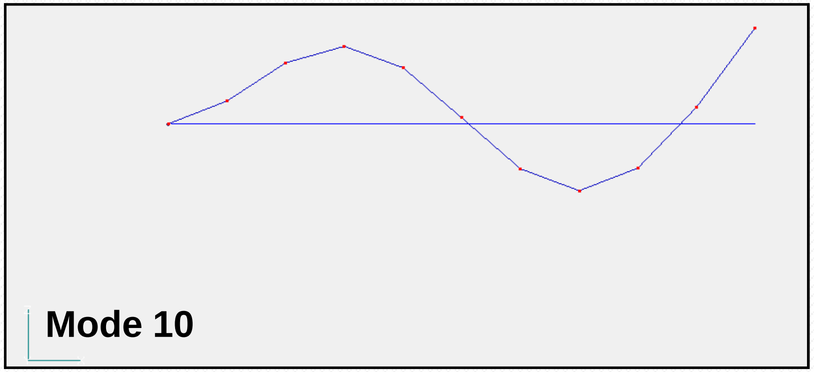
DDAM Analysis (Continued)

Summary of analysis (vertical shock only)



Modes 2, 5 and 10 are the only modes to show displacement in the vertical plane





DDAM Analysis (Continued)

Summary of analysis (vertical shock only)

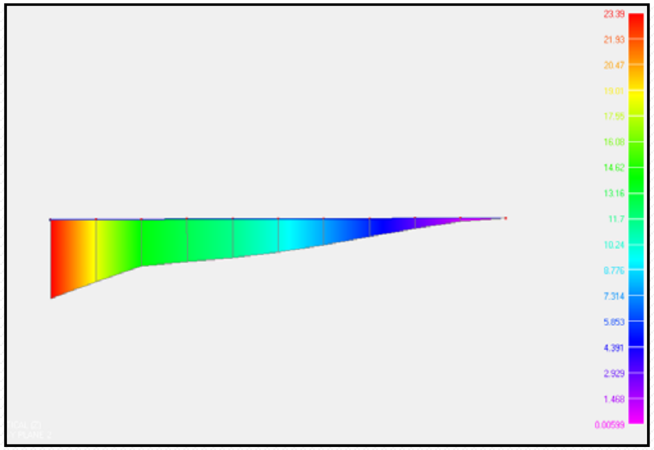
T O T A L   B A S E   R E A C T I O N

COMPONENT	MAXIMUM MODE	REACTION	SRSS	NRL SUM
1	8	0.000000E+00	0.000000E+00	0.000000E+00
2	1	0.000000E+00	0.000000E+00	0.000000E+00
3	2	2.509431E+00	2.488521E+00	4.997952E+00
4	0	0.000000E+00	0.000000E+00	0.000000E+00
5	2	1.831502E+01	5.077361E+00	2.339238E+01
6	1	0.000000E+00	0.000000E+00	0.000000E+00

- The Total Base Reaction Table confirms there are no contributions from other component directions other than 3 and 5 (vertical and pitch) and that mode 2 response is maximum in both.
- The total vertical reaction is 5 lbf, 50% from the peak mode value and 50% from the SRSS of the other modes.
- The total pitch reaction is 23.4 lbf -in , 18.3 lbf-in from the peak, 5.1 lbf -in from the SRSS of the other modes

DDAM Analysis (Continued)

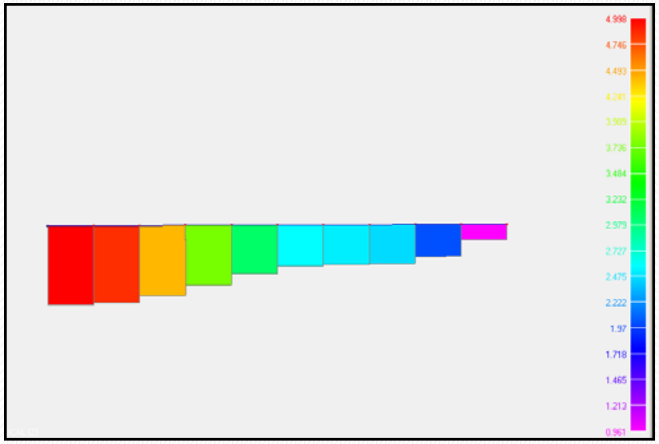
Summary of analysis (vertical shock only)



NEiNASTRANModeler Results Subcase 3

Peak Bending Moment Diagram

Maximum value 23 lbf-in at root



Peak Shear Force Diagram

Maximum value 5 lbf at root

AGENDA

- MODAL EFFECTIVE MASS THEORY
- DDAM BACKGROUND.
- SIMPLE DDAM ANALYSIS
- **MODAL DATABASE USAGE**
- BRACKET DDAM ANALYSIS – CHASING MODAL EFFECTIVE MASS
- MODESET USAGE
- ENGINE DECK CRADLE - LARGE SCALE ANALYSIS
- DDAM STRESSES

Modal Database Usage

- Simple Modal Data save and re-use option
- Contains Modes, Frequencies, PF’s, MEM’s – all modal data
- Very big savings in CPU time are possible with all Modal based response methods as the main burden is always the calculation of the Modal data
- Parameter:

MODALDATABASE, *option*

where *option* is

DELETE = Modal database is deleted

STORE = Modal database is stored

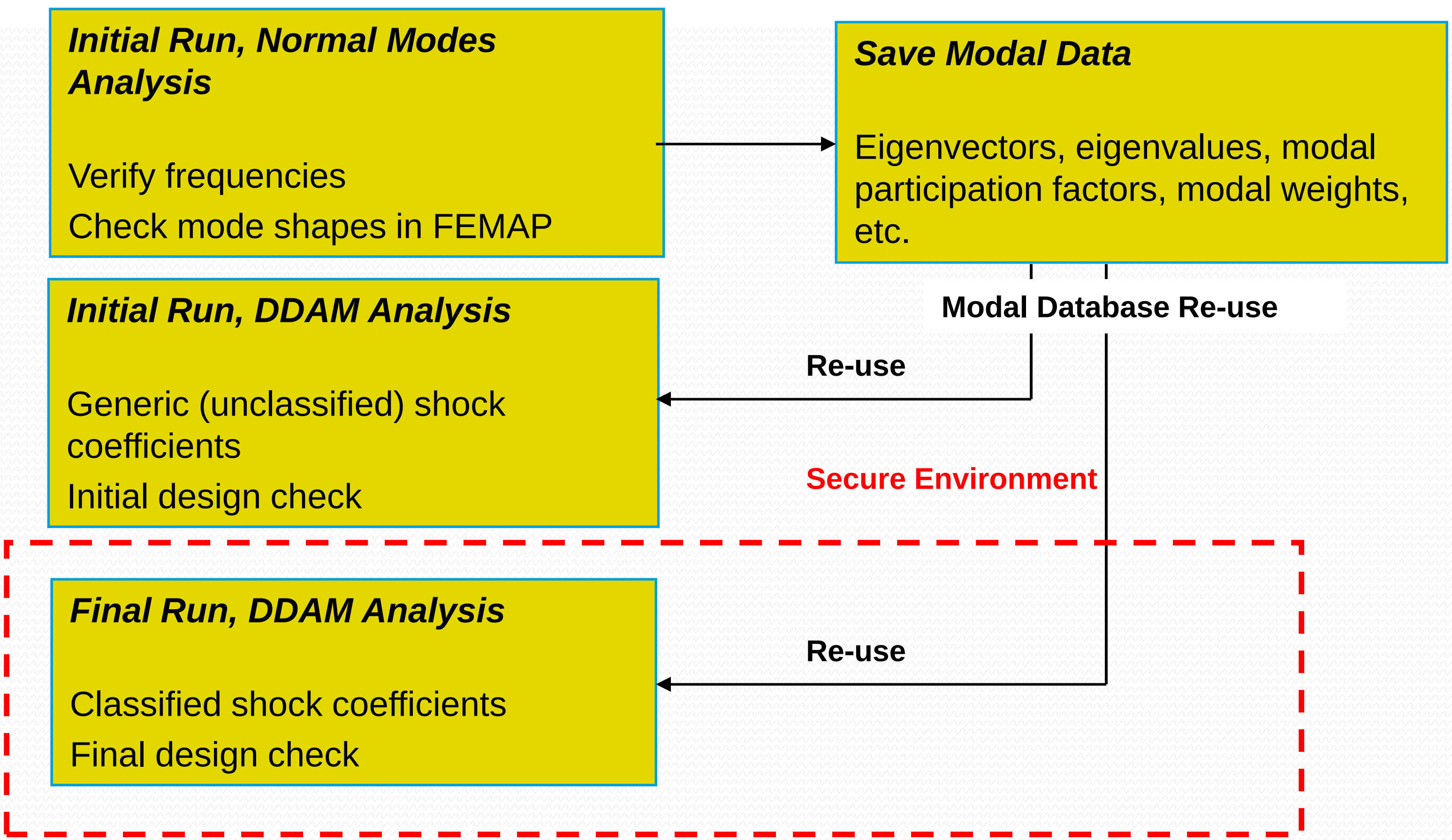
FETCH = Modal database is retrieved

(default is DELETE)

The data is stored in a file called *jobname*.mdb (may be specified using **MODALDATFILE** directive)

Modal Database Usage

The example shows running modal based DDAM analyses



Modal Database Usage

Multi Phase DDAM

Added multi-phase DDAM operation capability:

A multi-phase DDAM operation capability has been added to improve productivity in a mixed secured and unsecured environment.

The integrity of the DDAM coefficients is essential and this feature preserves this, while allowing the user more flexibility.

A new parameter controls which phase of a DDAM analysis is to be run.

This allows an initial (phase 1) DDAM checkout run to be carried out in an unsecured environment; the run can then be restarted in a secure environment using the Modal database (phase 2).

A new DDAM database has been created which allows storage of the shock input G versus frequency spectra calculated from the DDAM coefficients.

This is the only file which needs to be exported from the secure environment, and is easily verifiable for content. The final phase, phase 3 , is then to calculate the DDAM responses in the unsecured environment.

Modal Database Usage

Multi Phase DDAM

Added multi-phase DDAM operation capability:

1 – Phase 1 DDAM operations consisting of an eigenvalue extraction analysis and a modal database store (*filename.MDB* is generated).

2 – Phase 2 DDAM operations consisting of a modal database fetch, the response/shock spectrum generation using the DDAMDAT Bulk Data entry input, and a DDAM database store (*filename.DDB* is generated).

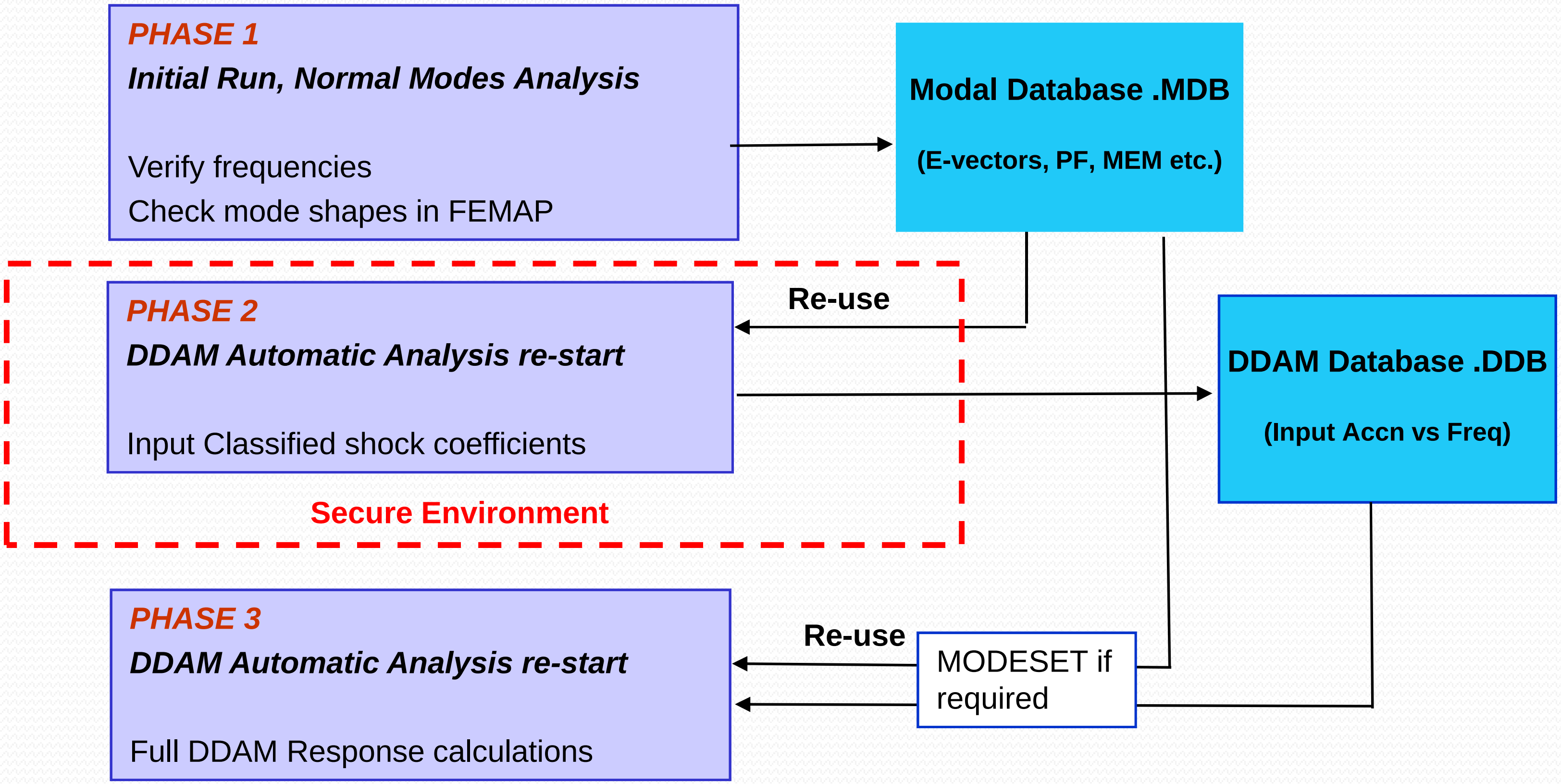
3 – Phase 3 DDAM operations consisting of a DDAM database fetch and grid point and element results processing.

```
SURFACE SHIP
HULL MOUNTED STRUCTURE
 8.0000000000+01
 3.8650000000+02
      20
       1
FORWARD-AFT (X) DIRECTED SHOCK
      20
 1.0960133665+02, 2.3190000004+04
 1.1668544295+02, 2.3199447718+04
 2.0836054355+02, 2.3190000383+04
 2.2832418716+02, 2.3190062197+04
 2.6878497329+02, 2.3190000000+04
 3.0950524327+02, 2.3190132911+04
 3.1928742806+02, 2.3190000005+04
 4.3291531753+02, 2.3190000007+04
 4.4358877284+02, 2.3190000008+04
 4.5384360061+02, 2.3190005344+04
 5.5116364945+02, 2.3190000003+04
 5.6815992589+02, 2.3190000005+04
 5.9211583358+02, 2.3190000000+04
 6.6682210047+02, 2.3190000000+04
 6.9201546050+02, 2.3191131068+04
 7.1491688393+02, 2.3191562356+04
 7.4530546799+02, 2.3190001108+04
 8.6909539139+02, 2.3190000272+04
 9.0200288256+02, 2.3190000296+04
 9.3009836269+02, 2.3190000025+04
-1
       2
ATHWARTSHIP (Y) DIRECTED SHOCK
      20
 1.0960133665+02, 4.4172779130+03
 1.1668544295+02, 4.2889643949+03
```

Modal Database Usage

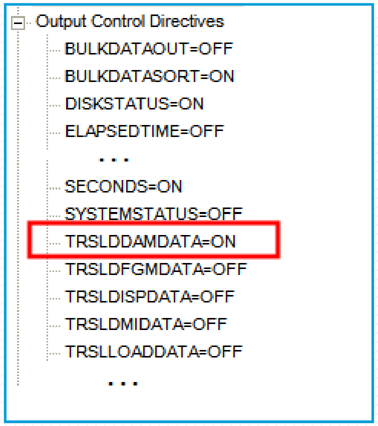
Multi Phase DDAM

Added multi-phase DDAM operation capability:



Enhanced DDAM output –shock curve

Enhanced DDAM output for shock curve (Acceleration vs Frequency):

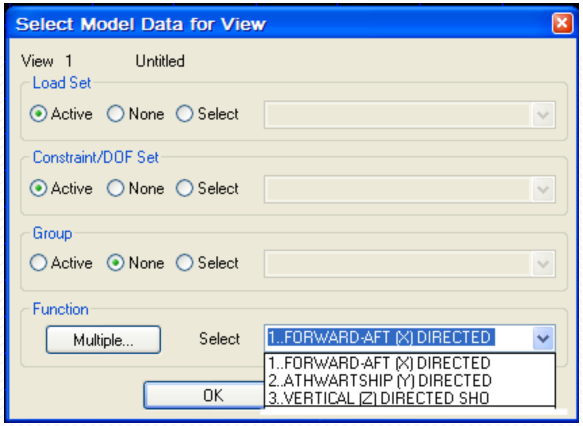


Initialization setting in the Editor

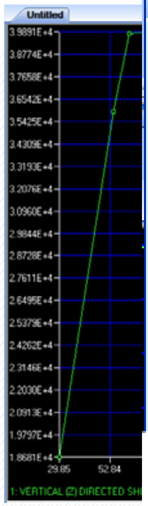
```
$
$ OUTPUT PRODUCED BY NEiNASTRAN VERSION 9.1.0.181   14:46  09/06/07
$
$-------2-------3-------4-------5-------6-------7-------8-------9-------0-------
$
$ FORWARD-AFT (X) DIRECTED SHOCK
$
TABLED1    16627
           29.8490 14096.0 54.3556 25641.4 61.5876 27804.0 70.9598 33483.8
           73.3611 34637.6 112.698 53220.7 123.550 56846.1 133.238 56846.1
           133.685 56866.9 134.473 56848.0 136.011 56846.7 136.472 56848.4
           141.729 56846.2 142.295 56846.2 145.685 56848.6 159.436 56846.1
           163.190 56846.2 177.277 56847.7 211.009 56846.3 224.775 56846.1
           227.581 56846.1 233.991 56960.6 246.709 56848.1 249.495 56846.3
           252.201 56848.6 253.651 56846.3 266.392 56847.0 268.853 56846.6
           277.157 56889.7 278.208 56847.3 282.453 56861.0 288.817 56846.2
           304.547 56846.7 316.788 56846.1 323.809 56846.5 327.720 56853.4
           339.144 56850.7 342.966 56852.9 343.827 56846.6 351.672 56852.6
               ENDT
$
$ ATHWARTSHIP (Y) DIRECTED SHOCK
$
TABLED1    16628
           29.8490 16909.5 54.3556 28982.0 61.5876 34827.4 70.9598 40187.3
           73.3611 41548.9 112.698 63846.4 123.550 69990.8 133.238 71050.5
           133.685 71050.8 134.473 71052.6 136.011 71050.5 136.472 71050.9
           141.729 71056.5 142.295 71063.5 145.685 71050.5 159.436 71050.5
           163.190 71050.8 177.277 71050.5 211.009 71050.5 224.775 71050.5
           227.581 71050.5 233.991 71050.7 246.709 71052.7 249.495 71052.2
           252.201 71050.5 253.651 71050.7 266.392 71050.5 268.853 71051.7
           277.157 71050.5 278.208 71050.7 282.453 71050.5 288.817 71051.0
           304.547 71050.6 316.788 71052.3 323.809 71050.5 327.720 71050.5
           339.144 71053.9 342.966 71050.8 343.827 71051.8 351.672 71051.8
               ENDT
$
$ VERTICAL (Z) DIRECTED SHOCK
$
TABLED1    16629
           29.8490 18680.8 54.3556 35903.8 61.5876 39805.9 70.9598 39890.5
           73.3611 39871.6 112.698 39801.5 123.550 39808.8 133.238 39801.2
           133.685 39800.8 134.473 39800.9 136.011 39800.8 136.472 39800.8
           141.729 39801.2 142.295 39802.2 145.685 39800.8 159.436 39800.8
           163.190 39803.3 177.277 39800.8 211.009 39800.8 224.775 39800.8
           227.581 39800.8 233.991 39800.8 246.709 39800.8 249.495 39800.8
           252.201 39800.8 253.651 39800.8 266.392 39800.8 268.853 39800.8
           277.157 39800.8 278.208 39800.8 282.453 39800.8 288.817 39800.8
           304.547 39800.8 316.788 39800.8 323.809 39800.8 327.720 39800.8
           339.144 39801.0 342.966 39801.4 343.827 39800.8 351.672 39801.8
           ENDT
```

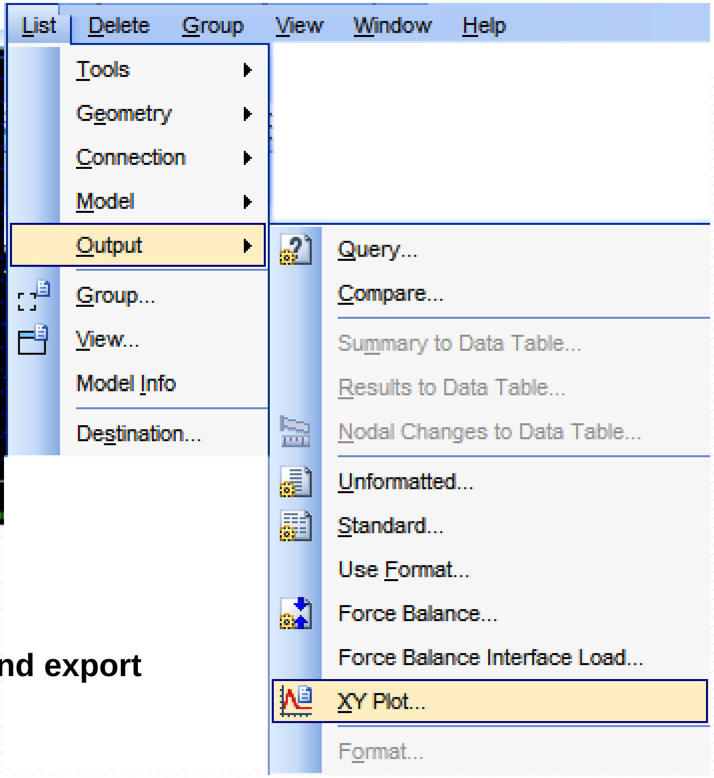
Auxiliary output to .BDF file

Enhanced DDAM output –shock curve



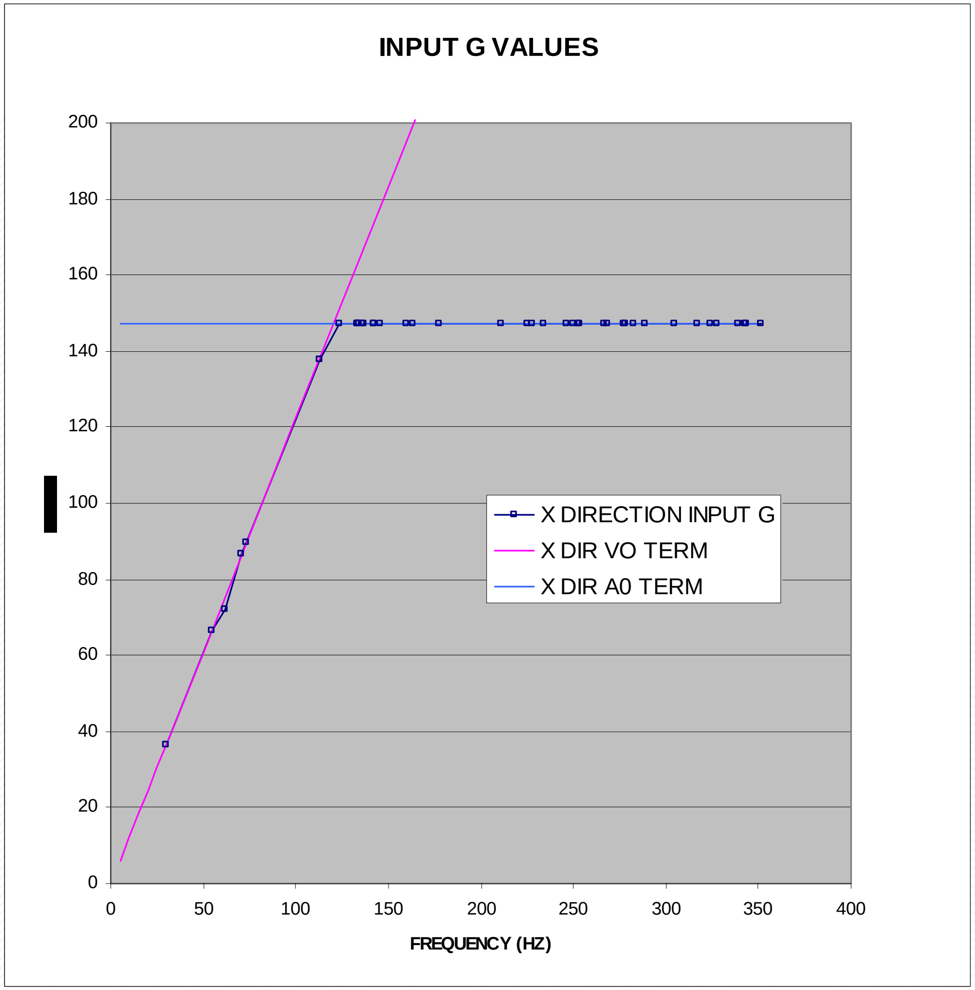
Shock curves available in .FNO file





Can be read into FEMAP for plotting and export

Enhanced DDAM output –shock curve



Calculated Input shock curve versus V0 and A0 calculation

AGENDA

- MODAL EFFECTIVE MASS THEORY
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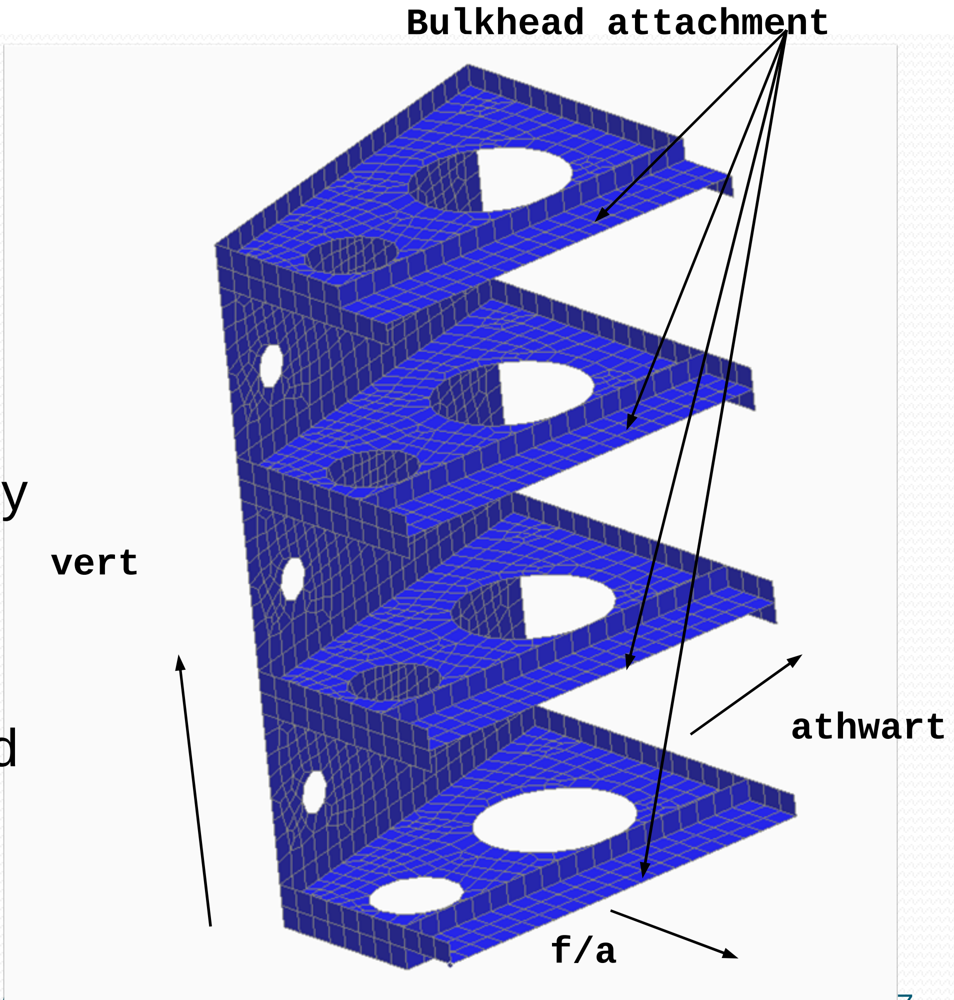
- MODESET USAGE
- ENGINE DECK CRADLE - LARGE SCALE ANALYSIS
- DDAM STRESSES

Effective Mass

- For a simple model, a few modes are adequate to represent > 80% Effective Mass.
- In a complex model like the one shown here we have many more DOF’s and many more available modes.
- How many modes are required to achieve 80% Effective Mass?

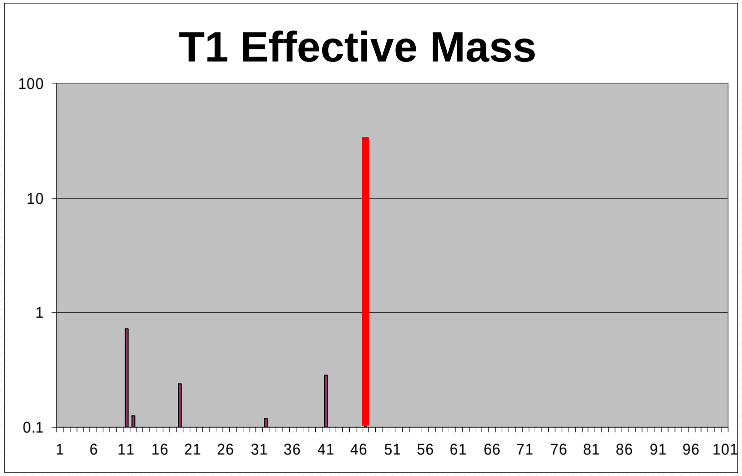


Results of a DDAM analysis with 100 Modes

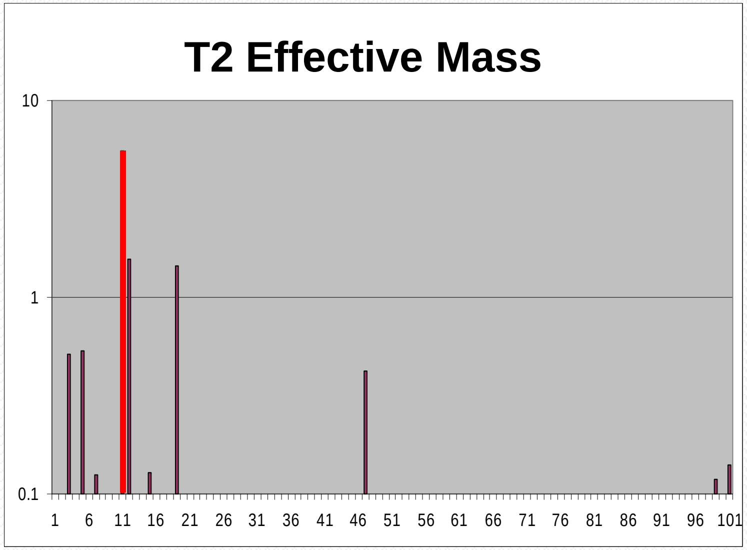
DIRECTION	TOTAL MASS	MODAL EFF MASS	PERCENT
1 Fore Aft	50.74	34.20	67.40
2 Athwart	50.74	10.85	21.38
3 Vertical	50.74	46.33	91.31

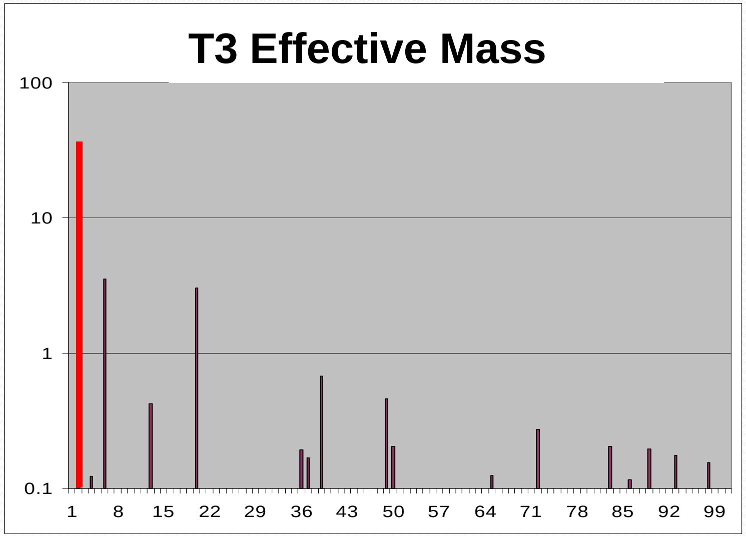
- The Frequency range is given by Mode 1 at 13.9 Hz to Mode 100 at 267 Hz
- The vertical direction is well represented. Inspection of the modes shows that the cantilever bending of each web dominates.
- Fore Aft direction modes are rich in back panel bending.
- Athwartship modes are limited to swaying/shearing modes of the webs

Effective Mass (Continued)

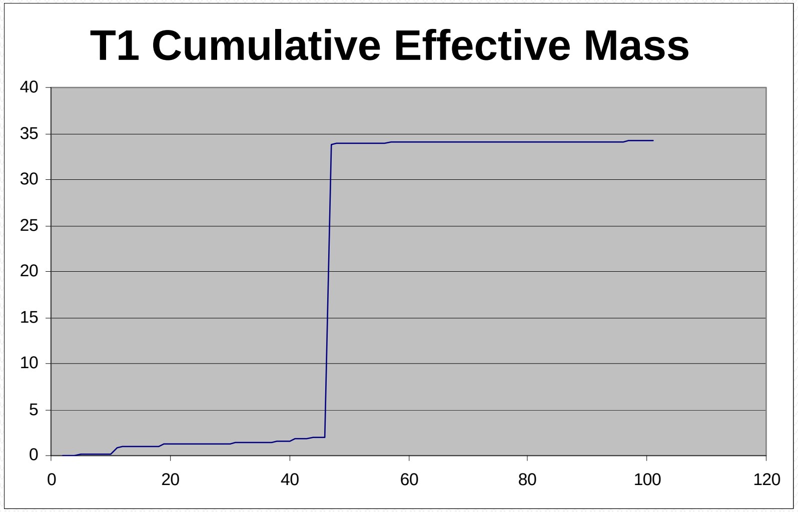


- The dominant Modes are shown in red
- The distribution of Effective Mass for each direction can be seen on the log/lin scale

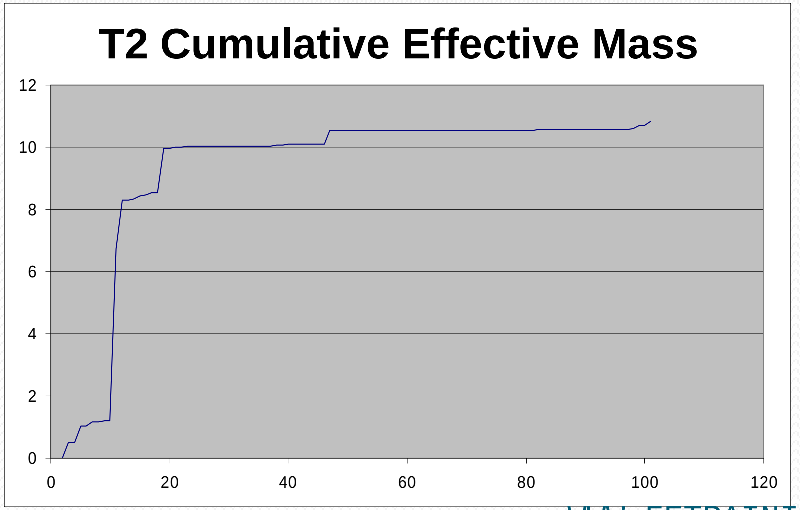


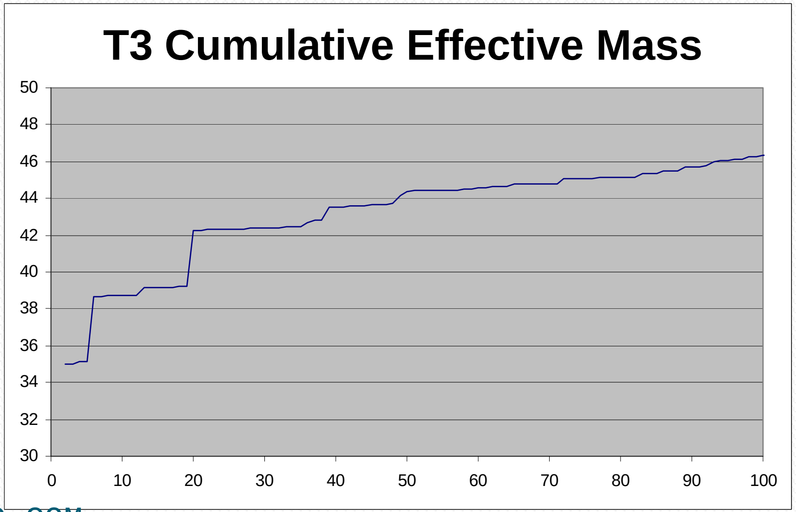


Effective Mass

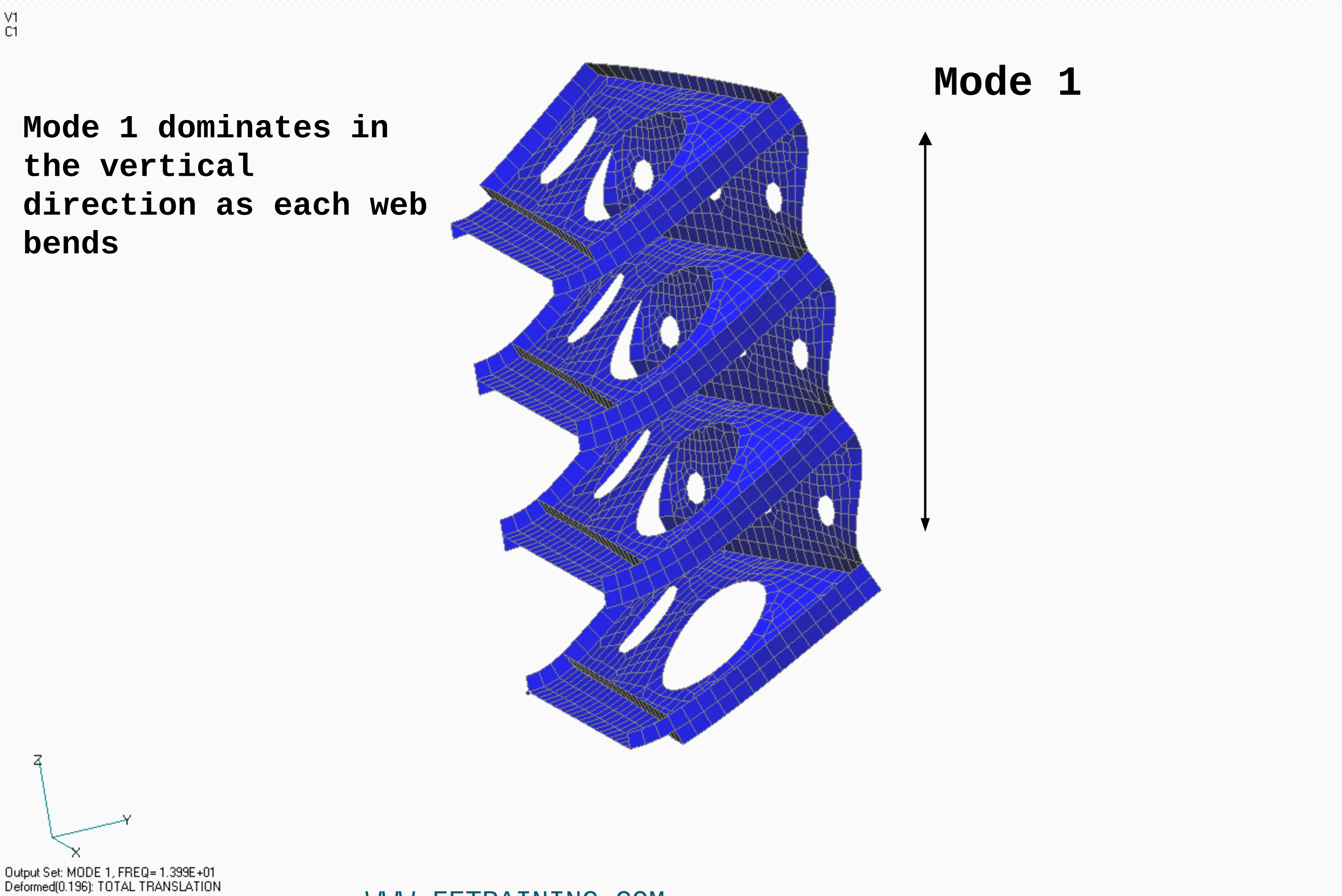


Another way to look at it...





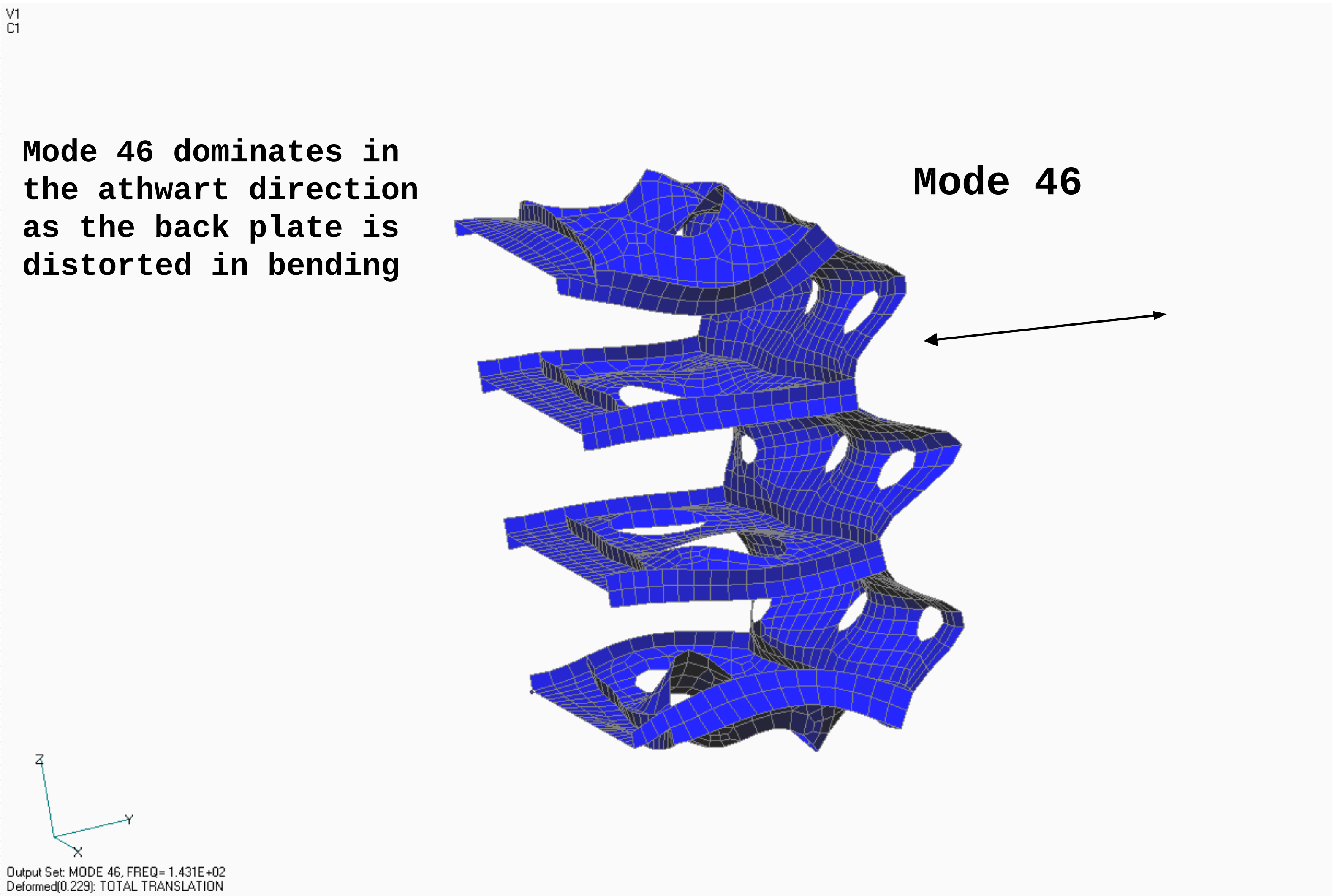
What the Modes Look Like



Mode 1 dominates in the vertical direction as each web bends

What the Modes Look Like (Continued)

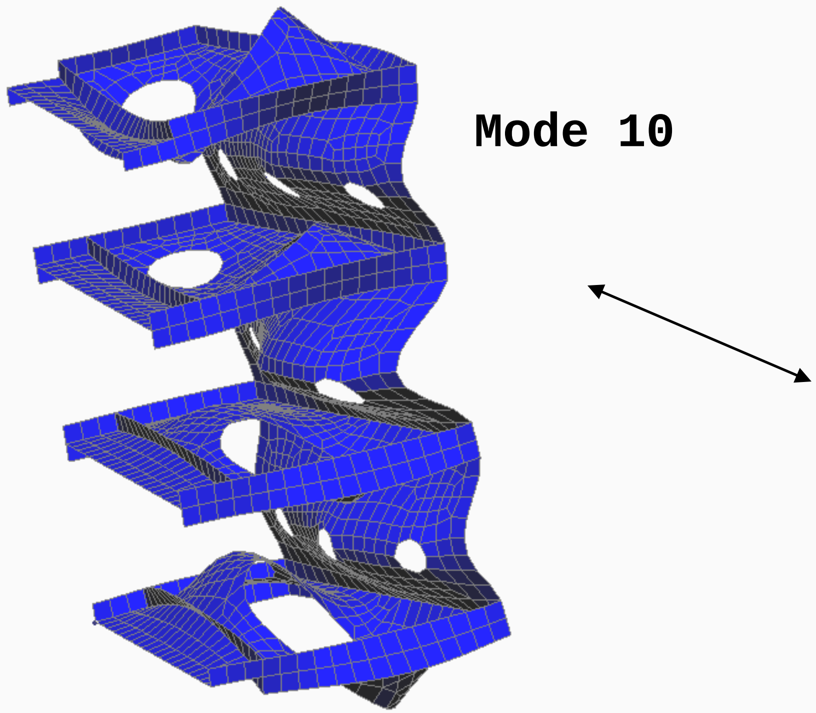
Mode 46 dominates in the athwart direction as the back plate is distorted in bending



What the Modes Look Like (Continued)

V1
C1

Mode 10 dominates in the fore aft direction as the webs are distorted in shear

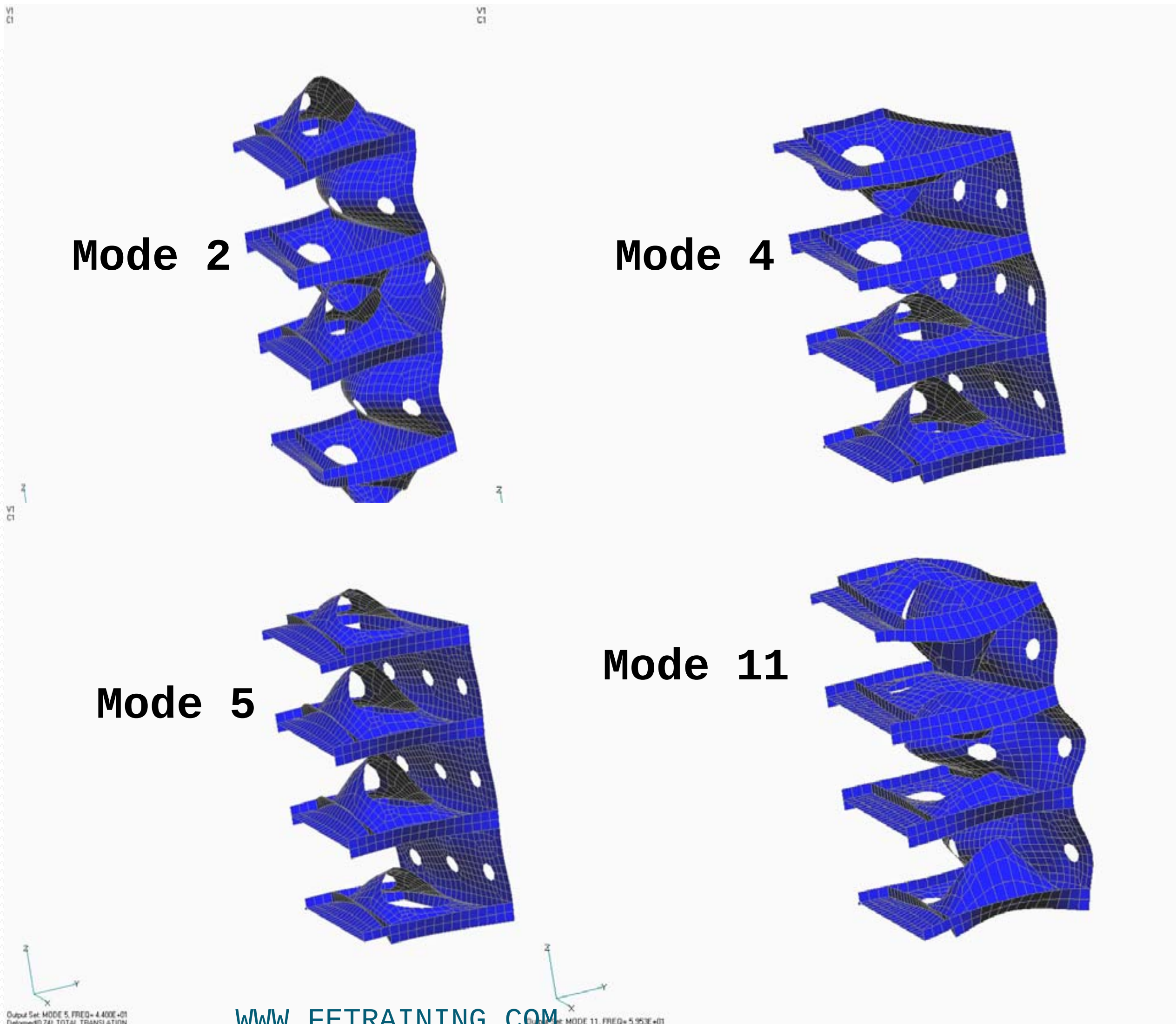


Mode 10

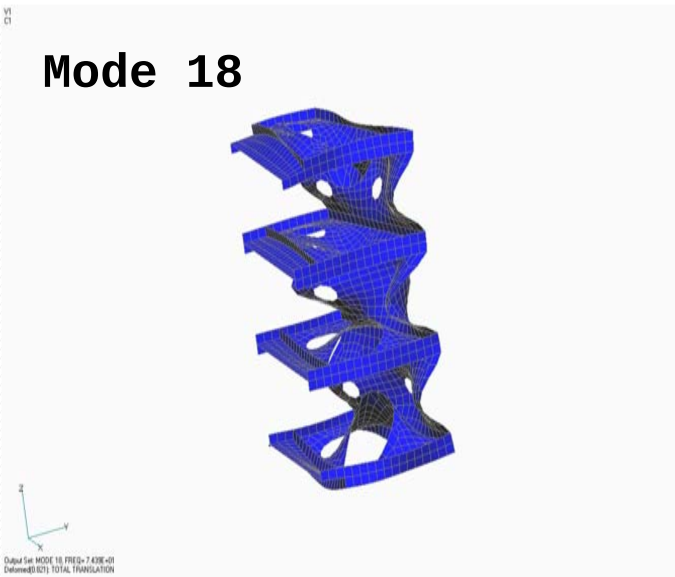
Z
Y
X

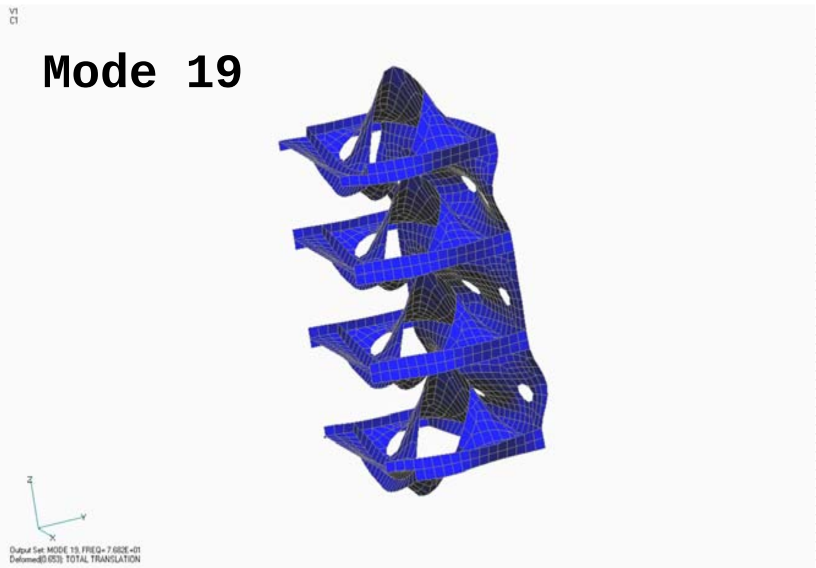
Output Set: MODE 10, FREQ= 5.510E+01
Deformed(0.611): TOTAL TRANSLATION

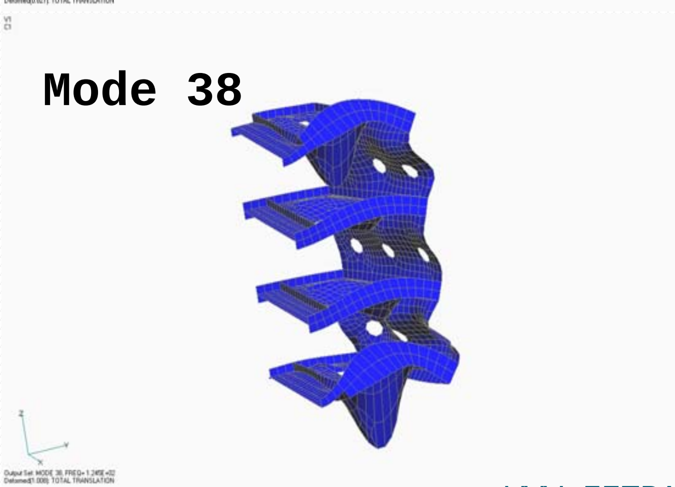
Other Dominant Modes



Other Dominant Modes (Continued)







Formal Numbers from the DDAM Analysis

Fore - Aft

DDAM ANALYSIS OF A DECK MOUNTED STRUCTURE ON A SURFACE SHIP

FORWARD-AFT (X) DIRECTED SHOCK SUBCASE 1

M O D A L E F F E C T I V E W E I G H T

MODE NUMBER	CYCLES	PARTICIPATION FACTOR	MODAL WEIGHT	MODAL PERCENT	CUMULATIVE WEIGHT	CUMULATIVE PERCENT
46	1.431045E+02	5.650084E+00	1.233841E+04	62.9119	1.233841E+04	62.9119
10	5.510104E+01	8.530688E-01	2.812662E+02	1.4341	1.261968E+04	64.3460
40	1.256555E+02	-5.315739E-01	1.092136E+02	0.5569	1.272889E+04	64.9029
18	7.438546E+01	4.891139E-01	9.246331E+01	0.4715	1.282136E+04	65.3744
11	5.952799E+01	3.548671E-01	4.867220E+01	0.2482	1.287003E+04	65.6225
31	1.079753E+02	-3.448361E-01	4.595947E+01	0.2343	1.291599E+04	65.8569
43	1.357897E+02	-3.143244E-01	3.818613E+01	0.1947	1.295417E+04	66.0516
37	1.232318E+02	-2.934976E-01	3.329344E+01	0.1698	1.298747E+04	66.2213
4	3.986048E+01	-2.397935E-01	2.222410E+01	0.1133	1.300969E+04	66.3346
51	1.534952E+02	2.377015E-01	2.183802E+01	0.1113	1.303153E+04	66.4460
96	2.557597E+02	-2.289278E-01	2.025566E+01	0.1033	1.305178E+04	66.5493
2	3.226531E+01	2.279338E-01	2.008016E+01	0.1024	1.307186E+04	66.6517
56	1.605290E+02	-2.071893E-01	1.659145E+01	0.0846	1.308846E+04	66.7363
47	1.474133E+02	1.992237E-01	1.534022E+01	0.0782	1.310380E+04	66.8145
14	6.732457E+01	1.856066E-01	1.331485E+01	0.0679	1.311711E+04	66.8824

--- (DATA CONTINUES) ---

Formal Numbers from the DDAM Analysis (Continued)

Athwart

M O D A L   E F F E C T I V E   W E I G H T

MODE NUMBER	CYCLES	PARTICIPATION FACTOR	MODAL WEIGHT	MODAL PERCENT	CUMULATIVE WEIGHT	CUMULATIVE PERCENT
10	5.510104E+01	-2.355943E+00	2.145255E+03	10.9384	2.145255E+03	10.9384
11	5.952799E+01	-1.247536E+00	6.015278E+02	3.0671	2.746783E+03	14.0055
18	7.438546E+01	-1.198498E+00	5.551678E+02	2.8307	3.301951E+03	16.8362
4	3.986048E+01	7.313262E-01	2.067149E+02	1.0540	3.508666E+03	17.8902
2	3.226531E+01	-7.159604E-01	1.981196E+02	1.0102	3.706785E+03	18.9004
46	1.431045E+02	6.491813E-01	1.628851E+02	0.8305	3.869670E+03	19.7309
100	2.666761E+02	3.760780E-01	5.466448E+01	0.2787	3.924335E+03	20.0097
14	6.732457E+01	-3.588405E-01	4.976824E+01	0.2538	3.974103E+03	20.2634
6	4.682373E+01	-3.539971E-01	4.843383E+01	0.2470	4.022537E+03	20.5104
98	2.579296E+02	-3.434915E-01	4.560175E+01	0.2325	4.068139E+03	20.7429
16	6.944919E+01	2.627076E-01	2.667440E+01	0.1360	4.094813E+03	20.8789
20	7.943116E+01	2.350775E-01	2.135854E+01	0.1089	4.116172E+03	20.9878
39	1.253063E+02	-1.805027E-01	1.259264E+01	0.0642	4.128764E+03	21.0520
81	2.243995E+02	1.415805E-01	7.747412E+00	0.0395	4.136512E+03	21.0915
8	5.115970E+01	-1.406313E-01	7.643871E+00	0.0390	4.144156E+03	21.1305
13	6.648926E+01	-1.396246E-01	7.534826E+00	0.0384	4.151690E+03	21.1689
80	2.168292E+02	-1.173435E-01	5.321909E+00	0.0271	4.157012E+03	21.1960

--- (DATA CONTINUES) ---

Formal Numbers from the DDAM Analysis (Continued)

Vertical

M O D A L   E F F E C T I V E   W E I G H T

MODE NUMBER	CYCLES	PARTICIPATION FACTOR	MODAL WEIGHT	MODAL PERCENT	CUMULATIVE WEIGHT	CUMULATIVE PERCENT
1	1.398901E+01	5.918081E+00	1.353665E+04	69.0216	1.353665E+04	69.0216
5	4.399860E+01	1.883970E+00	1.371821E+03	6.9947	1.490847E+04	76.0163
19	7.682255E+01	-1.738562E+00	1.168234E+03	5.9567	1.607671E+04	81.9730
38	1.245205E+02	8.206635E-01	2.603033E+02	1.3273	1.633701E+04	83.3002
48	1.475497E+02	6.772558E-01	1.772780E+02	0.9039	1.651429E+04	84.2041
12	6.315209E+01	-6.491054E-01	1.628471E+02	0.8303	1.667714E+04	85.0345
71	1.989739E+02	-5.210544E-01	1.049339E+02	0.5350	1.678207E+04	85.5695
82	2.250989E+02	-4.529868E-01	7.930867E+01	0.4044	1.686138E+04	85.9739
49	1.515428E+02	-4.510805E-01	7.864255E+01	0.4010	1.694002E+04	86.3749
88	2.369557E+02	-4.424514E-01	7.566250E+01	0.3858	1.701568E+04	86.7607
35	1.202262E+02	-4.396944E-01	7.472251E+01	0.3810	1.709041E+04	87.1417
92	2.419596E+02	-4.190874E-01	6.788264E+01	0.3461	1.715829E+04	87.4878

--- (DATA CONTINUES) ---

How can we easily characterize the important modes?

Table 1. Summary of All Modes Contributing > 1%

Direction		Modes
1	Fore-Aft	10,46
2	Athwart	2,4,10,11,18
3	Vertical	1,5,19,38

- The 11 distinct modes here should be able to represent the response of the structure

How can we easily characterize the important modes?

Table 2. Summary of Modes Contributing Top 10 Effective Mass in Each Direction

Direction		Modes
1	Fore Aft	46,10,40,18,11,31,43,37,4,51
2	Athwart	10,11,18,4,2,46,100,14,6,98
3	Vertical	1,5,19,38,48,12,71,82,49,88

- The 25 distinct modes ensure a good spread of modes from each direction. It will avoid elimination of directions with low total effective mass.

AGENDA

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- DDAM STRESSES

MODESET Enhancement

- NEiNASTRANimplementation now allows simplification of modes used in DDAM (and all Modal Response Analysis) using these ideas

- Options:

  - Automatically select top n effective modes in each direction. (User defines n). The result is as Table 1.

  - Automatically select all modes contributing > xx % Effective Mass in any direction. (user defines xx). The result is as Table 2.

  - User Picks individual modes to be used in the analysis (requires user skill and verification)

MODESET Enhancement

- The user is able to select the modes that will be included in a DDAM analysis (or any modal solution)
- This is via the following options:
  - User specifies a collection of mode id's to be used on a SET entry (less than or equal to no of modes on EIGRL)
  - User specifies the top N modes for each direction sorted by modal contribution (default 20 or max modes on EIGRL card).
  - User specifies a maximum % contribution to modal effective mass. Only those modes that equal or exceed this value will be used.
- The options 2 and 3 allow for quick specification of modes in a general case and will avoid the need for manual inspection of all of the modes.

MODESET Enhancement

New case control

MOESET = Option, Value

Option is SET, TOP or PERCENT and Value is either an integer or real.

Examples...

- MODSET, TOP, n
- MODESET, PERCENT, x.x
- MODESET, SET, n

MODESET Enhancement

- This enhancement to selectively choose Modes for a DDAM analysis was requested by NAVSEA for a different purpose.
- But is very applicable to general usage with large complex models.

MODESET Enhancement

Added EXCLUDE and INCLUDE options to the MODESET Case Control command:

Primarily for use in DDAM analysis, but with applications in all response analysis, this feature allows a user to quickly isolate a few important modes from a large number of modes and test the response.

Combined with the Modal Database restart feature, it becomes a fast and powerful investigation tool.

Added an EXCLUDE option to the MODESET Case Control command. EXCLUDE allows the specification of a SET of modes that are to be excluded from the extracted set.

Also, added an INCLUDE option which is functionally the same as SET.

MODESET Enhancement

- DDAM analysis models will get bigger and bigger.
- Large models versus modes required to achieve target Effective Mass will continue to be debated.
- MODESET is very powerful, particularly when used with the Modal Database

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Guidance Documentation

- Original DDAM research work and development at NRL in the early 1960's by O'Hara et al.
- Original NAVSEA report version released in May 1976
  - formalized original work
  - all calculations carried out by hand
- The 'bible' for DDAM analysis is current NAVSEA report 9098-LP-000-3010 Rev.1 Sept. 1995
- Scope of Analysis had increased significantly over this period. 1995 document reflected this and introduced discussion on:
  - Closely Spaced Modes
  - Multi-Directional Response
  - Dynamic Reduction Techniques
  - Mode Selection Criteria

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Guidance Documentation

- However modeling techniques presented in 1995 were very different from current methodologies
- Lumped mass representation
  - Allowed simple ‘manual’ assumptions to be made
  - 50% base mass contribution is prime example
  - Eliminated local modes due to distributed mass
- Bar stiffness representation
  - Frames, girders etc. all heavily idealized
  - Removed many local modes present in shell (or solid!) idealizations
- Small Models
  - Small number of modes
  - DDAM criteria of high contributing mass (MEM) readily achievable

Guidance Documentation

- Two FEM examples available in current NAVSEA report 9098-LP-000-3010 Rev.1 Sept. 1995
    - Simple cabinet on foundation – single degree of freedom
    - Equipment rack multi degree of freedom
- Stated purpose is to illustrate some concepts, not to provide examples of best practice

Equipment Specification

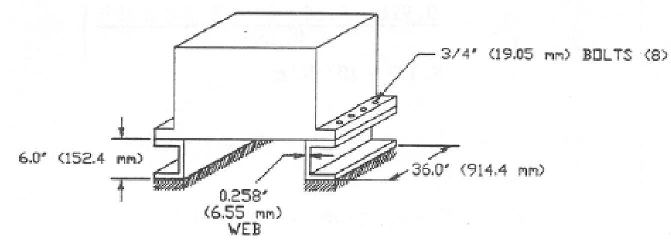
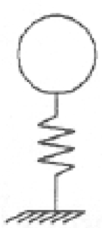


Figure 4-2. Single Degree of Freedom Foundation Model

For the system shown in Figure 4-2, assume the following characteristics:

Equipment Weight	- 5000 lbs (22.241 kN)
Foundation Weight	- 720 lbs (3.202 kN) each beam
Equipment Location	- Deck
Category of Shock Design Value	- Elastic-Plastic
Foundation Material	- Steel, $E = 30 \times 10^6$ PSI (210×10^9 Pa)

Idealization

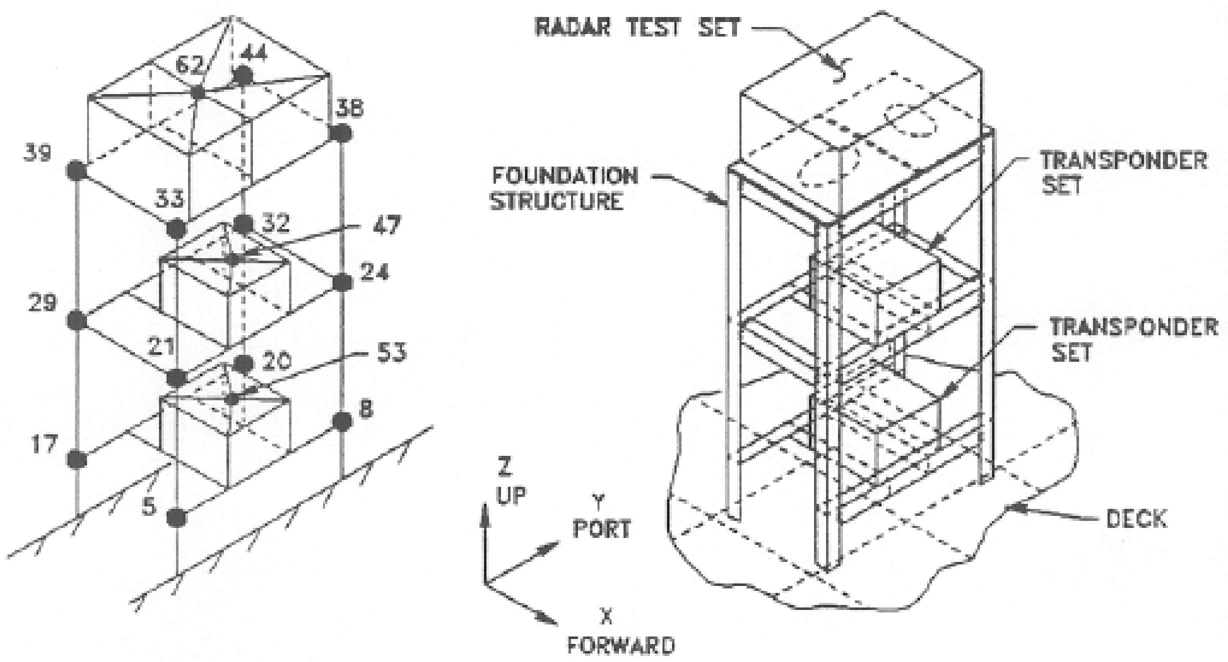


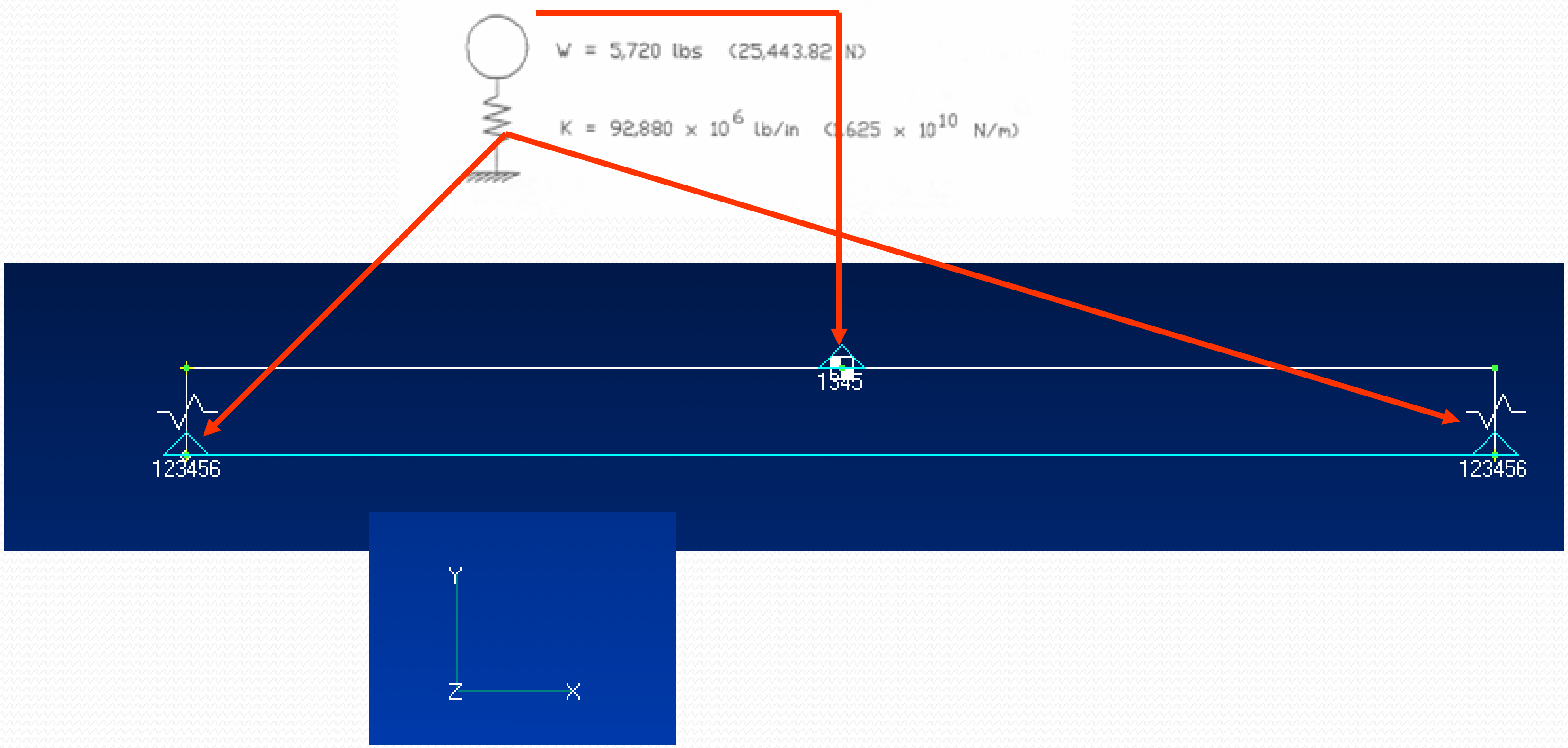
$W = 5{,}720$ lbs (25,443.82 N)

$K = 92{,}880 \times 10^6$ lb/in (1.625×10^{10} N/m)

Equipment Specification

Idealization





W = 5,720 lbs (25,443.82 N)
K = 92,880 x 10^6 lb/in (1.625 x 10^10 N/m)
1545
123456
123456
Y
Z
X

R E A L   E I G E N V A L U E S

MODE NUMBER	EIGENVALUE	RADIANS	CYCLES	GENERALIZED MASS	GENERALIZED STIFFNESS	ORTHOGONALITY LOSS
1	6.267756E+06	2.503549E+03	3.984522E+02	1.000000E+00	6.267756E+06	0.000000E+00

$= 2,504 \frac{rad}{sec}$

NEiNASTRAN SUBCASE 1

M O D A L   P A R T I C I P A T I O N   F A C T O R S

MODE NUMBER	T1	T2	T3	R1	R2	R3
1	0.000000E+00	3.849506E+00	0.000000E+00	0.000000E+00	0.000000E+00	5.774260E+01

NEiNASTRAN SUBCASE 1

M O D A L   E F F E C T I V E   M A S S

MODE NUMBER	T1	T2	T3	R1	R2	R3
1	0.000000E+00	1.481870E+01	0.000000E+00	0.000000E+00	0.000000E+00	3.334207E+03
TOTAL	0.000000E+00	1.481870E+01	0.000000E+00	0.000000E+00	0.000000E+00	3.334207E+03

NEiNASTRAN SUBCASE 1

P E R C E N T   M O D A L   M A S S

DIRECTION	TOTAL	MODAL	PERCENT
1	1.481870E+01	0.000000E+00	0.00
2	1.481870E+01	1.481870E+01	100.00
3	1.481870E+01	0.000000E+00	0.00
4	5.927480E+01	0.000000E+00	0.00
5	3.334207E+03	0.000000E+00	0.00
6	3.393482E+03	3.334207E+03	98.25

D D A M   A N A L Y S I S   D A T A   D E F I N I T I O N

```
DDAM DATA SET      = 1

SHIP TYPE          = SURFACE
MOUNTING LOCATION  = DECK
MATERIAL TYPE      = ELASTIC-PLASTIC
SUMMATION METHOD   = NRL
MINIMUM G          = 6.000000E+00

TOTAL MASS         = 1.481870E+01
TOTAL WEIGHT       = 5.725946E+03
CONVERSION FACTOR  = 3.864000E+02
```

```
DDAM ANALYSIS OF A DECK MOUNTED STRUCTURE ON A SURFACE SHIP

ATHWARTSHIP (Y) DIRECTED SHOCK                                  SUBCASE 1

                                 M O D A L   E F F E C T I V E   W E I G H T

   MODE        CYCLES      PARTICIPATION         MODAL                    CUMULATIVE
  NUMBER                      FACTOR         WEIGHT      PERCENT       WEIGHT      PERCENT
     1      3.984522E+02   3.849506E+00   5.725946E+03  100.0000   5.725946E+03  100.0000


MASS AVAILABLE   = 100.0000 PERCENT
MASS USED        = 100.0000 PERCENT
```

Step 6 - <u>Effective Static Force F</u>

$F = WD$

$= 5,720\ (40.7) \qquad (25,443.82\ (40.7))$

$= 232,804\ \text{lbs} \qquad (1.036 \times 10^{6}\ \text{N/m})$

Guidance Documentation

M O D A L   R E A C T I O N

MODE NUMBER	CYCLES	PARTICIPATION FACTOR	RESPONSE ACCELERATION	RESPONSE REACTION	INPUT ACCELERATION	INPUT SOURCE
1	3.984522E+02	3.849506E+00	6.053919E+04	2.330460E+05	4.070000E+01	ACCELERATION

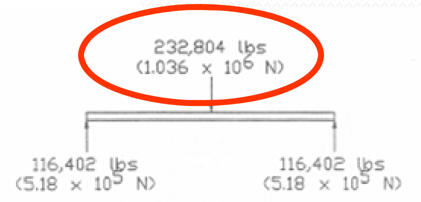
Based on acceleration, D = A = 40.7 g's.

The shock design value to use is the lesser of the these values. Therefore, use D = 40.7 g's.

ATHWARTSHIP (Y) DIRECTED SHOCK SUBCASE 1

T O T A L   B A S E   R E A C T I O N

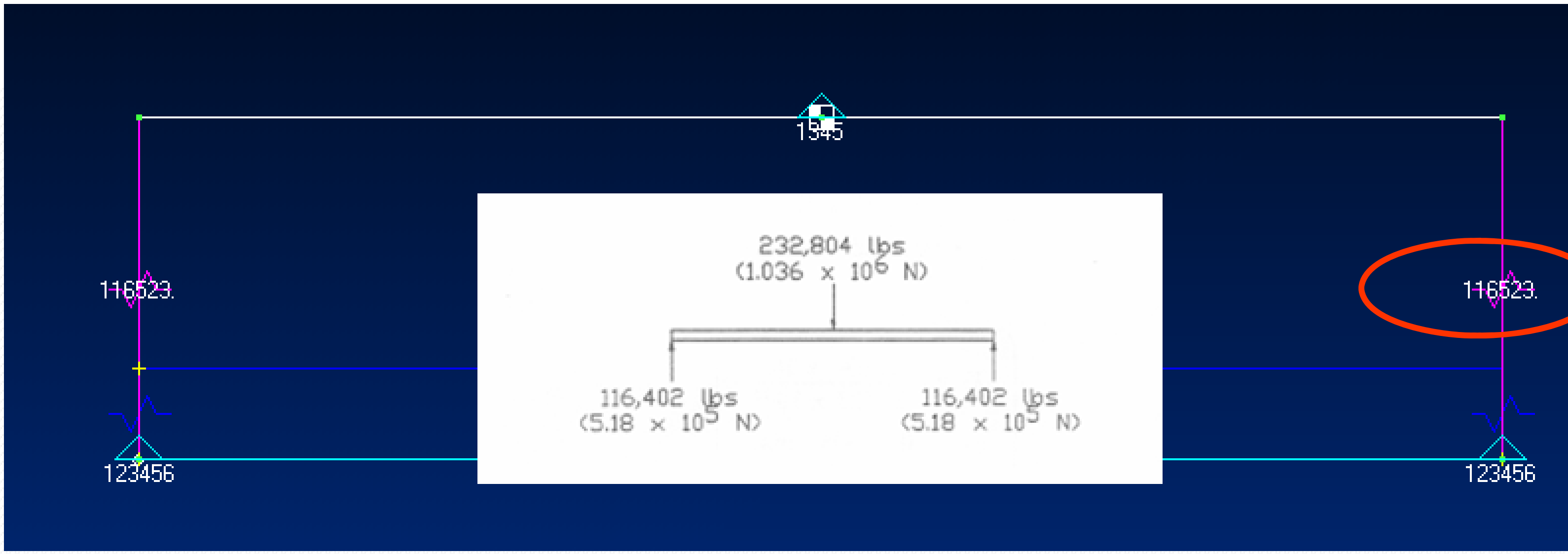
COMPONENT	MAXIMUM MODE	REACTION	SRSS	NRL SUM
1	0	0.000000E+00	0.000000E+00	0.000000E+00
2	1	2.330460E+05	0.000000E+00	2.330460E+05
3	0	0.000000E+00	0.000000E+00	0.000000E+00
4	0	0.000000E+00	0.000000E+00	0.000000E+00
5	0	0.000000E+00	0.000000E+00	0.000000E+00
6	1	3.495690E+06	0.000000E+00	3.495690E+06

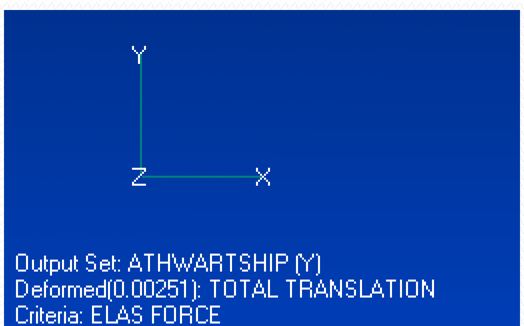


ATHWARTSHIP (Y) DIRECTED SHOCK SUBCASE 1

P E A K   M O D A L   R E S P O N S E

MODE NUMBER	DISPLACEMENT	VELOCITY	ACCELERATION
1	9.658829E-03	2.418135E+01	6.053919E+04





$$X = \frac{F}{K}$$

$$= \frac{232,804}{92.88 \times 10^6}$$

$$= 0.0025 \text{ inches}$$

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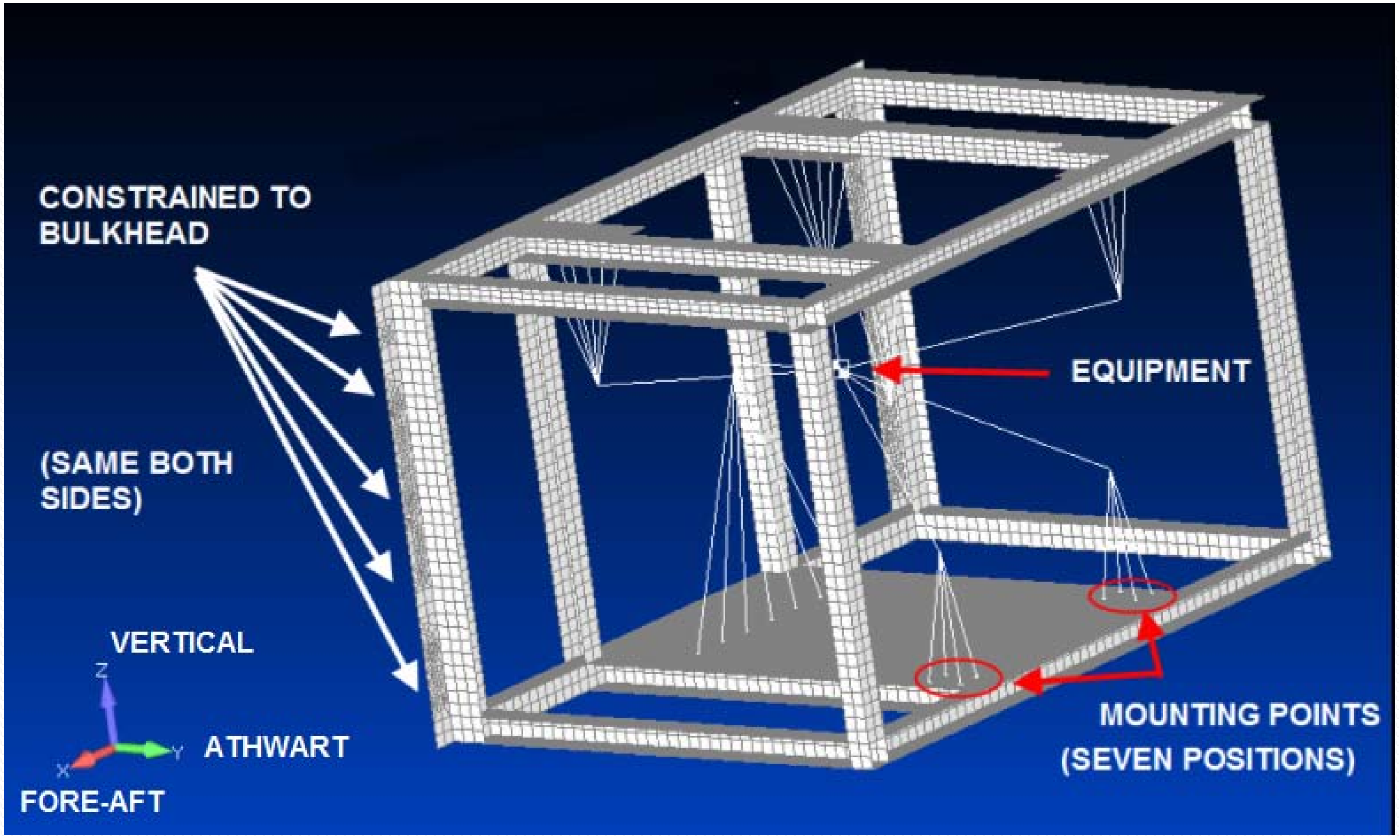
- MODESET USAGE
- **RACK EXAMPLE**
- ENGINE DECK CRADLE - LARGE SCALE ANALYSIS
- DDAM STRESSES

RACK EXAMPLE



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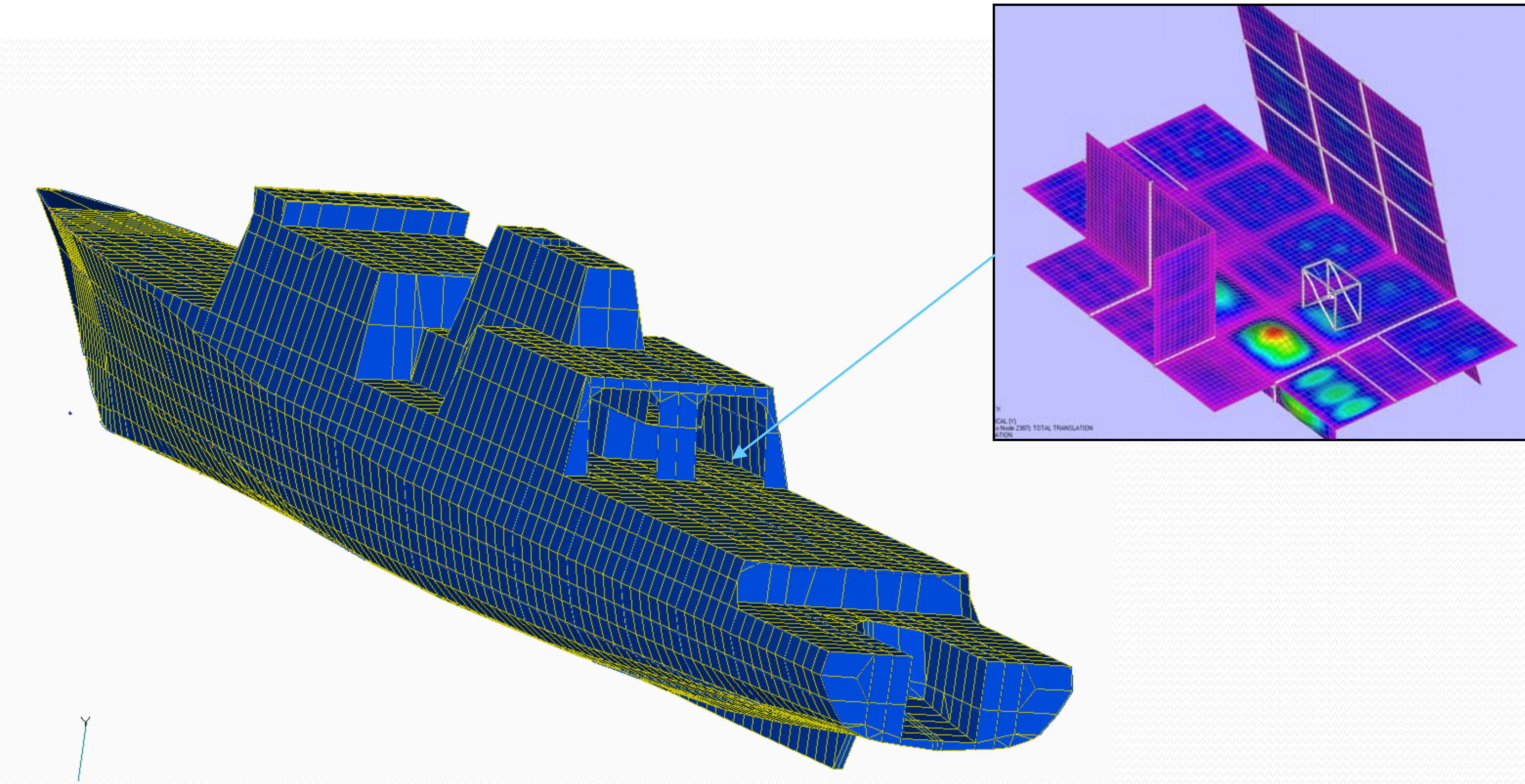
- DDAM STRESSES

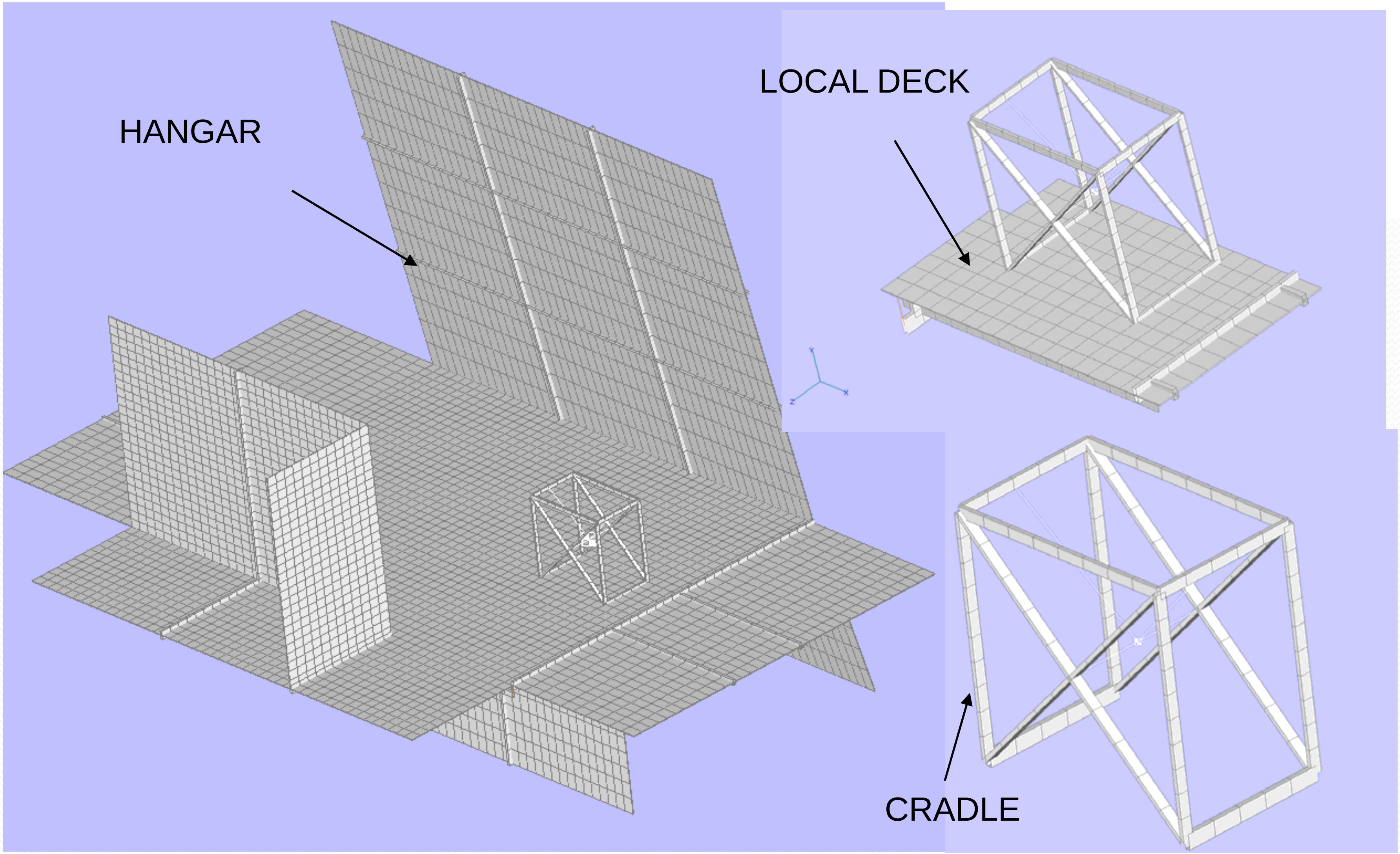
DDAM ANALYSIS
ENGINE CRADLE MOUNTING IN A SURFACE VESSEL HANGAR DECK



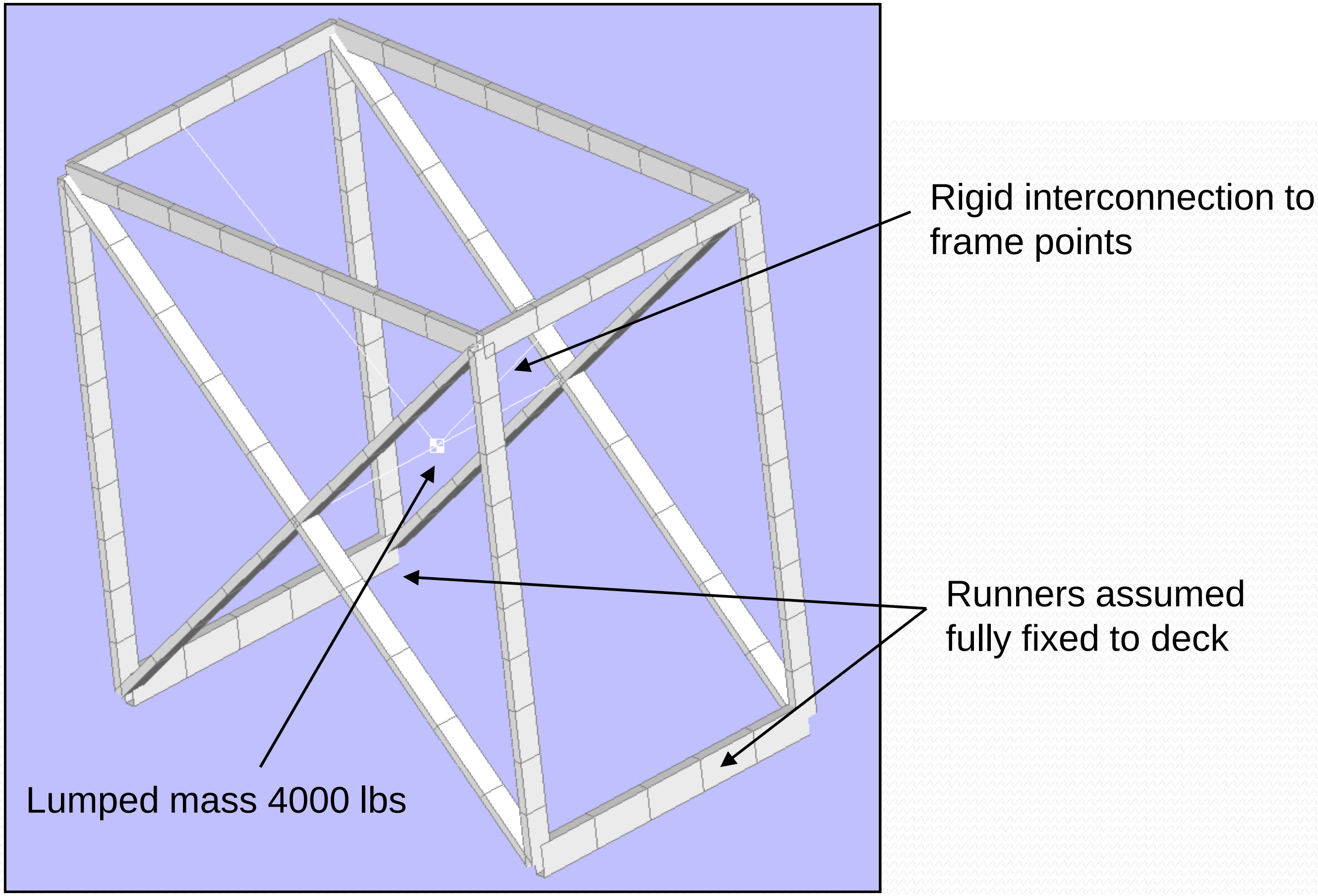
DDAM ANALYSIS
ENGINE CRADLE MOUNTING IN A SURFACE VESSEL HANGAR DECK

- DDAM analysis carried out on Cradle Mounting
- ‘Vanilla’ coefficients used
- Accelerations Measured
- Three levels of idealization used
    - Cradle in Isolation
    - Cradle mounted on local deck structure
    - Cradle assembled in Hangar structure
- Comparison of Modeling Accuracy and DDAM results in each case
- How much backing structure should be modeled?

The three levels of idealization used



CRADLE IN ISOLATION



Modal Input and Response from DDAM

- Each dominant mode drives a shock response direction
- No coupling

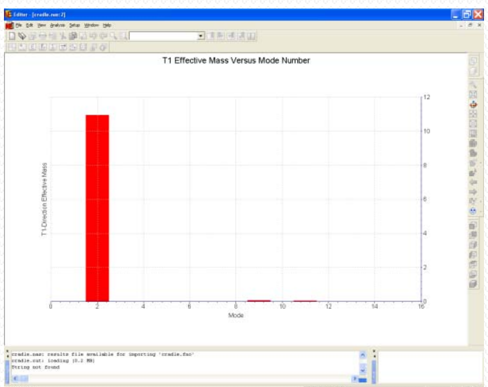
FORWARD-AFT (X) DIRECTED SHOCK				SUBCASE 1		
MODE	CYCLES	PARTICIPATION	RESPONSE		INPUT	
NUMBER		FACTOR	ACCELERATION	REACTION	ACCELERATION	SOURCE
2	8.330861E+01	3.307479E+00	1.832549E+04	6.061118E+04	1.433538E+01	VELOCITY
ATHWARTSHIP (Z) DIRECTED SHOCK				SUBCASE 2		
MODE	CYCLES	PARTICIPATION	RESPONSE		INPUT	
NUMBER		FACTOR	ACCELERATION	REACTION	ACCELERATION	SOURCE
1	1.067862E+01	3.313163E+00	7.683225E+03	2.545578E+04	6.000000E+00	MINIMUM-G
VERTICAL (Y) DIRECTED SHOCK				SUBCASE 3		
MODE	CYCLES	PARTICIPATION	RESPONSE		INPUT	
NUMBER		FACTOR	ACCELERATION	REACTION	ACCELERATION	SOURCE
8	1.031109E+02	-3.250511E+00	2.446288E+04	-7.951686E+04	1.947181E+01	VELOCITY

CRADLE IN ISOLATION

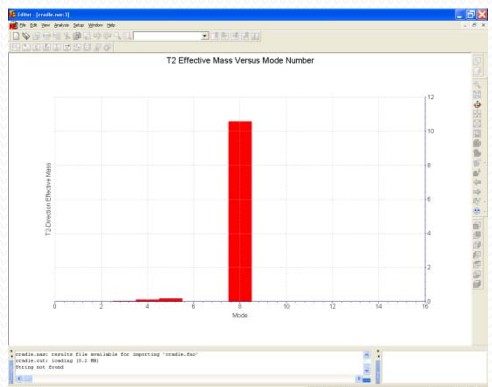
- High Modal Mass achieved with 15 modes, little noise

P E R C E N T   M O D A L   M A S S

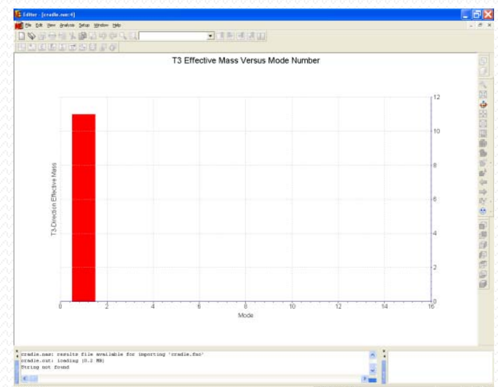
DIRECTION	TOTAL	MODAL	PERCENT
1	1.128501E+01	1.104935E+01	97.91
2	1.128501E+01	1.088630E+01	96.47
3	1.128501E+01	1.098078E+01	97.30
4	3.065230E+06	2.984946E+06	97.38
5	9.623747E+07	9.364481E+07	97.31
6	9.859524E+07	9.515650E+07	96.51



FORWARD-AFT (X)
MODE 2



ATHWARTSHIP (Z)
MODE 8

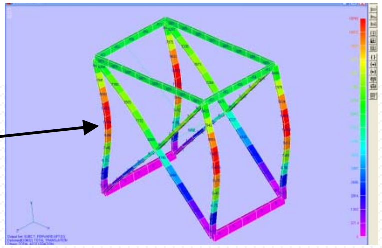


VERTICAL (Y)
MODE 1

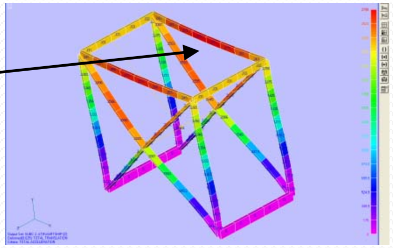
CRADLE IN ISOLATION

DDAM peak accelerations

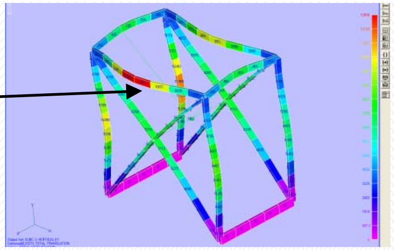
FORWARD-AFT (X)
PEAK ACCN 10,734 IN/S^2
27.8g



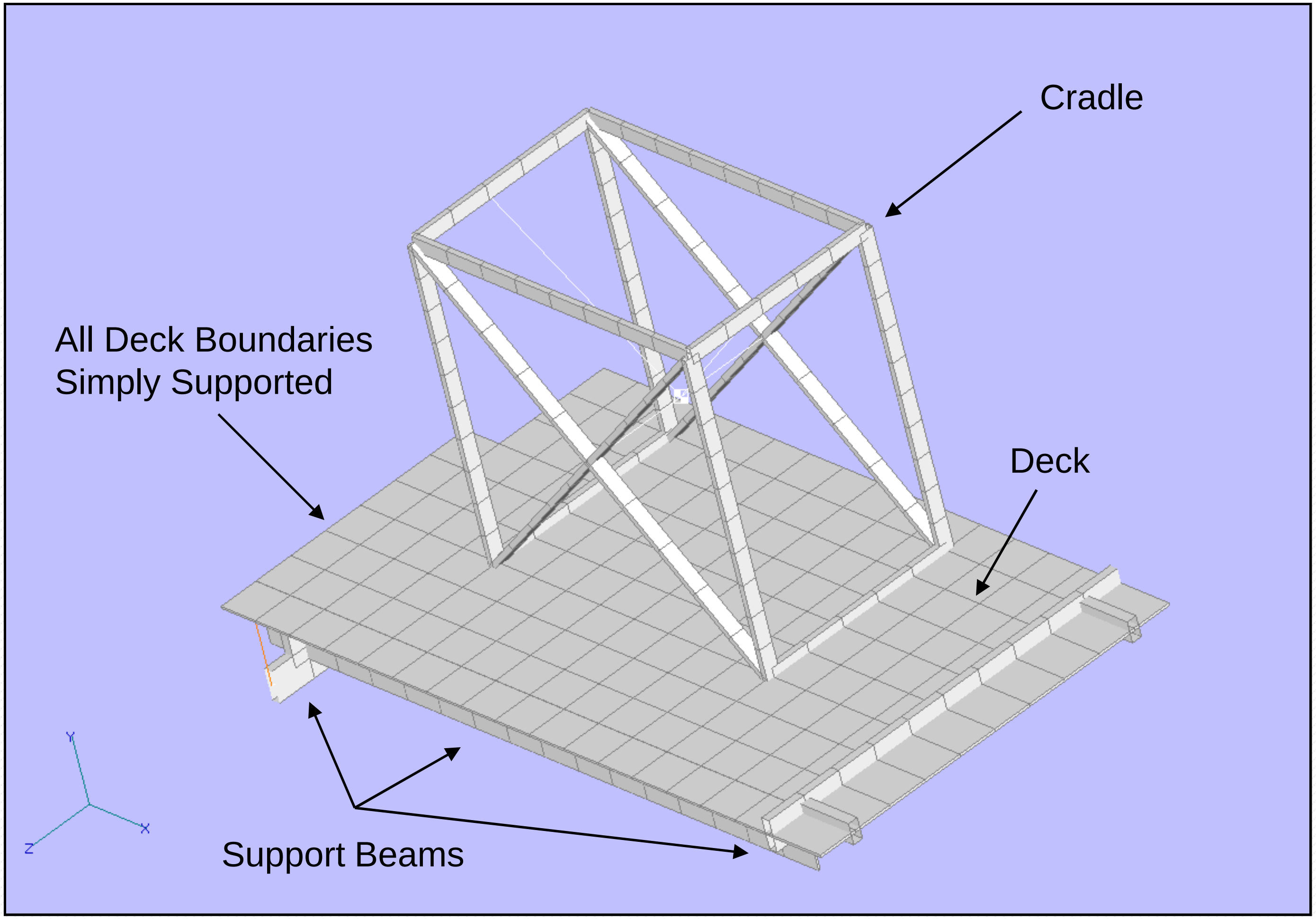
ATHWARTSHIP (Z)
PEAK ACCN 2,799 IN/S^2
7.3g



VERTICAL (Y)
PEAK ACCN 12,916 IN/S^2
33.43g



CRADLE PLUS LOCAL DECK



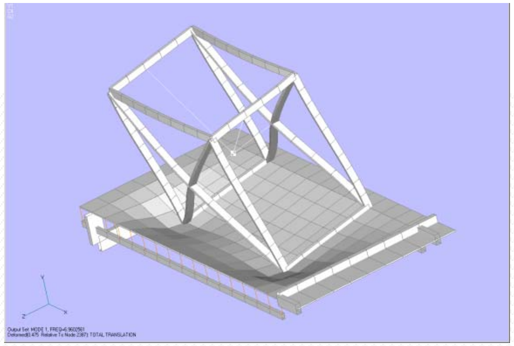
CRADLE PLUS LOCAL DECK

- High Modal Mass achieved little noise
- 25 Modes would be sufficient to achieve 80%
- frequencies significantly lowered

P E R C E N T   M O D A L   M A S S

DIRECTION	TOTAL	MODAL	PERCENT
1	1.393104E+01	1.133629E+01	81.37
2	1.393104E+01	1.309284E+01	93.98
3	1.393104E+01	1.132716E+01	81.31
4	3.714471E+06	3.130420E+06	84.28
5	1.188631E+08	9.659414E+07	81.27
6	1.217118E+08	1.140065E+08	93.67

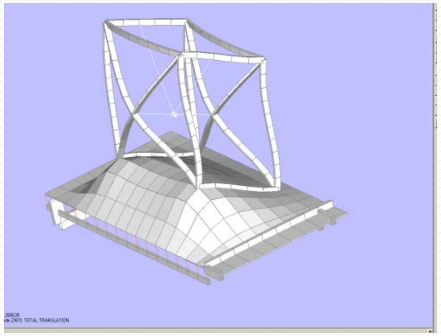
CRADLE PLUS LOCAL DECK



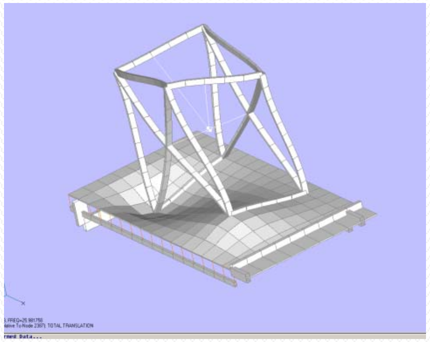
MODE 1 6.9Hz

• Deck influence is significant

MODE 2 18.2 Hz



MODE 3 25.9 Hz



Modal Weight from DDAM

- Multiple modes now contributing, but Mode 1, 2 and 3 dominate

FORWARD-AFT (X) DIRECTED SHOCK SUBCASE 1

M O D A L E F F E C T I V E W E I G H T

MODE NUMBER	CYCLES	PARTICIPATION FACTOR	MODAL WEIGHT	MODAL PERCENT	CUMULATIVE WEIGHT	CUMULATIVE PERCENT
3	2.598175E+01	-2.941868E+00	3.344997E+03	62.1245	3.344997E+03	62.1245
12	1.094031E+02	-7.069750E-01	1.931780E+02	3.5878	3.538175E+03	65.7123
11	1.004843E+02	6.436787E-01	1.601356E+02	2.9741	3.698311E+03	68.6864
14	1.297679E+02	5.990904E-01	1.387184E+02	2.5763	3.837029E+03	71.2627

ATHWARTSHIP (Z) DIRECTED SHOCK SUBCASE 2

M O D A L E F F E C T I V E W E I G H T

MODE NUMBER	CYCLES	PARTICIPATION FACTOR	MODAL WEIGHT	MODAL PERCENT	CUMULATIVE WEIGHT	CUMULATIVE PERCENT
1	6.960256E+00	3.112394E+00	3.744024E+03	69.5354	3.744024E+03	69.5354
2	1.826064E+01	1.137331E+00	4.999465E+02	9.2852	4.243971E+03	78.8206
38	2.611058E+02	2.027063E-01	1.588123E+01	0.2950	4.259852E+03	79.1155

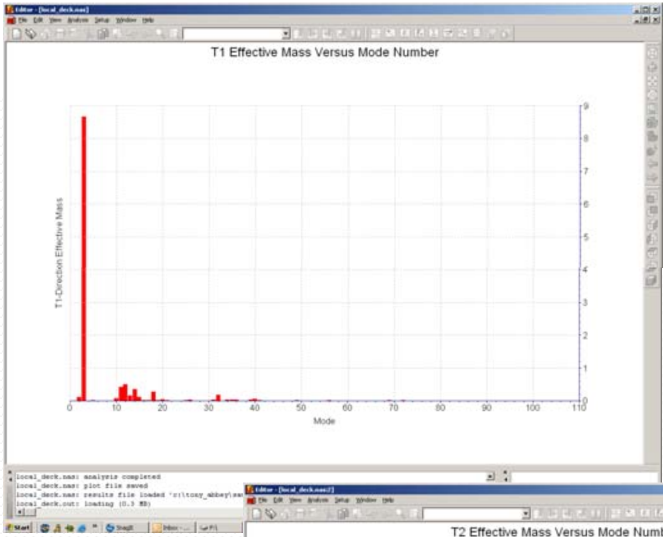
VERTICAL (Y) DIRECTED SHOCK SUBCASE 3

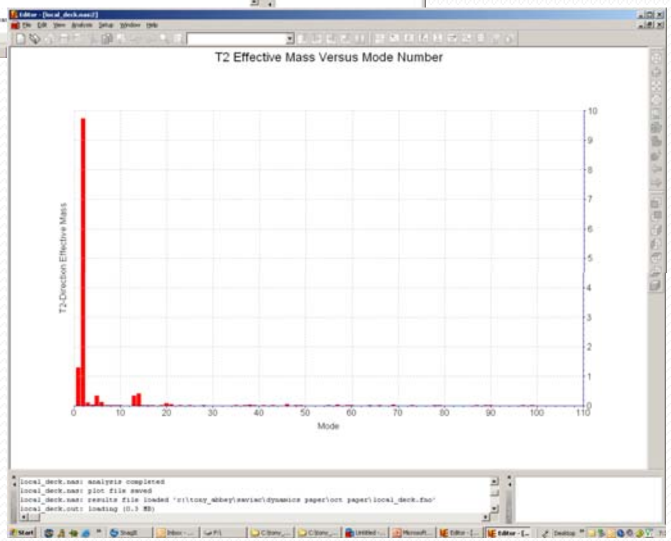
M O D A L E F F E C T I V E W E I G H T

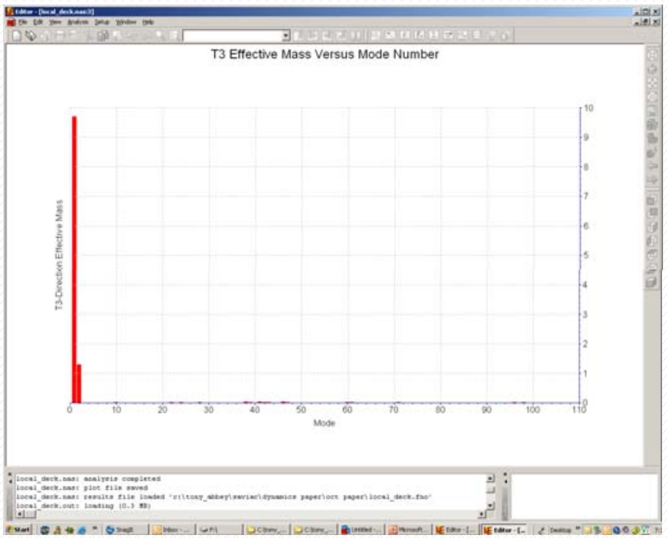
MODE NUMBER	CYCLES	PARTICIPATION FACTOR	MODAL WEIGHT	MODAL PERCENT	CUMULATIVE WEIGHT	CUMULATIVE PERCENT
2	1.826064E+01	3.120129E+00	3.762657E+03	69.8814	3.762657E+03	69.8814
1	6.960256E+00	-1.135033E+00	4.979283E+02	9.2477	4.260585E+03	79.1291
14	1.297679E+02	6.349527E-01	1.558232E+02	2.8940	4.416409E+03	82.0231

CRADLE PLUS LOCAL DECK

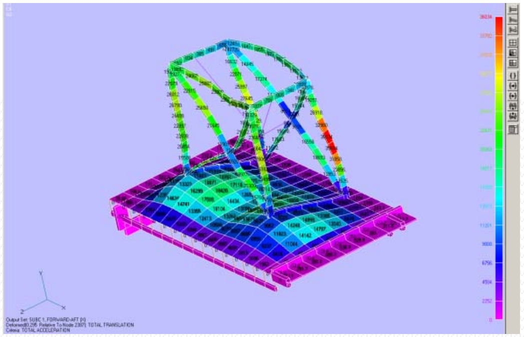
- Modal Effective Mass charts clearly show this





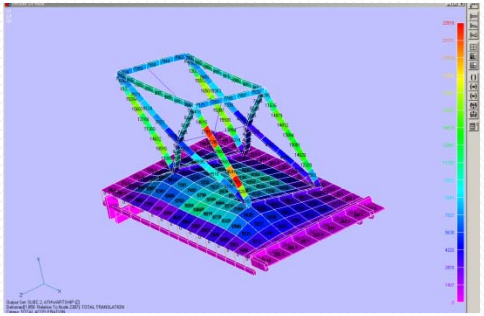


CRADLE PLUS LOCAL DECK



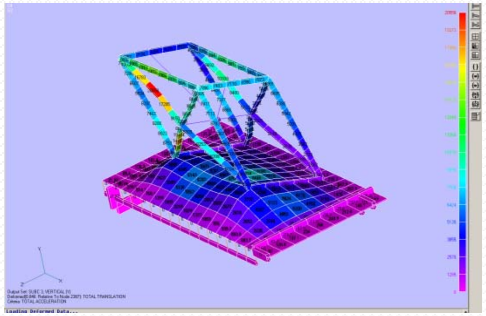
FORWARD-AFT (X)

PEAK ACCN 36,034 IN/S^2
93.3g 26.2 Hz dominates



ATHWARTSHIP (Z)

PEAK ACCN 22,518 IN/S^2
58.3g 6.96 Hz dominates

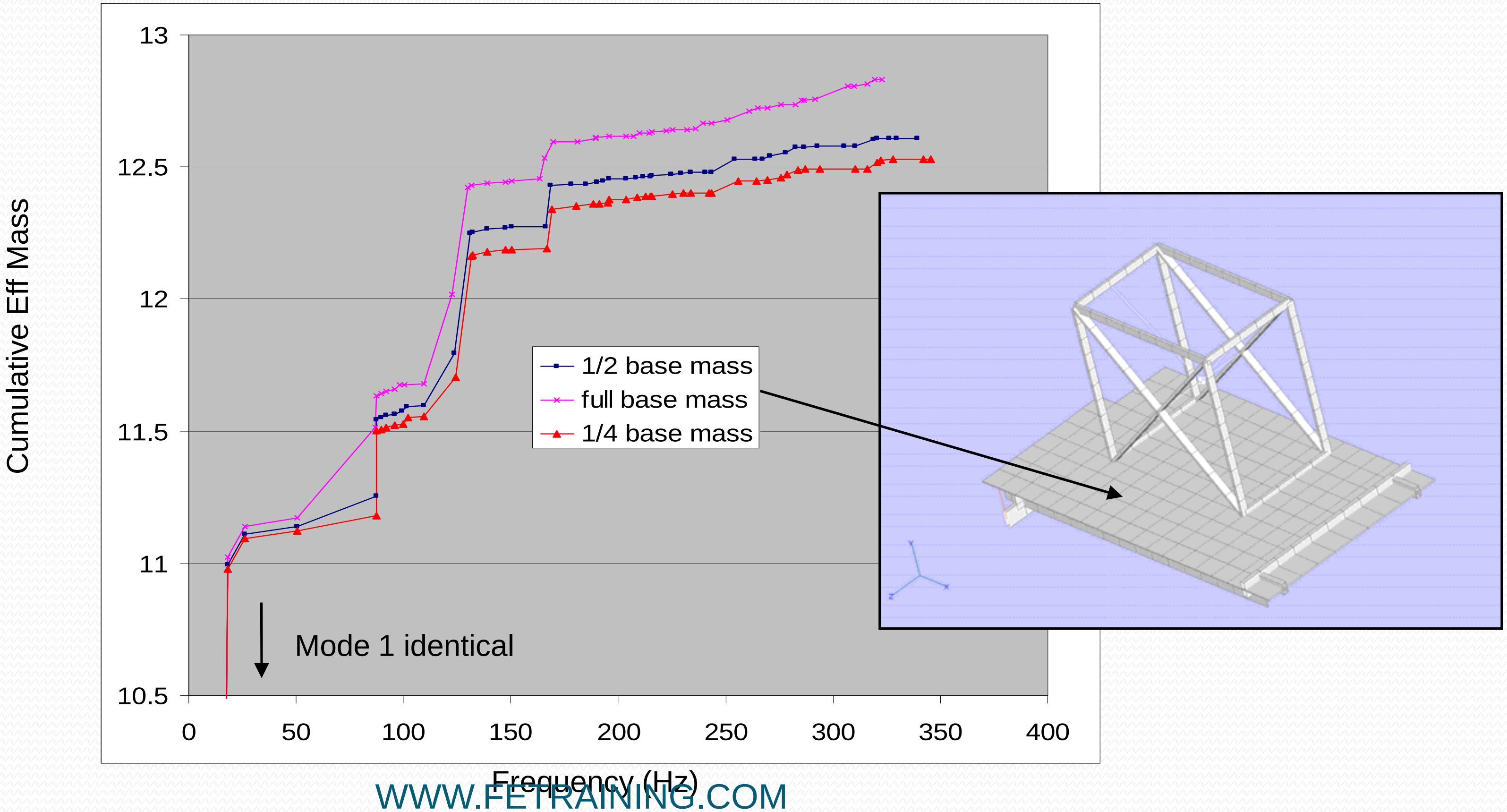


VERTICAL (Y)

PEAK ACCN 20,558 IN/S^2
53.2g 18.3 Hz dominates

CRADLE PLUS LOCAL DECK

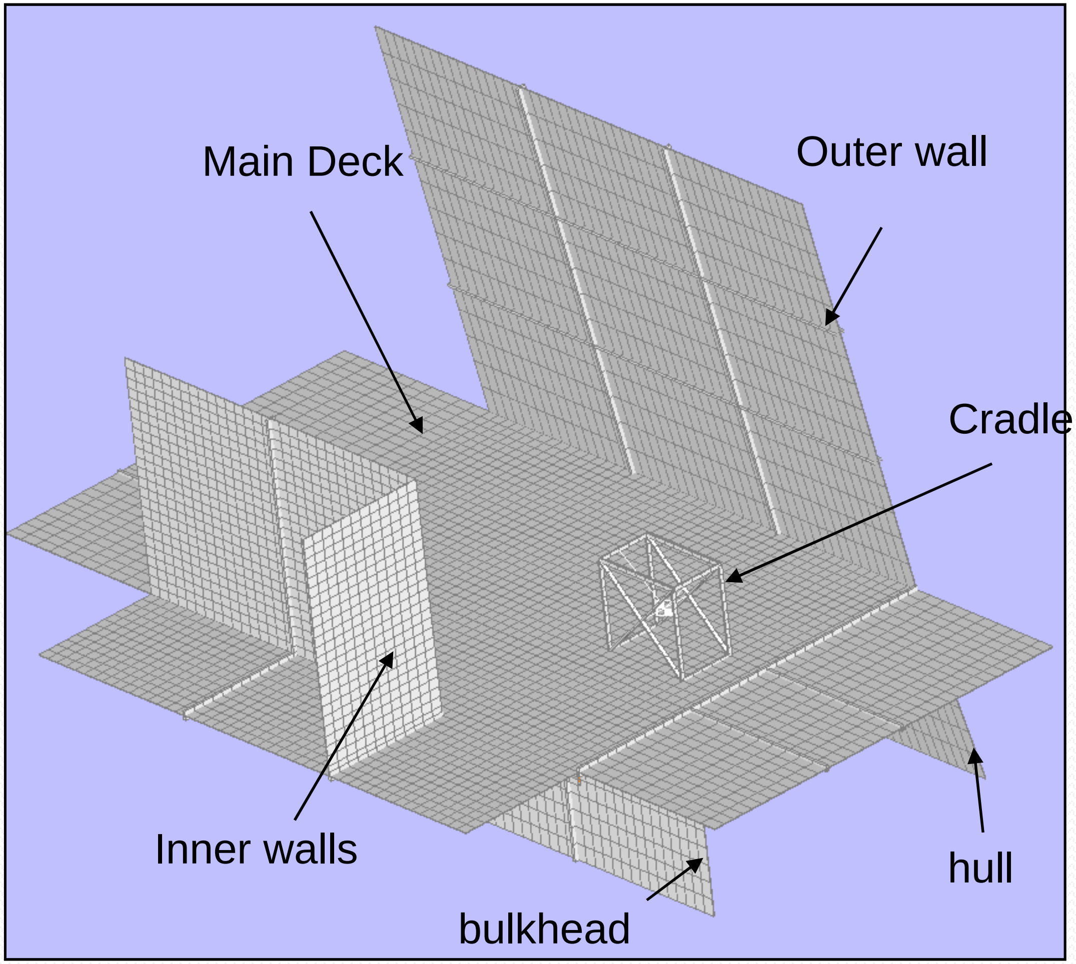
- Formal DDAM approach is probably to use only ½ of local deck mass plus full cradle mass
- parametric study carried out
- small frequency shift, drop in MEM



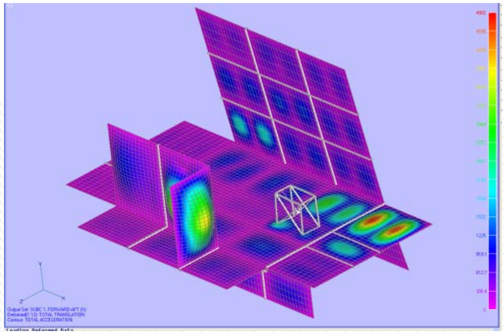
COMPARISON SO FAR

- Influence of local deck structure has lowered frequencies
- assumption of rigidly attached runners is poor
- drop from is from 10.7 - 90.8 Hz to 6.9 - 25.9 Hz
- absolute peak acceleration response has increased significantly
- increase is 33 g to 93 g
- Formal DDAM approach is to use only ½ of local deck mass plus full cradle mass
- Analysis is insensitive to this

CRADLE PLUS HANGAR

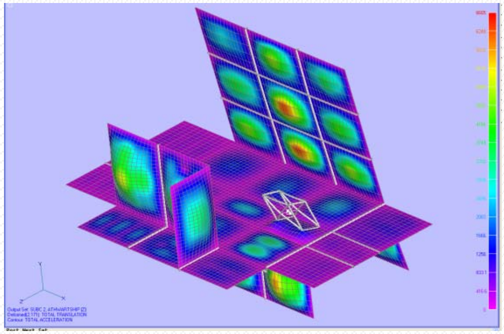


CRADLE PLUS HANGAR



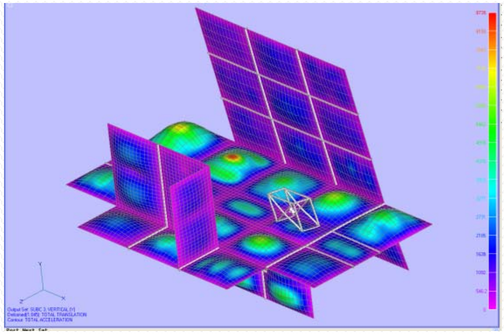
FORWARD-AFT (X)

- Peak Accelerations from DDAM

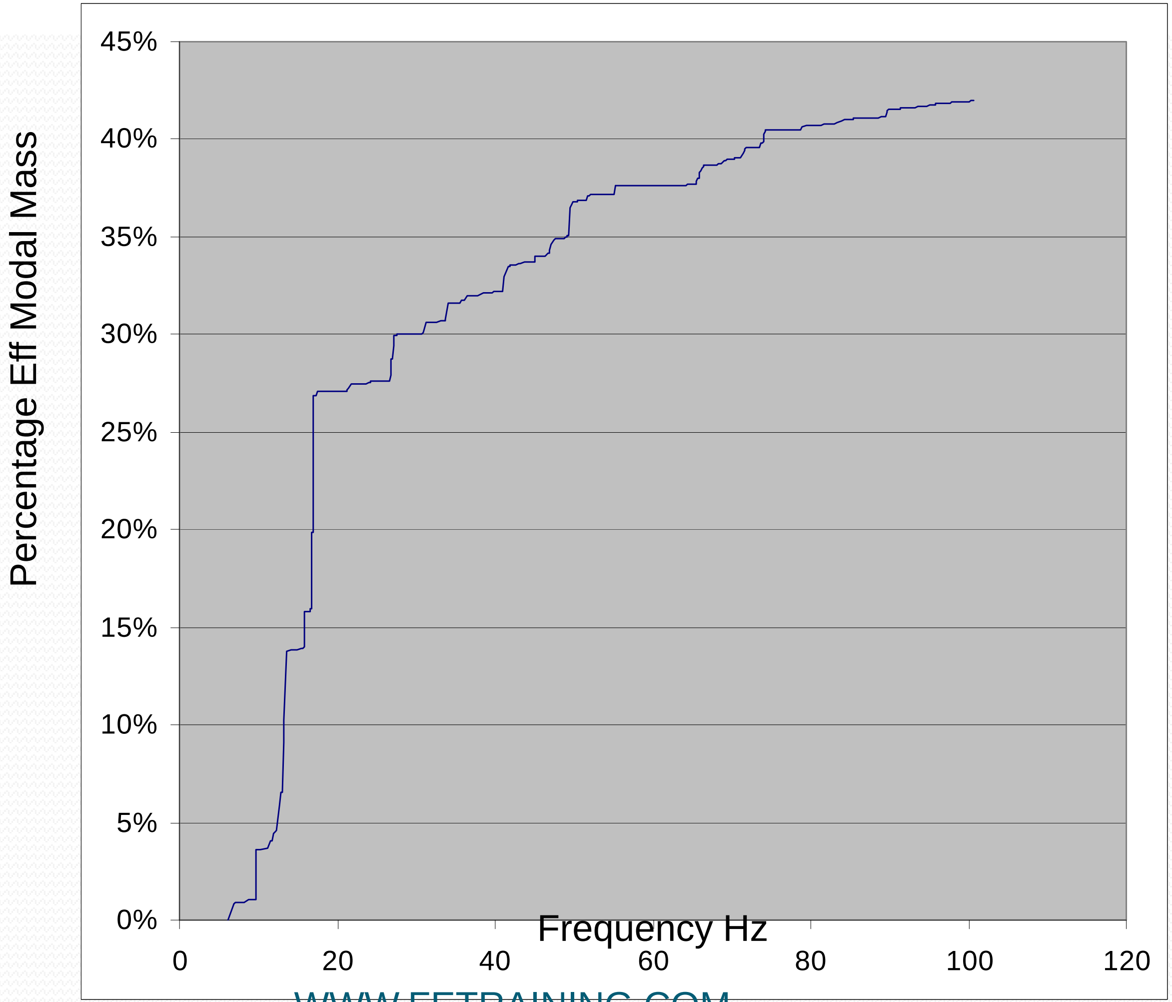


ATHWARTSHIP (Z)

VERTICAL (Y)



- Modal Effective mass count 400 modes

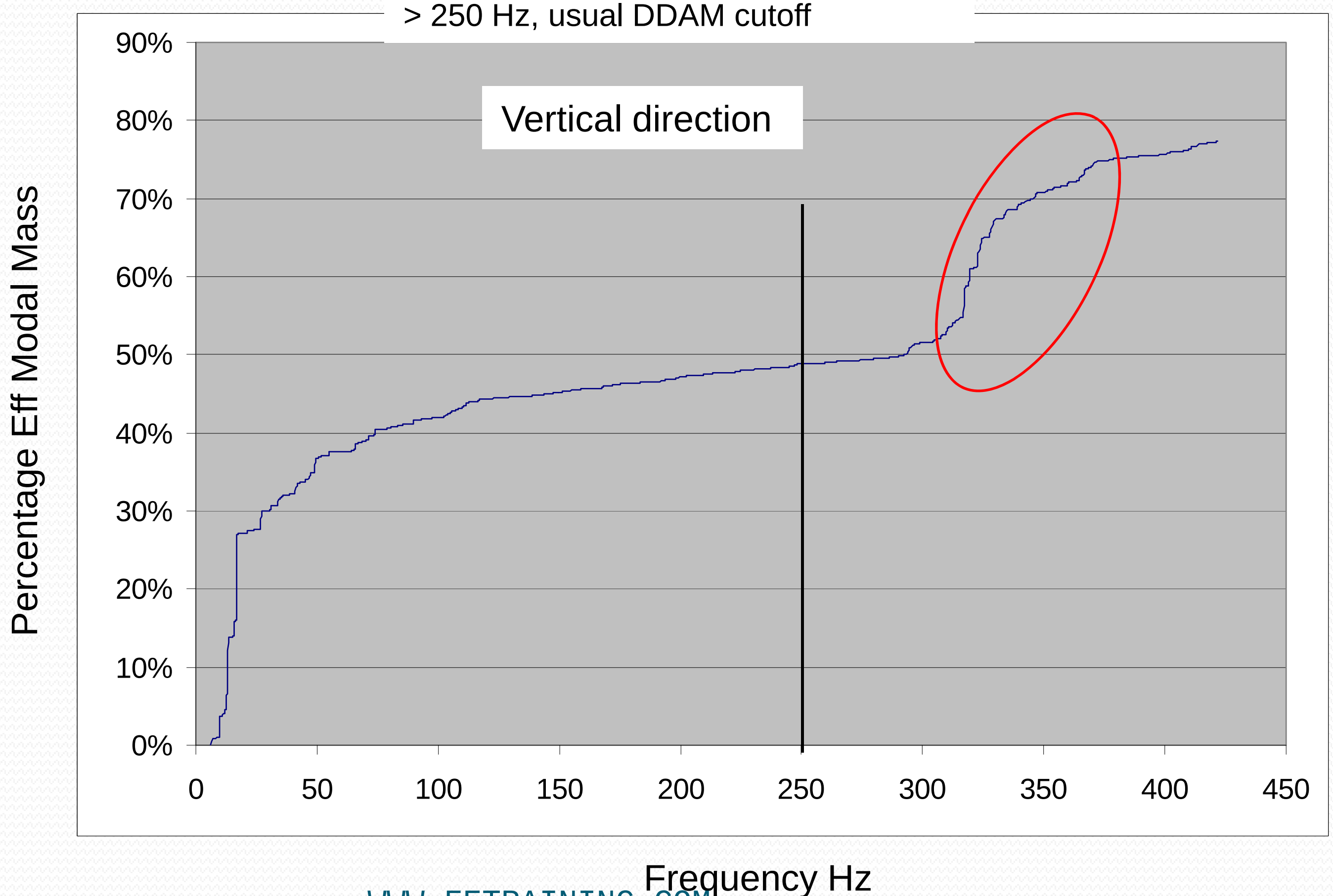


CRADLE PLUS HANGAR

Desperation – used 1500 modes

reveals contribution at higher frequency

> 250 Hz, usual DDAM cutoff

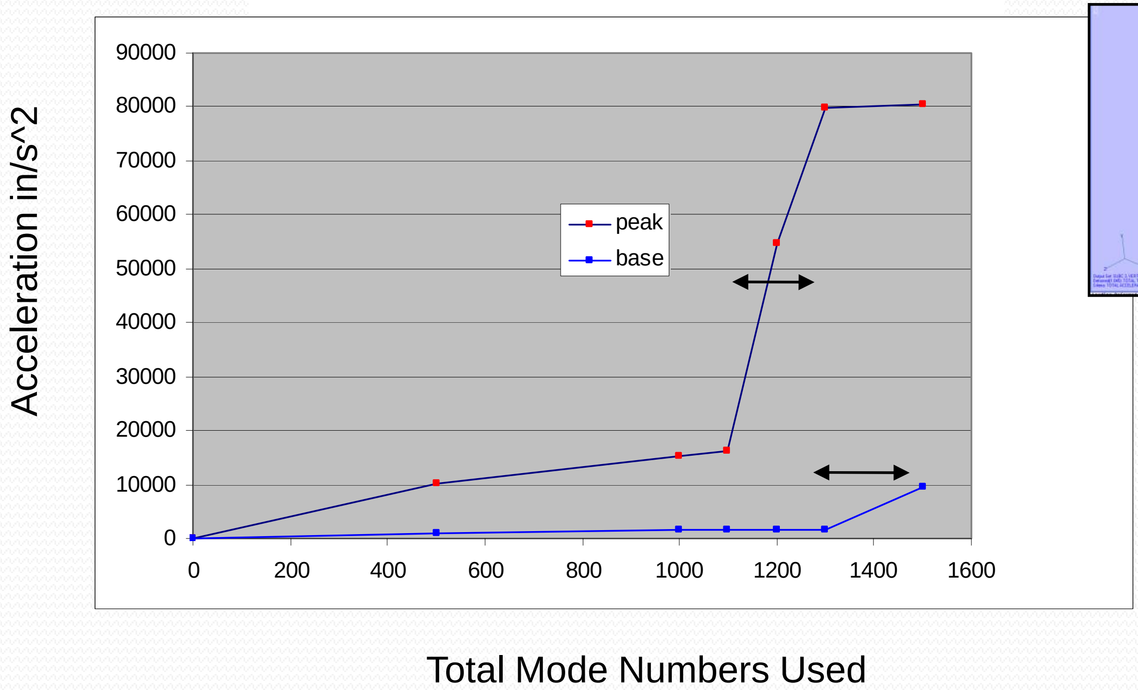


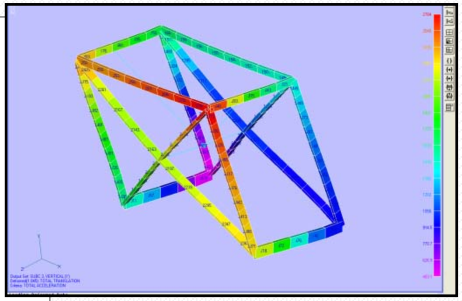
CRADLE PLUS HANGAR

‘MODESET’ feature used with modal database re-use makes multiple DDAM runs cheap and fast

Peak acceleration increases in 286 – 352 hz band
Base acceleration Increases in 352 – 422 hz band

Vertical direction Peak Cradle Acceleration





COMPARISON OF 3 IDEALIZATION LEVELS

- cradle model in isolation is too stiff at base
- cradle needs local deck structure for accurate natural frequency calculations
- low overall Modal effective Mass and low acceleration input for DDAM with hangar included unless very high mode count used
- increasing the complexity of the surrounding structure is a trade off
  - more accurate frequencies

    versus

  - impossible to assign Modal Effective Mass to cradle contribution from overall response
- using mode count in DDAM as a filter re-using a modal database may be feasible

ADVICE

- KEEP MODELS AS SIMPLE AS POSSIBLE
- DO THOROUGH MODAL SURVEY TO UNDERSTAND WHAT YOU HAVE GOT
- CONSIDER MESH CONVERGENCE STUDY IF MODEL QUALITY IS IN DOUBT
- USE RESIDUAL VECTORS OR CMS (CRAIG-BAMPTON) IF MODAL TRUNCATION IS SUSPECTED
- INCLUDE LOCAL BACKING STRUCTURE WHERE FLEXIBILITY IS IMPORTANT
- IF SURROUNDING STRUCTURE SWAMPS MODAL EFFECTIVE MASS USE MULTIPLE DDAM ACCELERATION OR STRESS CONVERGENCE STUDIES WITH MODESET AND MODAL DATABASE

AGENDA

- MODAL EFFECTIVE MASS THEORY
- DDAM BACKGROUND.
- DDAM PROCEDURE
- SIMPLE DDAM ANALYSIS
- MODAL DATABASE USAGE
- BRACKET DDAM ANALYSIS – CHASING MODAL EFFECTIVE MASS
- MODESET USAGE
- ENGINE DECK CRADLE - LARGE SCALE ANALYSIS
- **DDAM STRESSES**

DDAM STRESSES

Enhanced DDAM von Mises output stress in bars, beams and shells:

As requested by the DDAM community, a new model parameter, EQVSTRESSTYPE now controls the von Mises stress calculation.

When set to 2 in linear solutions this will output membrane only von Mises stress in bar, beam, and shell elements.

The default setting of 0 will output membrane and bending von Mises stress.

The beam and bar von Mises calculation has been completely updated to include both transverse shear terms and the torsional shear stress term.

The effective section shear area is used to calculate the former. The latter uses either a user supplied effective torsional radius, or the appropriate dimension if the user inputs a section via a PBEAML or PBARL.

DDAM STRESSES

The effective transverse shear stress is a result of two components:

τ_{uy}, transverse shear in beam y local direction

$$\tau_{uy} = \frac{V_y}{A_y}$$ A_y = effective shear area in y direction

τ_{uz}, transverse shear in beam z local direction

$$\tau_{uz} = \frac{V_z}{A_z}$$ A_z = effective shear area in z direction

The maximum torsional shear stress on the surface of a section is evaluated from the equation:

$$\tau_{tors} = G * \theta' * t$$

Where: G is the shear Modulus
θ' is the twist per unit length of element
t is the maximum thickness for a regular open section without fillet radii

DDAM STRESSES

Enhanced DDAM von Mises output stress in bars, beams and shells:

Normal stress, σ_{normal} where $\sigma_{normal} = \sigma_{bend} + \sigma_{axial}$

Bending Stress, $\sigma_{bend} = \frac{M_y \bar{y}}{I_y} + \frac{M_z \bar{z}}{I_z}$

Axial Stress, $\sigma_{axial} = \frac{F}{A}$

Where F = axial force, A is Cross Sectional Area.

So Normal stress, $\sigma_{normal} = \frac{F}{A} + \frac{M_y \bar{y}}{I_y} + \frac{M_z \bar{z}}{I_z}$

Von Mises Stress , $\sigma_{vm} = \sqrt{\sigma^2{}_{norm} + 3\tau^2{}_s}$

Where τ_s is total shear stress.