

Modal Dynamics in LS-DYNA[®]

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Abstract

In LS971 R71 LSTC has enhanced its capabilities in Modal Dynamics from previous versions. This talk will give an overview of the enhanced capabilities which include mode selection and modal damping. We will present an industrial example of using this capability including a comparison of using Modal Dynamics and a full simulation.

Modal Dynamics

Modal Dynamics is the modeling approach that uses normal modes to approximate the response of a model to forces. It is also known as modal superposition. This approach has been in LS-DYNA since LS960 via the keyword *CONTROL_IMPLICIT_DYNAMICS with option IMASS=2. Due to customer requests this feature has been elevated to have its own keywords and additional features.

With Modal Dynamics the nodal displacement \mathbf{d} is approximated with modal displacement

$$\mathbf{d} = \Phi \mathbf{d}_m$$

where Φ is the matrix of normal modes and \mathbf{d}_m is the modal displacement., With this approximation the governing differential equation becomes

$$\mathbf{M}\Phi \mathbf{a}_m + \mathbf{C}\Phi \mathbf{v}_m + \mathbf{K}\Phi \mathbf{d}_m = \mathbf{F}$$

Where \mathbf{v}_m is the modal velocity and \mathbf{a}_m is modal acceleration. Multiplication on the left by Φ^t yields the governing equation for modal dynamics

$$\Phi^t \mathbf{M} \Phi \mathbf{a}_m + \Phi^t \mathbf{C} \Phi \mathbf{v}_m + \Phi^t \mathbf{K} \Phi \mathbf{d}_m = \Phi^t \mathbf{F}$$

Because normal modes are used this becomes

$$\mathbf{a}_m + \mathbf{C}_m \mathbf{v}_m + \Lambda \mathbf{d}_m = \Phi^t \mathbf{F}$$

where Λ is the diagonal matrix of natural frequencies and \mathbf{C}_m is the user specified damping matrix. This equation is solved for \mathbf{a}_m . The nodal accelerations \mathbf{a} are then recovered using

$$\mathbf{a} = \Phi \mathbf{a}_m$$

When Should Modal Dynamics Be Used

The reason for using modal dynamics is to reduce the cost of an analysis. Modal Dynamics replaces the element and material computation per explicit time step with two multiplications by the matrix of normal modes Φ , one to map the nodal forces to the modes and the other to map the modal accelerations to the nodal accelerations. An additional benefit is a potential reduction in the number of time steps as the time per cycle will probably increase as it is a function of the largest frequency used.

Good candidates for using Modal Dynamics are

- Explicit transient simulation
- Same model with several load cases
- Element and material behavior is linear
- Model response is well captured by a small number of modes
- Only lower frequency modes are needed

When Not to Use Modal Dynamics

Modal Dynamics uses a linear approximation to compute the model response. So Modal Dynamics should not be used to model nonlinear response.

If a large number of modes are required to capture the response of the model to the various load cases then the cost reduction of Modal Dynamics will be lost and should not be used. First the cost of the eigencomputation will increase. The multiplication by the modal matrix Φ will become more expensive. With more modes it is expected that the largest frequency will increase and the largest frequency will reduce the explicit time step increasing the number of explicit time steps.

If the load cases are point loads Modal Dynamics will smear the affect of a point load across the eigenmodes. Accuracy of the response to point loads will be lost. But that may be acceptable to the analysis.

What is New in LS-DYNA 971 R71

Modal Dynamics has been in LS-DYNA since LS-DYNA 960. All the user could do is to turn it on. The analysis started with an initial eigenmode computation and then all modes were used in the modal dynamic computation. With 971 R71 we have elevated Modal Dynamics by giving the feature its own keywords. And we have added features such as importing an already computed d3eigv database, selecting a subset of modes and specification of modal damping.

***CONTROL_IMPLICIT_MODAL_DYNAMICS**
MD_FLAG, VALDMP, MD_STRESS
MD_FILENAME

Where

MD_FLAG turns modal dynamics on and off

MD_VALDMP	global damping coefficient (% of critical damping) used for all modes
MD_STRESS	turn on and off stress recovery
MD_FILENM	user specified file holding the eigenmodes in a d3eigv database

If MD_FLAG \neq 0 means Modal Dynamics will be used. If MD_FILENM is not specified then the analysis starts with an eigenmode computation controlled via

*CONTROL_IMPLICIT_EIGENVALUE. If MD_FILENM is specified the eigenmodes will be read from that file which must be a d3eigv database. The resultant stresses can be computed and output to d3plot by using MD_STRESS. MD_VALDMP will be used as a damping factor for all modes unless further damping is specified.

***CONTROL_IMPLICIT_MODAL_DYNAMICS_MODE_LIST**

MD1, MD2, MD3, ...

Specify a subset of modes to use by giving a list of mode numbers corresponding to the d3eigv database.

***CONTROL_IMPLICIT_MODAL_DYNAMICS_MODE_GENERATE**

MD1BGN, MD1END, MD2BGN, MD2END,

Use modes MD1BGN through MD1END, MD2BGN through MD2END, etc. Similar to *SET_XXX_GENERATE options.

***CONTROL_IMPLICIT_MODAL_DYNAMICS_DAMPING**

MD_VALDMP

Specify a value of damping for all modes overriding that on the *CONTROL_IMPLICIT_MODAL_DYNAMICS keyword.

***CONTROL_IMPLICIT_MODAL_DYNAMICS_DAMPING_SPECIFIC**

MD1, MD_VALDMP1, MD2, MD_VALDMP2, ...

Provide damping factors for specific modes. For mode MD1 use damping MD_VALDMP1, for mode MD2 use damping MD_VALDMP2, etc.. If this keyword is used modes not specified will have their damping factor set to 0.

***CONTROL_IMPLICIT_MODAL_DYNAMICS_DAMPING_FREQUENCY_RANGE**

FREQ1, MD_VALDMP1

FREQ2, MD_VALDMP2

....

Specify a damping coefficient function by a piecewise linear function. The damping coefficient for a mode is then computed by using the frequency associated with the mode for interpolating this function. If this keyword is used all damping factors will be computed by interpolating this function.

In all cases damping is a percentage of critical damping. The actual damping will be

$$\zeta_i = 2 * MD_VALDMP * \lambda_i$$

Rayleigh Damping of $\alpha\mathbf{M} + \beta\mathbf{K}$ can be used by using the property of normal modes to realize that the resulting modal damping is

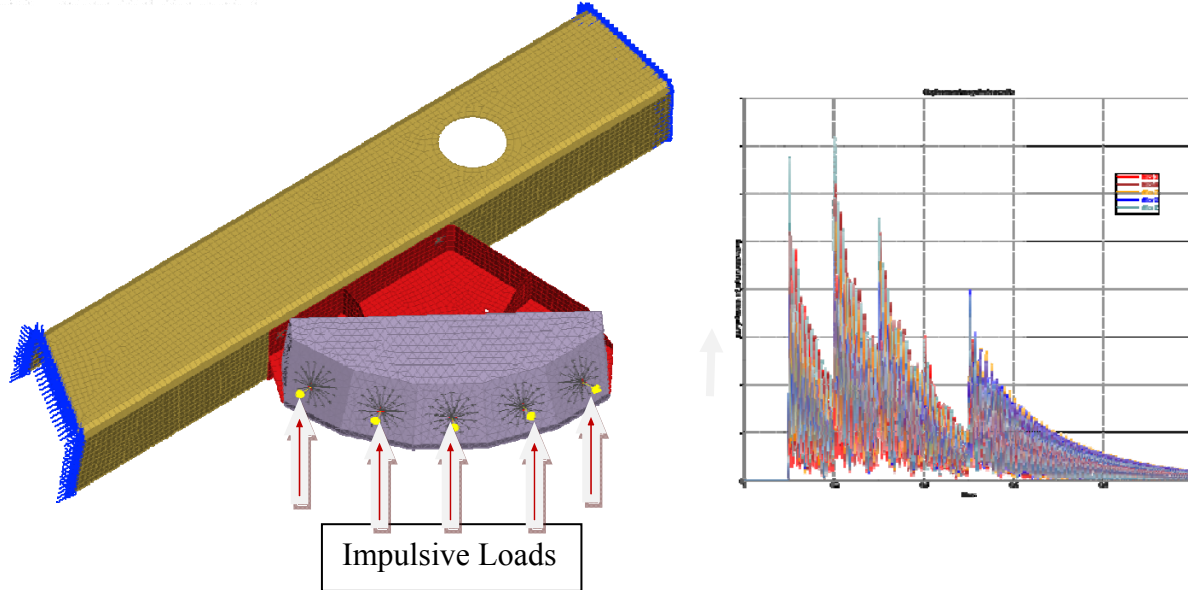
$$\zeta_i = \alpha + \beta \lambda_i$$

The user needs to specify this as percentage of critical damping using

$$MD_VALDMP_i = (\alpha + \beta \lambda_i) / (2 * \lambda_i)$$

An Industrial Example

The following example comes from Anders Jonsson, Dynamore Nordic, and Robert Bergner, BAE Systems Hägglunds. It is an instrument bracket with 5 impulsive load cases modeled with Modal Dynamics using 30 eigenmodes and 1% critical damping.



Resultant displacement is plotted. Time for explicit transient analysis is 3.5 hours. Using Modal Dynamics the run time is reduced to 3.5 minutes. Most of the savings is due to an almost 1000 times increase in the time step reducing the number of time steps by 1000.