

Resolving errors related to eigenvalue analysis for building structures

For a building with regularity, seismic analysis will be often performed by static analysis using equivalent seismic loads. However, irregular structures with significant changes in story stiffness and mass, or a tall building influenced by higher modes should be analyzed to correctly evaluate the effect of the irregularities under a given earthquake. For this purpose, response spectrum analysis will often be used through eigenvalue analysis.

Eigenvalue analysis will be performed to analyze the dynamic properties of the structure such as mode shapes, fundamental periods of vibration, modal participation factors, etc. This analysis cannot be performed together with a buckling analysis. The eigenvalue analysis must precede time history analysis or response spectrum analysis.

In this note, the causes of and solutions to errors frequently encountered in eigenvalue analysis will be summarized. Understanding such errors will be helpful when performing time history analysis or response spectrum analysis.

■ Errors encountered in eigenvalue analysis

Most errors encountered during eigenvalue analysis are Jacobi Error due to singularity. A singularity error will occur when a node has a degree of freedom without appropriate stiffness. Such errors frequently occur in elements without stiffness in a particular direction, like truss element, plate element, etc. Even when a singularity error has been detected, static analysis will be continued and a warning message is displayed for the corresponding degree of freedom at the node.

If a nodal load is applied to the corresponding degree of freedom where a singularity error occurs, a very large displacement will be calculated. (see Figure 1)

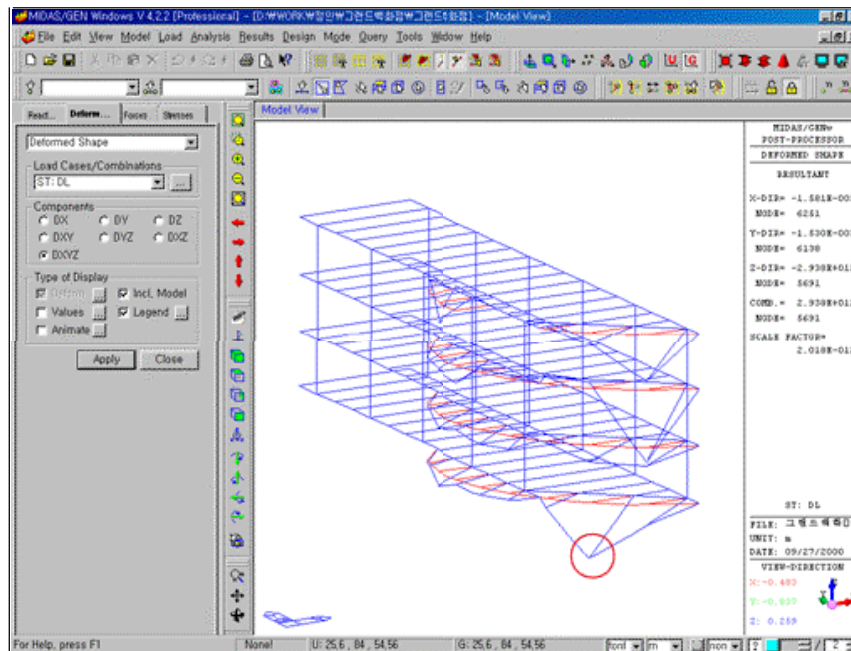


Figure 1. Nodal Displacement with Singularity Error

In this case the eigenvalue analysis will produce the Jacobi Error at the corresponding node or result in a very large period. The node having the singularity error may have a nodal mass due to self-weight or conversion by the Load to Mass functionality. During the response spectrum analysis, large calculated periods may result. The fact that Spectral Data is typically prepared up to less than about 10 seconds, the program may not find the corresponding spectral data. At this point, the response spectrum analysis will terminate with a message indicating that the calculated period lies beyond the range of the spectral data. (see Figure 2)

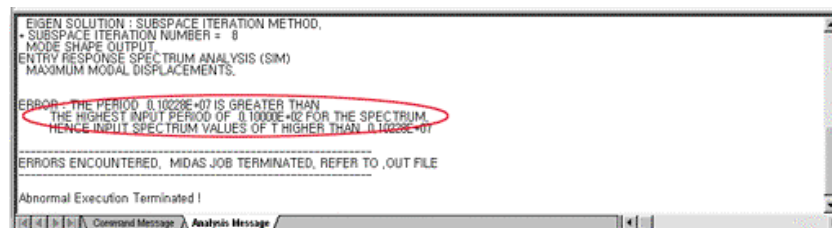


Figure 2. Error Message resulting from Incorrect Period Calculation

Moreover, vibration modes pertaining to some incorrectly modeled elements contained in the total model render the analysis useless to evaluate the dynamic properties of the structure. This phenomenon often becomes apparent in a structure, which cannot define Floor Diaphragm such as roof trusses resisting lightweight.

Even if the calculated modes avoided singularity errors, and the corresponding periods remained within the range of periods of the spectral data, the modal participation masses may become very small. In such a case, the sum of effective modal masses may not reach 90% of the total mass that many building codes require. Simply increasing the Number of Frequencies in Eigenvalue Analysis Control or number of

eigenvalue modes does not address the problem. The sum of modal participation masses can be verified by "Results > Result Tables > Vibration Mode Shape".

■ Resolving the error

Jacobi error and errors caused by large periods exceeding the range of spectral data can be detected by performing a static analysis under lateral loads. In such a case, the lateral loads should be applied to all the nodes in the model. This is most easily achieved by applying self-weight.

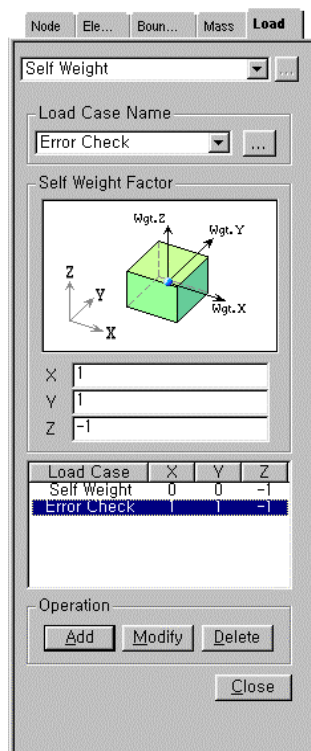


Figure 3. Specifying Self-weight to detect errors

As shown in Figure 3, the user is able to detect those nodes exhibiting large displacements from a static analysis after the self-weight is imposed in the lateral directions. Regardless of the loading directions, the user should check the elements connected to the nodes having large displacements to correct the causes for singularity errors. Prime targets for checking such errors are where there are truss or plate elements in the model, release in floor diaphragms, beam end releases, plate end releases, etc.

A similar method applies to errors caused by local vibration modes. If selection of appropriate elements is difficult, or singularity errors are inevitable for model idealization, you can change the structural model, add point spring supports to the nodes in question to resolve the problems. In this case, it is imperative that the point spring supports do not affect the behaviors of the adjacent nodes or elements. The spring support stiffness should be sufficiently small enough so that it does not affect the structural behavior.

If the sum of the effective masses falls short of 90% of the total mass calculated, you are advised to check whether or not the mass of substructure has been included in the total mass. (see "Getting Started>Model>Building>Control Data" in the Online Manual)

■ Analysis results without errors or problems

When the eigenvalue analysis is completed, without encountering such errors, you can see the distinct vibration mode shapes for each direction as shown in Figure 4. Also, you will notice that the sum of effective masses calculated up to 12 modes exceeds 90% of the total mass. Such a result is considered to include the correct dynamic properties of the structure and thus can be used for response spectrum analysis and structural design.

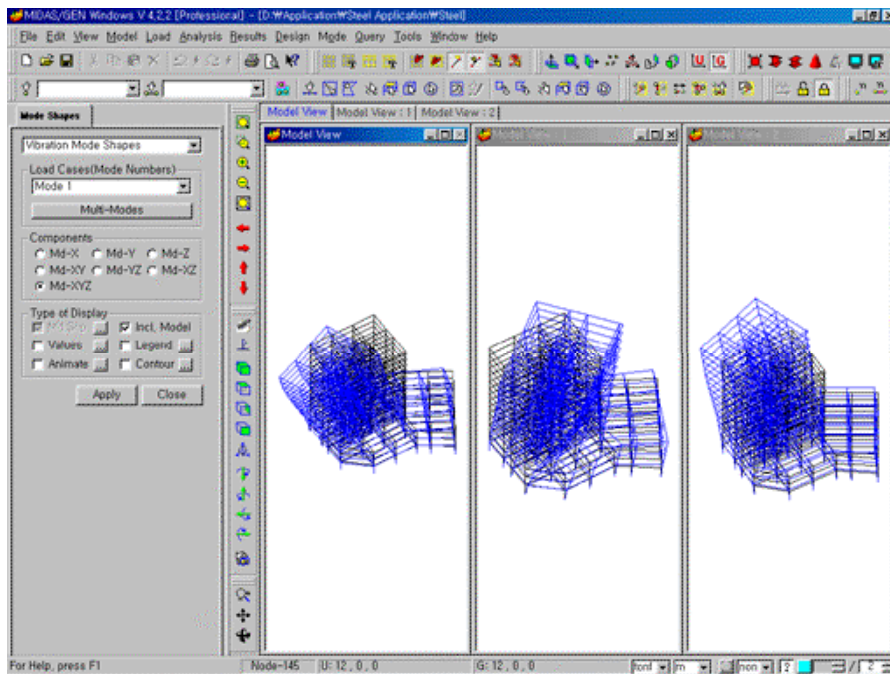


Figure 4. Vibration Mode Shapes

Node	Mode	UX	UY	UZ	RX	RY	RZ					
EIGENVALUE ANALYSIS												
Mode No	Frequency		Period		Tolerance							
	(rad/sec)	(cycle/sec)	(sec)									
1	2.173692	0.345954	2.890560	0.0000e+000								
2	2.167254	0.348112	2.872636	1.6709e-015								
3	2.651418	0.421986	2.369745	3.7902e-016								
4	5.494256	0.874438	1.143592	0.0000e+000								
5	7.076519	1.126263	0.887892	3.1216e-015								
6	7.880007	1.254142	0.797358	1.4876e-015								
7	9.098261	1.448033	0.690592	1.7167e-016								
8	13.618027	2.167376	0.461387	1.6290e-011								
9	14.375902	2.287996	0.437064	1.5206e-011								
10	16.132842	2.567622	0.389465	1.7024e-009								
11	18.803374	2.992650	0.334152	3.1113e-010								
12	21.785389	3.467252	0.288413	8.3293e-007								
MODAL PARTICIPATION MASSES(%) PRINTOUT												
Mode No	TRAN-X		TRAN-Y		TRAN-Z		ROTN-X		ROTN-Y		ROTN-Z	
	MASS	SUM	MASS	SUM	MASS	SUM	MASS	SUM	MASS	SUM	MASS	SUM
1	67.48	67.48	0.06	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01
2	0.03	67.51	4.75	4.82	0.00	0.00	0.00	0.00	0.00	0.00	49.26	49.27
3	0.02	67.52	62.16	66.98	0.00	0.00	0.00	0.00	0.00	0.00	4.00	53.27
4	1.74	69.26	3.97	70.94	0.00	0.00	0.00	0.00	0.00	0.00	24.70	77.97
5	19.79	89.05	0.54	71.48	0.00	0.00	0.00	0.00	0.00	0.00	0.52	78.50
6	0.31	89.36	17.72	89.20	0.00	0.00	0.00	0.00	0.00	0.00	0.14	78.63
7	0.13	89.50	1.74	90.94	0.00	0.00	0.00	0.00	0.00	0.00	2.95	81.58
8	5.70	95.19	0.32	91.26	0.00	0.00	0.00	0.00	0.00	0.00	0.34	81.92
9	0.16	95.35	1.46	92.72	0.00	0.00	0.00	0.00	0.00	0.00	0.18	82.10
10	0.04	95.39	2.87	95.60	0.00	0.00	0.00	0.00	0.00	0.00	6.12	88.21
11	0.12	95.51	0.55	96.15	0.00	0.00	0.00	0.00	0.00	0.00	2.06	90.27
12	1.80	97.32	0.05	96.20	0.00	0.00	0.00	0.00	0.00	0.00	0.36	90.63

Figure 5. Table of Vibration Mode Shapes