Blog

Warning Messages Related to Negative Eigenvalues in Abaqus

Posted by Support

In this post, we want to explain the negative eigenvalues error in Abaqus. In the Q&A part, we discussed this message briefly:

How to solve a negative eigenvalue error?

As mentioned, the basic reason for this warning message is stability. Generally, Abaqus warns such messages for the non-positive definiteness of the system matrix. Mathematically, the appearance of a negative eigenvalue means that the system matrix is not positive definite.

As you know, in general, a finite-element problem is written as:

$$F = K\,x$$

Where **F**, **K**, and **x** are the vector of nodal load, stiffness matrix, and nodal displacement vector, respectively.

Then a positive-definite system matrix K will be non singular and satisfy if:

$$x^T Kx > 0$$

For all nonzero x. Thus, when the system matrix is positive definite, any displacement that the model experiences will produce positive strain energy.

Abaqus negative eigenvalues messages are generated during the solution process when the system matrix is being decomposed. Physically, negative eigenvalue messages are often associated with a loss of stiffness or solution uniqueness in the form of either material instability or the application of loading beyond a bifurcation point (possibly caused by a modeling error). During the iteration process, the stiffness matrix can then be assembled in a state which is far from equilibrium, which can cause the warnings to be issued.

Main reasons for negative eigenvalues errors:

In practice, the messages can be issued for a variety of reasons, some associated with the physics of the model and others associated with numerical issues. The Abaqus message itself shows some origins of this warning:

```
***WARNING: THE SYSTEM MATRIX HAS 16 NEGATIVE
EIGENVALUES.
```

1
```
IN AN EIGENVALUE EXTRACTION STEP THE NUMBER OF
NEGATIVE EIGENVALUES IS THIS MAY BE USED TO
CHECK THAT EIGENVALUES HAVE NOT BEEN MISSED.
```

2
```
NOTE: THE LANCZOS EIGENSOLVER APPLIES AN INTERNAL
SHIFT WHICH WILL RESULT IN NEGATIVE EIGENVALUES.
```

3
```
IN A DIRECT-SOLUTION STEADY-STATE DYNAMIC ANALYSIS,
NEGATIVE EIGENVALUES ARE EXPECTED. A STATIC ANALYSIS
CAN BE USED TO VERIFY THAT THE SYSTEM IS STABLE.
```

4
```
IN OTHER CASES, NEGATIVE EIGENVALUES MEAN THAT THE
SYSTEM MATRIX IS NOT POSITIVE DEFINITE:

FOR EXAMPLE, A BIFURCATION (BUCKLING) LOAD MAY HAVE BEEN
EXCEEDED.
```

5
```
NEGATIVE EIGENVALUES MAY ALSO OCCUR IF QUADRATIC ELEMENTS
ARE USED TO DEFINE CONTACT SURFACES.
```

In addition to the causes shown in the warning message, some situations in which negative eigenvalues messages can appear include:

1. Buckling analyses in which the pre-buckling response is not stiff and linear elastic.

In this case, the negative eigenvalues often point to not-real modes. Remember that the formulation of the buckling problem is predicated on the response of the structure is stiff and linear elastic prior to buckling.

2. Unstable material response:

- A hyper-elastic material becoming unstable at high values of strain.

- The onset of perfect plasticity.

- Cracking of concrete or other material failures that cause softening of the material response.

3. The use of anisotropic elasticity with shear moduli that are unrealistically very much lower than the direct moduli. In this case, ill-conditioning may occur, triggering negative eigenvalues during shearing deformation.

4. A non-positive-definite shell section stiffness is defined in a **UGENS** routine.

5. The use of a pretension node that is not controlled by using the ***BOUNDARY** option and lack of kinematic constraint of the components of the structure. In this case, the structure could fall apart due to the presence of rigid body modes. The warning messages that result may include one related to negative eigenvalues.

6. Some applications of hydrostatic fluid elements.

7. Rigid body modes due to errors in modeling (not enough BC, …)

Negative eigenvalue warnings will sometimes be accompanied by other warnings, addressing such things as excessive element distortion or magnitude of the current strain increment. In cases where the analysis will not converge, the resolution of the non-convergence will often eliminate the negative eigenvalue warnings as well.

For analyses that do converge, carefully check the results if the warnings appear in converged iterations. A common cause of negative eigenvalue warnings is the assembly of the stiffness matrix about a non-equilibrium state. In these instances, the warnings will normally disappear with continued iteration, and, if there are no warnings in any iterations that have converged, warnings that appear in non-converged iterations may safely be neglected. If the warnings appear in converged iterations, however, the solution must be checked to make sure it is physically realistic and acceptable. It may be the case that a solution satisfying the tolerance for convergence has been found for the model while it is in a non-equilibrium state. I hope you understand the negative eigenvalues (Abaqus negative eigenvalue) error origin in Abaqus and can solve your problem correctly. It would be useful to see **Abaqus Documentation** to understand how it would be hard to start an Abaqus simulation without any **Abaqus tutorial**.

How to learn the basic concepts of Abaqus?

Although this article will help you to start your Abaqus project, FEM simulation is a little complicated and based on our feedback from hundreds of students and researchers during the last three years, the **Abaqus course for beginner| FEM simulation tutorial** training package has saved a lot of time when simulating in Abaqus, and prepared codes in this package without any bugs or errors can speed up your simulation.
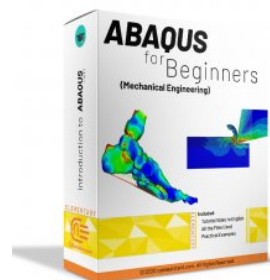
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