

Excessive Pivot Ratios Cheatsheet

Recommended procedure:

1. Below is an example of an excessive pivot ratio error. Above the fatal error is a warning message, showing which nodes and their DOF have the pivot ratio problems.

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*** USER WARNING MESSAGE 4698 (DCMPD)
    STATISTICS FOR DECOMPOSITION OF MATRIX KLL.
    THE FOLLOWING DEGREES OF FREEDOM HAVE FACTOR DIAGONAL RATIOS GREATER THAN
    1.000000E+07 OR HAVE NEGATIVE TERMS ON THE FACTOR DIAGONAL.
    USER INFORMATION:
    THIS MESSAGE MAY BE IGNORED IF NO GRID POINT IDS OR HIGH RATIO MESSAGES APPEAR IN THE TABLE ON THE NEXT PAGE.
1   MSC.NASTRAN JOB CREATED ON 09-NOV-11 AT 16:53:56                NOVEMBER 9, 2011 MD NASTRAN 4/27/11 PAGE 6
0
0
0
    GRID POINT ID      DEGREE OF FREEDOM  MATRIX/FACTOR DIAGONAL RATIO  MATRIX DIAGONAL
    11077              R2              1.84205E+12      2.06674E+03
    1198               T3             -1.73615E+14      6.82135E+05
    387                T1              2.73639E+07      1.36819E+07
    387                T2              2.73639E+07      1.36819E+07
    387                T3              6.46199E+07      6.46199E+07
    387                R1              1.61135E+07      3.22269E+07
    387                R2              1.61135E+07      3.22269E+07
    387                R3              2.24193E+07      2.24193E+07
^^^
^^^ USER FATAL MESSAGE 9050 (SEKRRS)
^^^ RUN TERMINATED DUE TO EXCESSIVE PIVOT RATIOS IN MATRIX KLL.
^^^ USER ACTION:  CONSTRAIN MECHANISMS WITH SPCI OR SUPORTI ENTRIES OR SPECIFY PARAM,BAILOUT,-1 TO
    CONTINUE THE RUN WITH MECHANISMS.
1   MSC.NASTRAN JOB CREATED ON 09-NOV-11 AT 16:53:56                NOVEMBER 9, 2011 MD NASTRAN 4/27/11 PAGE 7
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2. If using a GUI, highlight or find the nodes in this error message. Look around the area of these nodes for problems. (See next section on hints for what to look for.)
3. Sometimes, the directions give a hint as to what the problem is.
 - For example, if Node 11077 belongs to a solid, having a problem with R2 should not be possible. This is because solid nodes have no rotational stiffness. The rotational stiffness should have been constrained; something else is connected to R2 that is having an unintended consequence. Look for a non-solid element connected to Node 11077.
 - In the example above, notice that Node 387 is listed in all 6 directions. When a node has all 6 directions listed, that means the stiffness of that node is either 0.0, too large for the model, or too small. Most often, it means it's a floating or completely unconstrained node. Sometimes, it's connected to a spring or element that is too soft or too stiff. Make sure that node is connected to an element, and if it is, make sure that element has reasonable material and element properties.
4. Sometimes the pivot ratio value can give a hint.
 - In the example above, Node 1198 has a negative sign on the pivot ratio. That usually indicates a constraints problem. That node is either completely unconstrained or the stiffness around the area of that node is too small compared to the rest of the structure.
 - On Node 387, the stiffness ratios are all positive and noticeably smaller than the other two stiffness ratios in this example. That means this node is probably connected to elements. However, the stiffness around these elements is almost good enough to pass. The Nastran parameter MAXRATIO controls how large a pivot ratio can be before a fatal message is issued. MAXRATIO by default is 1.0e7. These are not too far above that. This means the user should check the stiffness of elements around that node. There's a very good chance this node sees a connection between two different types of elements, and these two different types of elements have very large differences in stiffness. For example, a spring connected to a shell element can show very large changes in stiffness. Check the element and property values of this area, and if they cannot be adjusted, it might be justified to use a different MAXRATIO or even use BAILOUT. MAXRATIO is adjusted, or bailout is used, check epsilon.

What are some causes of Excessive Pivot Ratios, exactly what are we looking for in these problem areas?

Cause #1: Bad Constraints

- Are there constraints in all three translations? Even if there's no load in one of the directions, all 3 translations need to be constrained.
- What about rotations? Rotational constraints:
 - Don't have to be in the rotational direction. For example two nodes constrained in X prevent rotation in Y and Z.
 - Rotational constraints don't work if the elements connected to the constrained node don't have stiffness in that direction. For example, constraining nodes on a solid element in 456 directions won't do anything since those elements don't have stiffness in rotations.
- Solution: Constrain the model, or if this is model is meant to be free-free or really is flying through space, consider inertia relief. There is insufficient time to cover inertia relief in detail. Hopefully a future SimAcademy presentation can explore this technique in detail.

Cause #2: Bad connections

- Elements might not be connected to each other. Look at a free edge plot. Free edges are edges that are not shared by multiple elements. Generally, free edges can indicate cracks on the inside of a model. There are two things to look for on a free edge plot:
 - There should only be free edges on the corners of a solid mesh or the outline of a 2-d mesh. Free edge plots won't tell you very much for a 1d mesh. On a solid tet-mesh, the free edges may show up as dashed or broken lines. This is normal since automatic meshes may randomly fill a corner with one or multiple tetrahedral elements.
 - If there are missing free edges on a corner or outline of a 2d mesh, there may be duplicate or extra elements. For example a duplicate mesh from a bad copy command to a 2d mesh sitting on top of a 3d mesh.
 - Solving a mesh that is not connected may be as simple as equivalencing or merging coincident nodes. Or it can be as complicated as modifying the underlying geometry and re-meshing. Newer versions of Nastran allow glued contact to dissimilar meshes. (See previous SimAcademy on using Glued Contact, RSPLINE and CINTC for gluing dissimilar meshes.)
- Mixing Element types:
 - If there are multiple types of elements, each element has different types of stiffness.

Element	Stiffness DOF/Node	Description
1D		
Rod	2, TX, RX	Axial + Torsional
Bar	6, TXYZ, RXYZ	Rod Stiffness + Bending
Beam	6+1, TXYZ, RXYZ+SPOINT	Bar Stiffness + optional warping
2D		
Shell	5, TXYZ, RXY, no RZ or 6 TXYZ, RXYZ (v2005+)	Membrane + Bending + Shear, all 3 translations + 2 rotations. No RZ stiffness. Recent Nastran versions have RZ stiffness by default using K6ROT=100.0. (around Nastran 2005) New Nastran CQUADR /CTRIAR has rotational stiffness built in.
3D		
Solid	3, TXYZ	Stiffness in translations only/Forces only.

OD		
Spring	1	User defined
CBUSH	1-6, TXYZ RXYZ	Stiffness in axial and 2 transverse directions. Can have stiffness in all 6, or any combination.

- For example, shells have stiffness in 5 directions, 3 translations, 2 rotations for bending. Solids only have stiffness in the 3 translations. If a shell connects to a solid, what happens to those extra rotational stiffnesses that the shells bring? If these rotations aren't coupled out as forces on the solid, the model can fail due to Excessive Pivot Ratios.
- Solutions: Turn off the rotational stiffnesses, use Rigid Elements to couple out rotations, or consider using glued contact in the case of shell to solid problems.

Brute Force Solution for Cause #1 and Cause #2

- Excessive pivot ratios can have multiple causes. However, cause #1 and cause #2 mean there is a stiffness in the model that is almost zero or a degree of freedom that is unconstrained. In this case a linear static solution is impossible. However, a normal modes solution is possible. In normal modes, MSC Nastran is actually trying to find situations where the stiffness ratio goes to zero.
- Running a normal modes analysis in this case will result in Eigenvalues/Natural Frequencies close to zero. They will not be exactly zero due to roundoff error. The worse the pivot ratio problem is, the farther from zero these rigid body modes will be. Plot the mode shapes to these rigid body modes. This will indicate the direction that needs to be constrained or the location of the mechanism.
- There will be a rigid body mode for every unconstrained mechanism in the model.
 - For example a structure that's missing a constraint in X will have 1 rigid body mode, and this eigenvector will show the structure moving in the X direction.
 - If there are no constraints, there will be 6 rigid body modes. Three rigid body modes for the 3 translations and 3 rigid body modes for the rotations. These will NOT necessarily line up with any particular coordinate system.
 - If there are more than 6 rigid body modes in a model, then there may be multiple connection problems in the model.
- This solution will not work if the pivot ratios are too high, or if there are too many rigid body modes. In that case, even a normal modes analysis will not run.

Cause #3: Pivot ratios are too high; this means that there is a large difference in stiffness in the model. MSC Nastran can handle when an element has infinite stiffness, (RBE2), or zero stiffness, (constrained with AUTOSPC.) However in this case, something in the model has almost infinite or almost zero stiffness.

- Check material properties and element properties. Specifically, check the E, thickness, and moment of inertia values.

Cause #3b: Pivot ratios are too high: Another cause for this problem is something with high stiffness is connected to something with low stiffness

- Example: A thick steel plate connected to a soft, thin rubber layer of elements. In this case, the different in stiffness is far too high, there may be a high amount of error due to roundoff. MSC Nastran will issue UFM 9050 as a safety feature to prevent giving a bad answer.

- Solution: Consider eliminating the low stiffness component or replace the high stiffness component with a rigid element.
- This also happens when customers make elements with arbitrary stiffness. For example the extra stiffnesses on a CBUSH element. Some users will use a CBUSH for axial stiffness and then guess values for the other 5 stiffnesses. For example, a user might assume that E for steel is 30e6 psi. So the stiffness in the area must be around 30e6 lb/in. This is not a good assumption because E does not equal stiffness. For a rod element, stiffness is actually EA/L. E indicates stiffness, but it's only proportional to stiffness.
 - Reconsider what a reasonable stiffness for those CBUSH's would be. To estimate the stiffness of a model, run a small portion of it and apply a load. Load/Displacement will give a crude estimate of the stiffness. Compare this value to guessed or arbitrary stiffnesses in the model.
- Sometimes, if all the stiffness values cannot be changed, it may be possible to force the model to run using param, BAILOUT or param, MAXRATIO. These settings increase the tolerance that Nastran will allow for an analysis.

Miscellaneous Causes:

- Some customers have accidentally switched the value of Poisson's Ratio, ν and Shear Modulus, G.
- Some customers have accidentally crossed DOF using Springs, rigid elements, or MPC's.
 - Normally, stiffness should go from X to X, Y to Y, etc. However for these types of elements, the directions for each node is user defined. The most common situation for this is when nodes in the model have different output coordinate systems. Even though the element looks like TX is connected to TX, since each node has a different coordinate system, the directions are crossed.
 - When springs, rigid elements, or MPC's are used, make sure all the nodes have the same output coordinate systems. If the nodes have different output coordinate systems, be extremely careful.

Recommendation if MAXRATIO or BAILOUT is used:

- Many established engineering groups use MAXRATIO and BAILOUT successfully. One very important model checkout to use if these settings are used is to look at epsilon.
- Check Epsilon. Epsilon is a measure of roundoff error in the model. It is obtained by calculating $F-[k]x$. This number should be zero, but it won't be because of roundoff error. This error parameter is a vector, (a long list of numbers that can be positive or negative.) and has the units of load, so multiply it by displacements to get work done. Work is one number for the whole model and is always positive. Take this work value and normalize by the strain energy in the model. This normalized single number based on error is epsilon.
- The magnitude of epsilon indicates how many decimal places the displacements are good for. For example, an epsilon of 1.0 means the displacements are good to NO decimal places. On the other hand, a displacement of 1e-16 means the displacements are probably good to 16 decimal places.
 - Epsilon only measures roundoff error. There are still plenty of other sources of error a human can introduce to the model. MAXRATIO and BAILOUT may be masking fundamental problems with a model. Use with caution.
- Epsilon should be no more than $0.001 * \text{max displacement}$. If epsilon is too high, then there is a modeling issue that should be addressed before the results can be trusted.