USE OF INERTIA RELIEF WITH REFLECTIVE SYMMETRY

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ABSTRACT

Many moving bodies for which inertia relief is desired also have a reflective plane. It is not obvious how to use MSC/NASTRAN to include both effects. There are conflicting procedural requirements for using the SUPORT condition and for boundary conditions on the reflective plane when general loading is present. A procedure has been worked out to obtain the proper support at the plane of symmetry so that a single computer run suffices. The approach is approximate, but the error can be driven below 1% by properly tuning the constraints in terms of location, mass, and stiffness of artificially introduced ROD elements.

INTRODUCTION

Motivation for this study comes from a study of an automobile engine connecting rod under running conditions. It was desired to model only a quarter of the rod to save memory and CPU time. The way the body was loaded with live (pressure) loads, inertial loads and reaction forces, it was desired to use inertia relief.[1] The rod design was being optimized and it was desired to do the analysis in a single computer run rather than in multiple runs or restarts. Existing procedures would have required neglecting one of the reflective planes or using multiple runs and superposing results.

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[1]One might ask why one would use inertia relief since the kinematics of the rod are known a' priori. MSC/NASTRAN cannot calculate all three of the common reversed effective forces due to acceleration. Only the centrifugal (RFORCE) and uniform translational fields (GRAV) can be automatically generated and applied to the body. Angular acceleration causes "tangential" inertial forces which cannot be found automatically. Therefore, even though the kinematics of the body are completely predetermined, the full set of reversed effective inertial loads is not available in the most direct way, but must be applied in an indirect way through inertia relief.

At the present time, the same SUPORT inertia relief card must apply to all subcases in the run. This means that both the symmetric and the antisymmetric load cases have to have the same coordinates supported to remove the rigid body modes. After some study, it was realized that the SUPORT card (under this condition) must be applied to grids on the plane of symmetry. The SUPORT card removes only a certain set of rigid body modes for the symmetric load case and a different set from the antisymmetric load case. Meanwhile, the supported grids should not interfere with the legitimate elastic modes.

In MSC/NASTRAN, the SUPORT calculation is redone at each subcase only if the boundary conditions change. This means that to change inertia loads from one subcase to the next, one must change the displacement boundary conditions. In the case of a reflective plane subjected to many load sets, the symmetric and antisymmetric load cases must be alternated.[2] A price is hence paid for the decompositions that must also be done each time.

To summarize, the proposed procedure was developed because of the following procedures and limitations within MSC/NASTRAN. If any of the following change, the method proposed here could be greatly improved or would not be needed.

1) MSC/NASTRAN does not calculate tangential inertia loads distributed over a body due to angular acceleration of the body.

2) MSC/NASTRAN requires that the SUPORT card attack all subcases at the same grids and same components. This prevents the use of different SUPORT cards for different subcases.

3) Inertia relief allows recalculation of new inertial loads at a subcase level only if the displacement boundary conditions change--not if the live loads change.

NUMERICAL EXPERIMENTS

Consider the two-dimensional membrane problem in Fig. 1. Displacements are limited to the xy plane. The body has a reflective plane in the sense of geometry, material and boundary conditions, but the loading is general (asymmetric). The body is made of steel with Young's modulus of 203,400. MPa, Poisson's ratio of 0.287, and

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[2]This alternate stacking idea was suggested by Jerry Joseph.

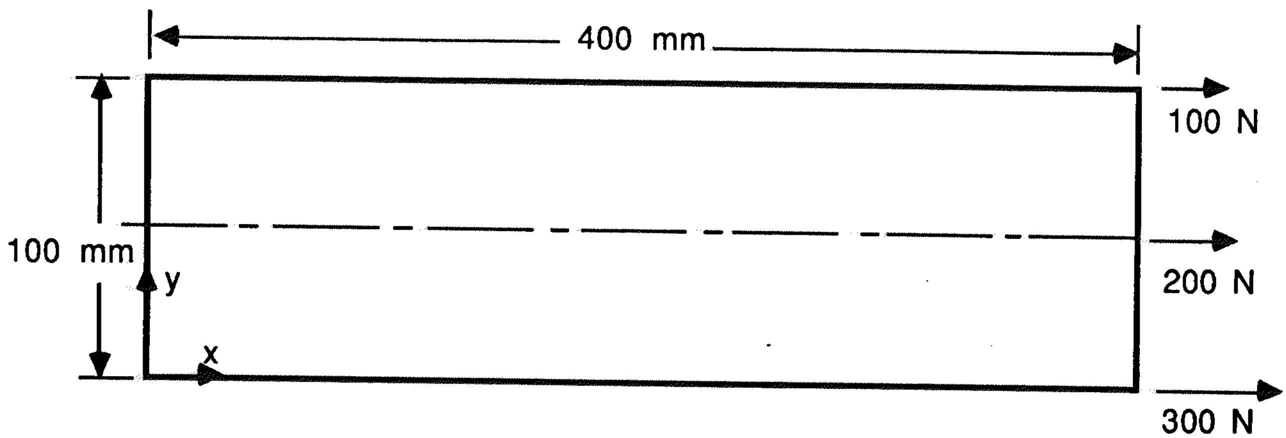

Figure 1. Membrane with Unbalanced Loads. (2 mm thick.)

density of 7.833 E-9 Mg/mm^3. There are no displacement boundary conditions specified. In this problem, the loading will accelerate the body in the x direction and will rotate it about an axis in the z direction. The dominant acceleration is essentially parallel to the reflective plane, but this is not crucial to the argument. In exploiting the reflective plane at y = 50., one can model the lower half (Fig. 2).

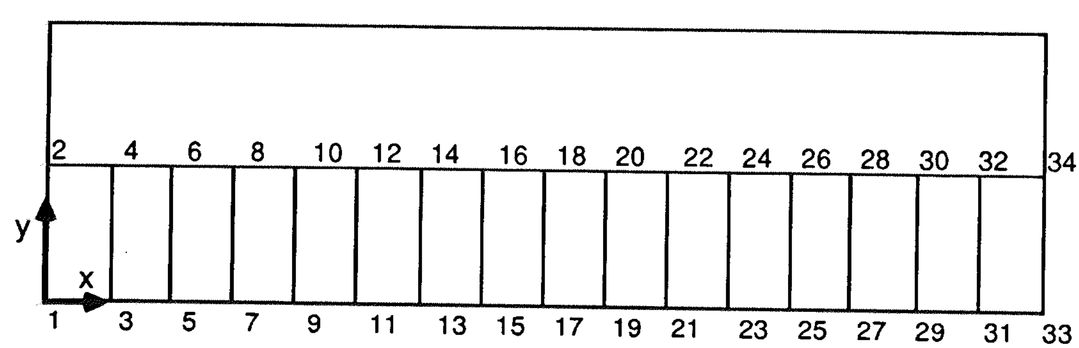

Figure 2. Finite Element Mesh, Exploiting Reflective Plane.

The loading is broken into symmetric and antisymmetric components as shown in Fig. 3. Also shown is the suggested orientation of 3 artificially introduced ROD elements, connected to 3 artificially introduced grids (which are grounded by the SUPORT card). These RODs act like "stand-off" springs, in a similar way that experimentalists find free-free vibration modes by using soft springs to support

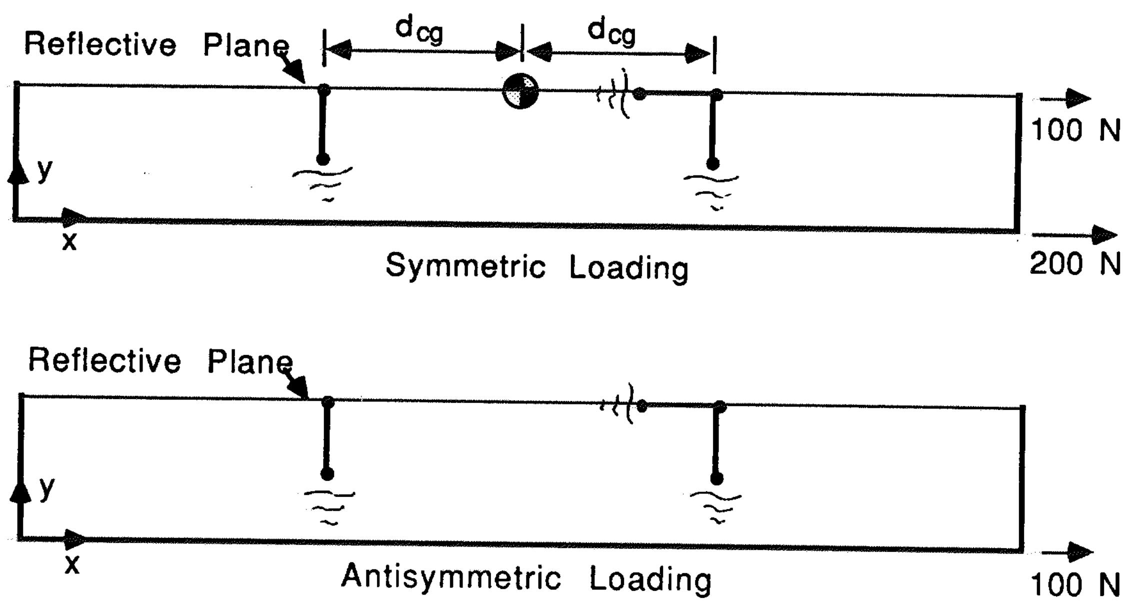

Figure 3. Suggested Use of RODS for Rigid Body Mode Removal.

the body during test. The main purpose of the RODS is to remove the rigid body modes from one of the load cases. The ROD in question must not interfere with the other load case. The RODS must therefore be stiff enough to provide the opposing force to the D'Alembert inertia in one SYM subcase, yet weak enough to allow the grids on the reflective plane to move elastically in the other SYM subcase.

Variables studied in this problem include the ROD stiffness, ROD mass and spacing d_{cg}.

A baseline model of the full problem was done (without exploiting the reflective plane). This model's results will be considered as the reference values for determining the modeling error due to the simultaneous use of inertia relief and a plane of symmetry. Error will be based on the maximum σ_x stress in the body.

A second approach for simultaneous use of inertia relief and a reflective plane involves the BAR element This proves not to be effective and is not recommended. This method appeared simpler, but in fact brings in another stiffness to calibrate (bending stiffness of the BAR) which is difficult to adjust.

It is tempting to try another method yet for accomplishing our goal. One could propose relaxing the physical symmetry conditions on the reflective plane, and to let only the inertia relief supports act there. This is another approximate approach, and constitutes a "tear" in the physical structure at the plane of symmetry. This is a type of dissimilar modeling which is harder to evaluate than the proposed scheme, and will be dropped.

PROPOSED PROCEDURE

Let us propose to SUPORT degrees of freedom on the reflective plane (Fig. 3). The grids to be supported must be artificially introduced--not a point on the physical structure--and will be connected to the body through artificially introduced ROD elements (Fig. 3). At first glance, one would think that massless ELAS1 elements could be used for this task, but the inertia relief process uses a mass condensation that becomes singular if the artificial bridge to ground is massless.

The presence of the mass in the ROD elements is a source of error. The ROD mass should be small so that the ratio of (artificial mass)/(true system mass) is negligible.

RESULTS

A number of ROD cases were tried and compared with the baseline (total model) solution. These results are given in Fig. 4. The location of the constraints from the c.g. seems to cause only a modest change in the percentage of stress error. On this body, spacing the supports at roughly one-third distances along the reflective plane seems to be practical.

The effect of mass ratio is clearly seen. The percentage error seems to be closely related to the percentage of (artificial mass)/(true system mass). If this mass ratio is taken to be too small, however, the mass condensation in the inertia relief becomes more ill-behaved. It is recommended to use a ratio of about 0.003 if possible.

The axial stiffness of the RODs was a little harder to adjust. If too stiff, the ROD has too great an effect on the elastic modes in the SYM load case which was not meant to be controlled. If the stiffness is too small, the rigid body modes are not restrained as well. The RODs used here were of axial stiffness of 12,780. N/mm.

Several sized BAR elements were also used to bridge the gap between the reflective plane and the ground point. The BAR elements had the same axial stiffness as the ROD elements. The best effort obtained is shown, resulting in several percent error. It is believed that this supporting system could be improved, but is probably not worth it.

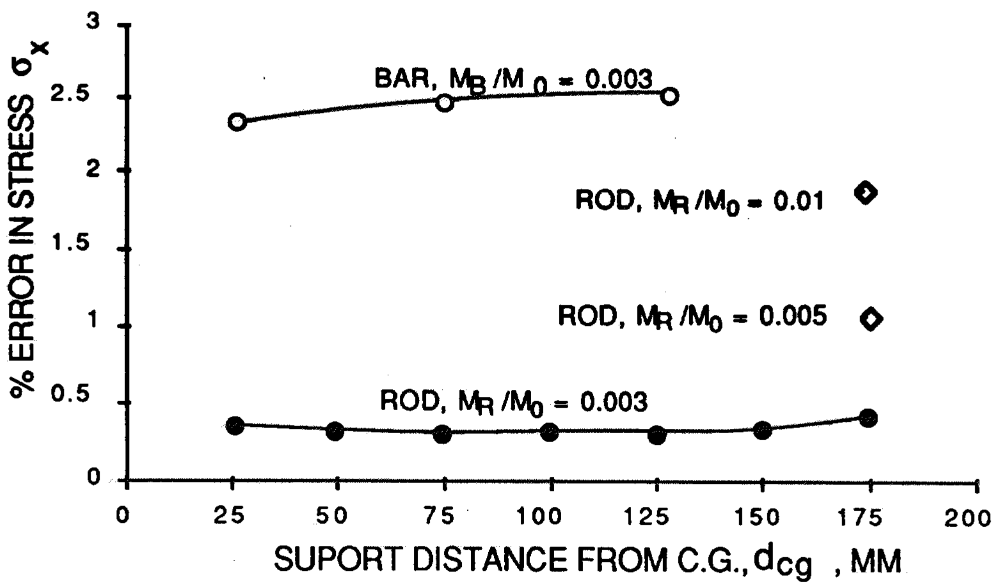

Figure 4. Error in Maximum Stress σ_x for Various Support Models.

CONCLUSIONS AND RECOMMENDATIONS

The procedure outlined is helpful if one wishes to combine inertia relief and use of a reflective plane with general loading, in one computer run. This can simplify some optimization schemes. The procedure will likely be superceded if program changes in MSC/NASTRAN are made or if appropriate DMAP procedures are developed.

One must apply SUPORT conditions to grids on the plane of symmetry in such a way as to remove rigid body modes from the symmetric (antisymmetric) load case, yet not overly constrain the elastic antisymmetric (symmetric) displacements on the reflective plane. This can be done by using artificial ROD elements of low mass (about 0.003 of the structural mass), by positioning the two constraint locations at one-third and two-thirds of the body length, and by choosing the ROD stiffness to be more flexible than the structural stiffness of the body. It will pay the user to run a small sample problem of similar size, mass and loading as the full scale problem in order to size the ROD elements.

If MSC/NASTRAN can be altered in such a way as to permit use of separate SUPORT cards for each subcase, then the present procedure will not be needed. In that case one could use one type of SUPORT for the symmetric loads (all stacked in a sequence) and another type of SUPORT for the antisymmetric load cases (all stacked in a sequence). This would eliminate CPU time currently needed for separate decompositions.