EXPERIENCES WITH SOLUTION 66 IN MSC/NASTRAN

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Abstract

Nonlinear analysis is finding its way into the everyday engineering environment for a variety of reasons including durability, material optimization, and cost effectiveness. There are several solution sequences available in MSC/NASTRAN for nonlinear analysis including SOL64 and SOL66. SOL64 is for geometric nonlinearity only, whereas SOL66 can handle both material and geometric nonlinearity. Also, SOL66 provides a number of attractive features not available in SOL64. Therefore, it is becoming increasingly important for analysts to be familiar with SOL66. This paper discusses the authors' hands on experience with some of the features of SOL66.

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Introduction

Since its introduction in MSC/NASTRAN, solution 66 has shown a great deal of promise for nonlinear analysis. Its potential is mainly due to the variety of capabilities available to the analyst. These include geometric and material nonlinearity, gap elements, automatic divergence checks, several stiffness update options and convergence criteria. For geometric nonlinearity, it appears that more future development will be concentrated on SOL66 than the other geometric nonlinear solution sequence, solution 64. The purpose of this work is to gain hands on experience with some of the features of SOL66. For the benefit of other users, this paper states some of the observations and questions encountered during the course of the work. Although some hypotheses are presented, the authors do not have answers to all the questions.

The topics discussed in this paper include convergence criteria, solution methods, restart capabilities, gap elements, load increments, path dependency, and effects of model size. This study was limited to geometric nonlinear solutions only and the major portion was done with solution 66 in version 64A. However, other versions and solution sequences were used as deemed appropriate for comparison purposes and these are noted in the text. All the studies were done using an IBM-3033 system.

Description of Models

There were three models exercised during the course of this work: a cantilever beam, a coarse tire model, and a fine tire model. The cantilever beam, shown in figure 1, was composed of two layers of HEXA elements with 180 DOF. A rubber-like isotropic material property was used via a MAT1 card.

Figure 2 shows the coarse quarter tire model created using QUAD4 plate elements with approximately 400 DOF. A rigid wheel was simulated by connecting the tire bead grid points to the spindle grid point using MPC relationships. Orthotropic material properties, accounting for the composite structure of the tire, were used via MAT2 cards. The properties included membrane, bending, transverse shear, and membrane-bending coupling.

The fine quarter tire model (Reference 1) is illustrated in figure 3. This model also used QUAD4 elements and had 2700 DOF. Material properties were similar to those of the coarse tire model. Compared to the coarse tire model, this model had more grid points per cross section and also used more section planes to define the tire.

Discussion

The following sections describe the results and experiences on each of the features studied.

Convergence Criteria:

In solution 66, convergence can be tested by checking the displacement error, load equilibrium error, and work error. The convergence criteria may be any combination of one or more of these tests. The efficiency and effectiveness of each of the seven combinations were studied using the cantilever beam with a pair of small concentrated loads at the free end. This was done for each of the six methods for controlling tangent stiffness updates: AUTO, ITER, SEMI, LSQN, AUTOQN, and SEMIQN. A total of forty-two cases were studied. The results showed that for each method convergence could be obtained with any of the seven criteria or would not work at all. All methods produced converged solutions except AUTO and ITER and the results were the same. In general, the displacement error check used less CPU time to obtain a converged solution while the difference in CPU time among other criteria was insignificant.

Solution Methods:

The cantilever beam was again employed to test the six different tangent stiffness matrix update methods (AUTO,ITER,...). It is understood that the various solution methods have different characteristics and it is not expected that they all will produce converged solutions on the same class of problems. To check the effectiveness of the different methods, a large concentrated load was applied to introduce large displacements. The default convergence test and error tolerance limit were specified. SEMIQN was the only method that provided a converged solution. It is not clear why SEMIQN, the only successful method, was not selected by the program when the automatic selection feature was utilized.

Restart Capabilities:

Unlike solution 64, solution 66 stores all the information required to restart from any load increment. Because of this, it is possible to restart from the database even if divergence is encountered. This can save the effort expended in reaching the last converged increment. However, it should be noted here that storage overflow problems may occur due to continued growth of the database.

To study this restart capability, the cantilever beam and also the fine tire model were used. Starting with the cantilever beam, a converged solution was first obtained in three increments for a concentrated load. Then three cases were studied for restart from the end of each increment. The restarts from one and two were intended to reach the converged solution obtained earlier. The restart from the third increment involved application of an additional load at the free end.

A converged solution was obtained for the restart from increment two, which was in good agreement with the solution obtained in the initial run. The restart from increment one failed to converge, the cause of which is unknown. From increment three, the success of restarting appeared to depend on the magnitude of additional load applied. When the additional load was very small, divergence occurred. It is hypothesized that in MSC/NASTRAN the load vector is handled in single precision, and therefore a very small load increment may lose its significance.

The fine tire model was used to study the effect of model size on the restart capability. The loading consisted of an internal pressure and a patch load via SPCs (Reference 2). Eighteen load increments were used. Several restarts from different locations were tested and convergence was obtained in all the cases. This suggests that the restart capability is not hampered by model size.

Path Dependency:

To study the effect of load path dependency on geometric nonlinear solution results, several tests were run using the cantilever and coarse tire models. With the cantilever, two load sets were used: a pair of concentrated loads at the free end and a distributed load along the length of the beam. Three cases were run in which the load sets were applied in different sequences. First, both load sets were applied together. In the second case, the concentrated load was applied and after convergence the distributed load was added. The third load sequence was the reverse of the second. The results showed that for this problem the solution was independent of load history. For comparison, an attempt was made to run the first case in SOL64, but a converged solution could not be obtained.

Path dependency was also tested with the coarse tire model. Again, two load sets were used: an internal pressure and a patch load using SPCs. The first case involved application of pressure followed by the patch load. The second case was the reverse of the first and in the third case both loads were applied simultaneously. Comparison of the first and third cases showed a few percent difference in the force at the spindle grid point. For the second case, the solution diverged during the application of the patch load. Due to divergence problems, it was not possible to conclusively determine the effects of load history dependency with this model. It is not clear if model size and/or degree of nonlinearity contributed to the divergence problems.

Gap Elements:

Gap elements can provide a convenient method for handling contact problems. To test their effectiveness, frictionless gaps were used to model the vertical contact between the tire and the ground (Figure 4). Both the coarse and fine tire models were utilized. Four methods were tested for applying the vertical load to the coarse model. For the first method the ground was fixed and a displacement was applied at the spindle point. In the second, the displacement was replaced by a force. Converged solutions were obtained for each method. The solution results were similar, however the application of force required twice as many load increments and therefore twice the CPU time.

The spindle was fixed for the third and fourth methods, with vertical displacement or force applied, respectively, at the ground. In these methods, solutions could not be obtained with the footprint center point fixed. Therefore, as illustrated in figure 5, a gap element was added to the footprint center point with an initial gap (Reference 3). For the third method, a solution was obtained similar to methods one and two, but the fourth diverged. With no fixed footprint nodes, some numerical problems were anticipated due to the use of initial gaps with zero stiffness. However, no such problems were encountered. When solving by the third method, a solution was obtained that complied with the convergence criteria, but the footprint load was seven times larger than the results of the other methods. However, by simply changing the load increment, the correct results were obtained. It is not clear why the load increment had an effect on the final results when both solutions had the same convergence.

Methods one, two and three were also tried on the fine tire model, in both V64A and V63, to study the effect of model size. Methods one and two failed to give a converged solution, whereas, method three provided convergence in each version. It was observed when using method one, that divergence occurred at different percentages of the total load when different load increments were used. In general, divergence was experienced earlier when the number of load increments was larger. In most cases divergence occurred with the gimbal angle of one or more DOF exceeding ninety degrees. Is it not understood whether larger model size was a factor in divergence with the fine model when using methods which provided convergence for the coarse model.

Load Increments:

In nonlinear analysis, it is believed that convergence rate can be improved by choosing smaller incremental load. The experience with SOL66 showed that this is not always true. For instance, the cantilever beam model with a concentrated load was tested with seven cases using one through six and also ten load increments. In this test, only the cases with two, three, five and six increments converged. Although a small incremental load was applied, the case of ten increments did not provide convergence.

In another example the same cantilever beam was axially loaded. After convergence, a vertical concentrated load was applied with cases using ten, five, four, three, and two load increments. Only the case with two load increments converged. The convergence problems experienced during these tests may have been due to the existence of local instability as illustrated in figure 6. In these examples, iterations of the smaller load increments happened to fall at the instability point while the others missed this point.

It was also noted in the first example that small load increments did not improve the convergence rate. The two increment case required a total of 41 iterations for convergence, while the case of six increments took 76 iterations.

General comments:

A few miscellaneous observations were made during the course of this work. These are described in the following sections.

Buffsize:

It was discovered, using SOL66 in V63, that obtaining a converged solution may depend on the BUFFSIZE defined on the NASTRAN card. For example, the fine tire model with a BUFFSIZE of 2350 gave a converged solution while a BUFFSIZE of 5860 did not. When this was tested in V64A, a converged solution could not be obtained with either BUFFSIZE. It should be noted that the patch load applied in this test was larger than that used in the test with gap elements.

Material Properties:

MSC/NASTRAN shell elements can have anisotropic material properties specified via MAT2 cards. These properties include membrane, bending, transverse shear, and membrane-bending coupling terms. SOL64 in all versions did not produce convergence when coupling terms were included in the material property. This difficulty was not encountered in SOL66.

Although SOL66 is designed for geometric and material nonlinear analysis, linear material property can also be used. If linear property is employed, it should not be changed in the restart runs, otherwise SOL66 may treat the material as elastic-plastic. On the other hand, when a new material property is included in the restart of SOL64, the previous properties are disregarded.

When MAT9 property cards were specified for solid elements, SOL66 in V64A (IBM version) stopped in the NLITER module without any message. It has been suggested that this is due to an error in the overlay structure embedded in V64A. The MAT9 card works properly in VAX versions.

Boundary Conditions:

At any restart in SOL64, boundary conditions and enforced displacements defined via SPC cards can be changed. However, in SOL66 these can be changed only by introducing a new subcase after closing the previous subcase.

If it is required that the final stiffness be updated, one more iteration may be run with a dummy load applied to a point isolated from the structure.

Conclusion:

The experience gained in this work suggests that SOL66 can be a valuable tool for nonlinear static analysis. The most attractive feature of SOL66 is the reduction of "baby sitting" involved in obtaining nonlinear solutions. Also, saving the necessary restart information at each load increment eliminates the need to back up the database. The introduction of gap elements provides the potential for analyzing complex contact problems.

SOL66 is a relatively new procedure and is continually being developed. It is hoped that future enhancements of SOL66 will eliminate some of the remaining obstacles. For example, finding an effective number of increments to obtain a converged solution for a nonlinear problem is a trial and error process. Also, there are several other parameters affecting convergence which must be selected by the user. Further automation in these areas would be a major benefit.

It is felt that elimination of the machine dependency of the code and an answer to the question on the effects of model size would be helpful to the analyst. Also, there is a need for more explicit documentation on the use of SOL66.

Nonlinear analysis is an inherently complex process and extensive experience is required for success. Specific implementation of nonlinear finite element techniques varies from code to code. Even with a strong background in nonlinear analysis, there is a need for the appropriate training courses to learn specific implementation details and to avoid pitfalls.

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References

1. Richards, T. R. et al, "Modal Analysis of Tires Relevant to Vehicle System Dynamics", 3rd International Modal Analysis Conference Proceedings, January, 1985, Orlando, Florida.
2. Sundaram, S. V. et al, "Vibration Modes of a Tire Using MSC/NASTRAN", MSC/NASTRAN Users' Conference Proceedings, March, 1985.
3. Wallerstein, D. V. et al, "Finite Element Analysis and the Modeling of Tires", MSC/NASTRAN Users' Conference Proceedings, March, 1984.
4. MSC/NASTRAN User's and Application Manuals.

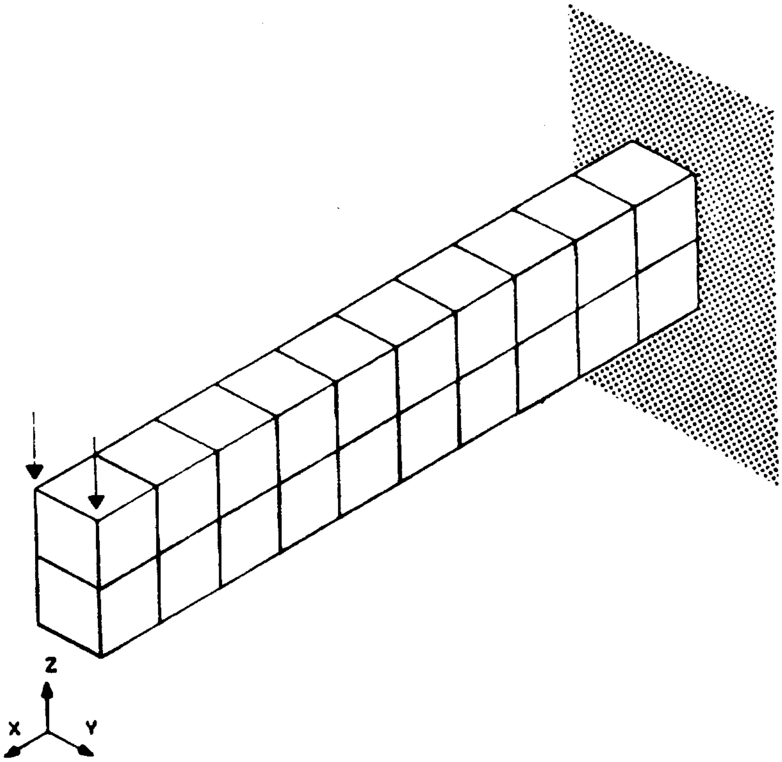

Figure 1. Cantilever Beam Model

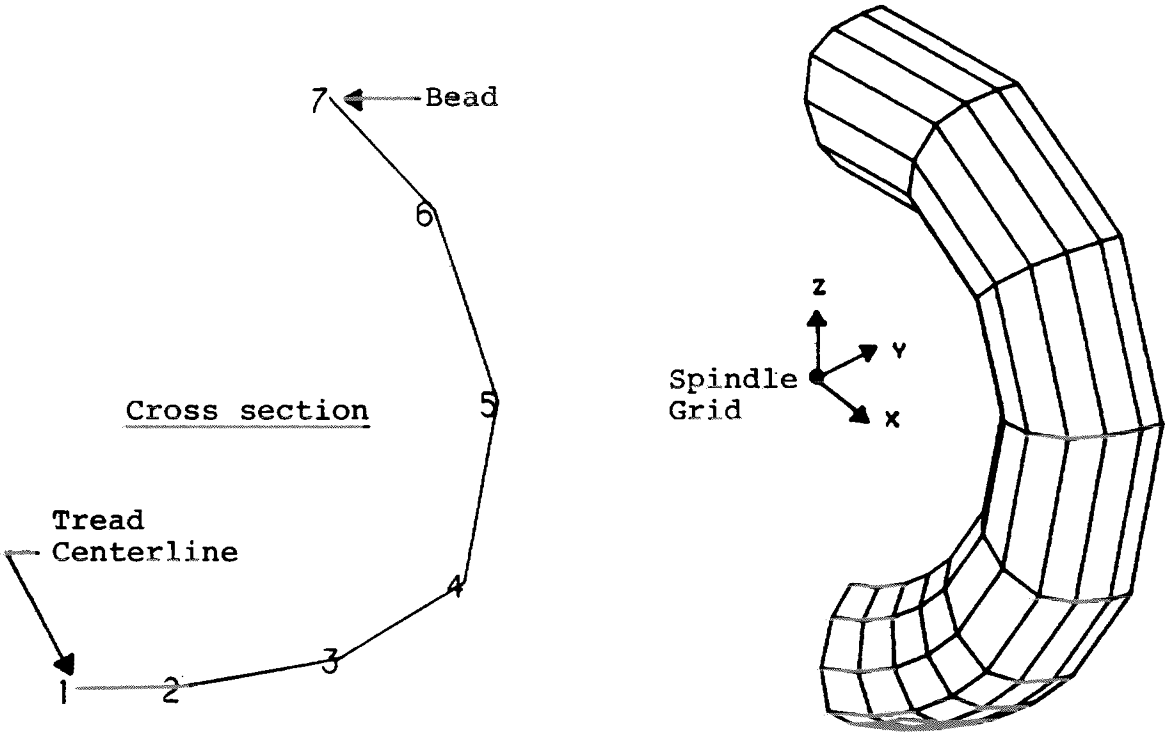

Figure 2. Coarse Tire Model

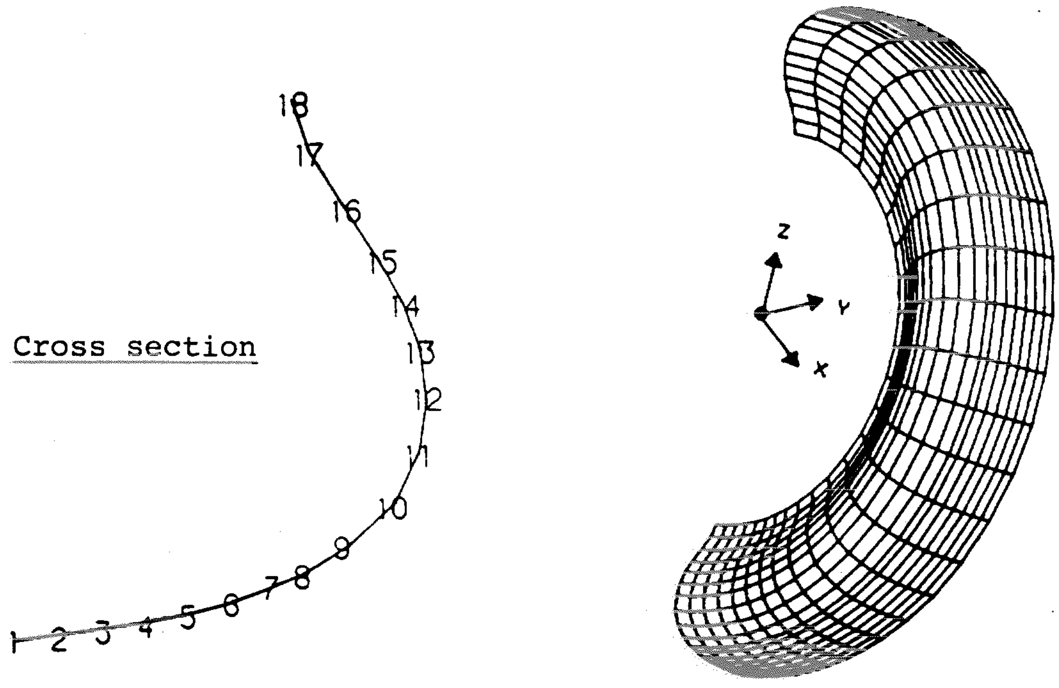

Figure 3. Fine Tire Model

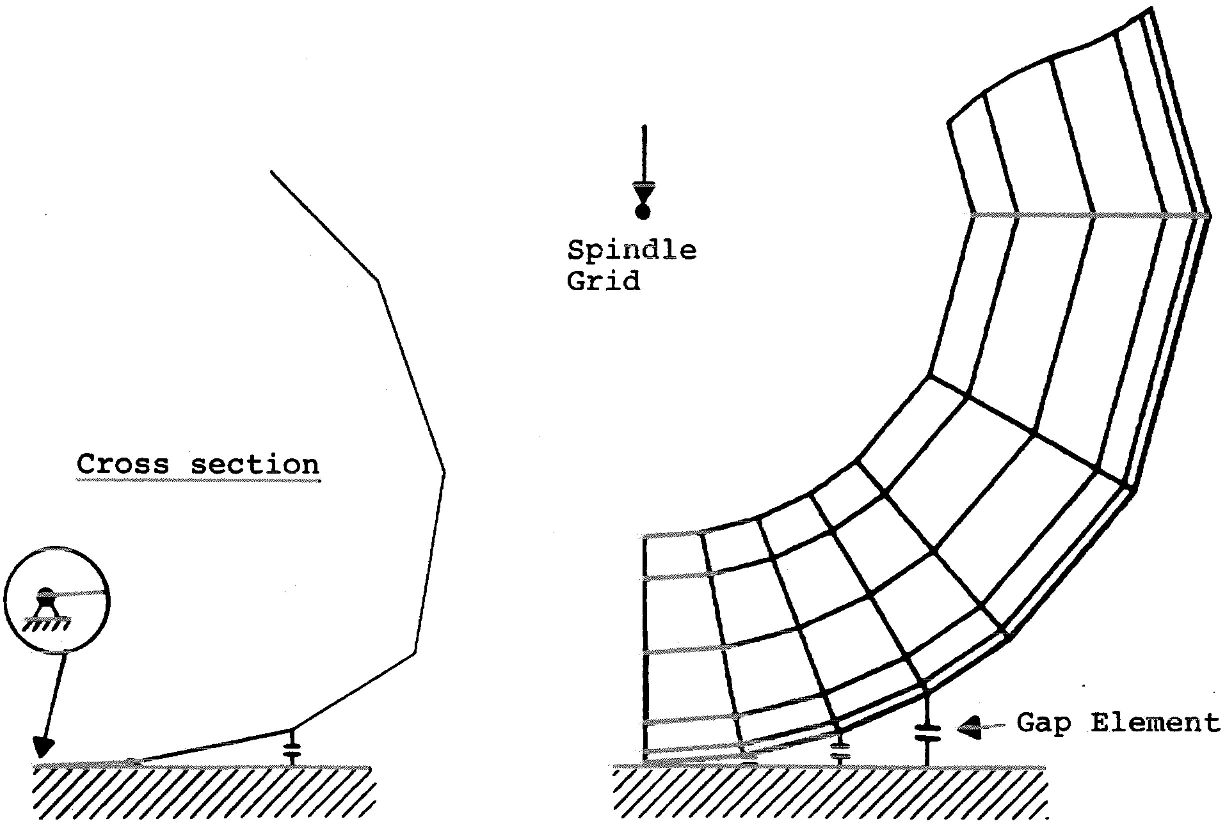

Figure 4. Tire Model with Gap Elements
(Footprint center grid fixed)

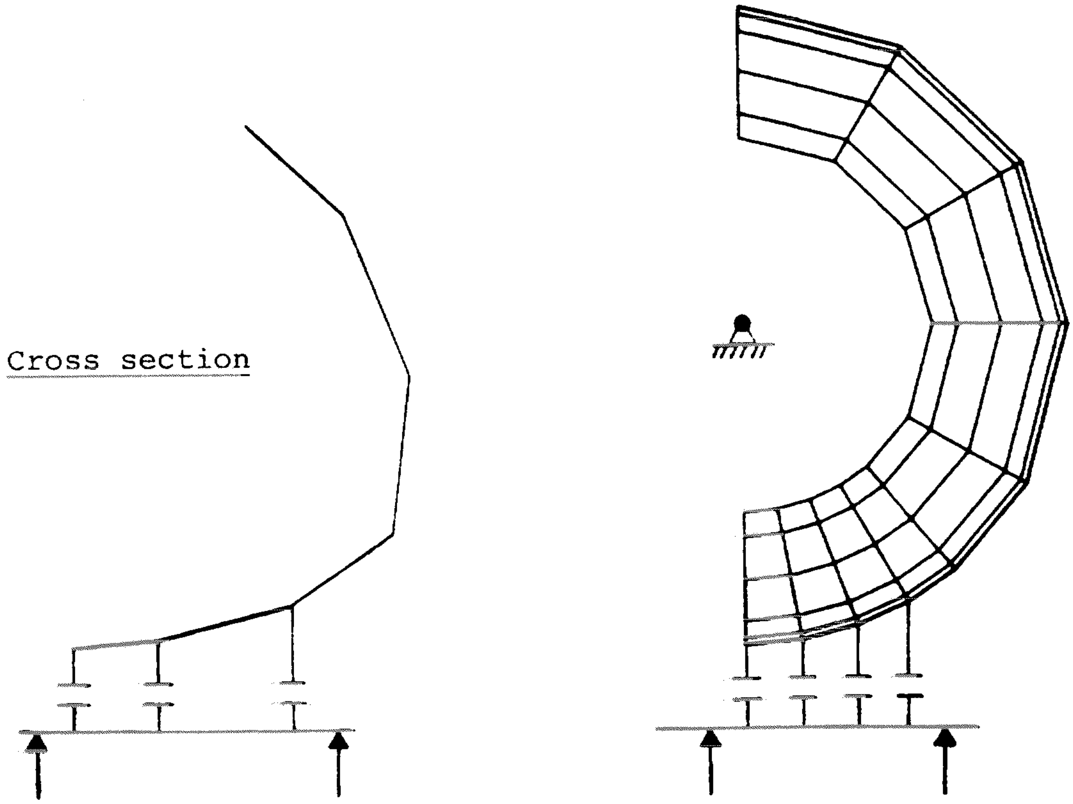

Figure 5. Tire Model with Initial Gap at Footprint Center Grid

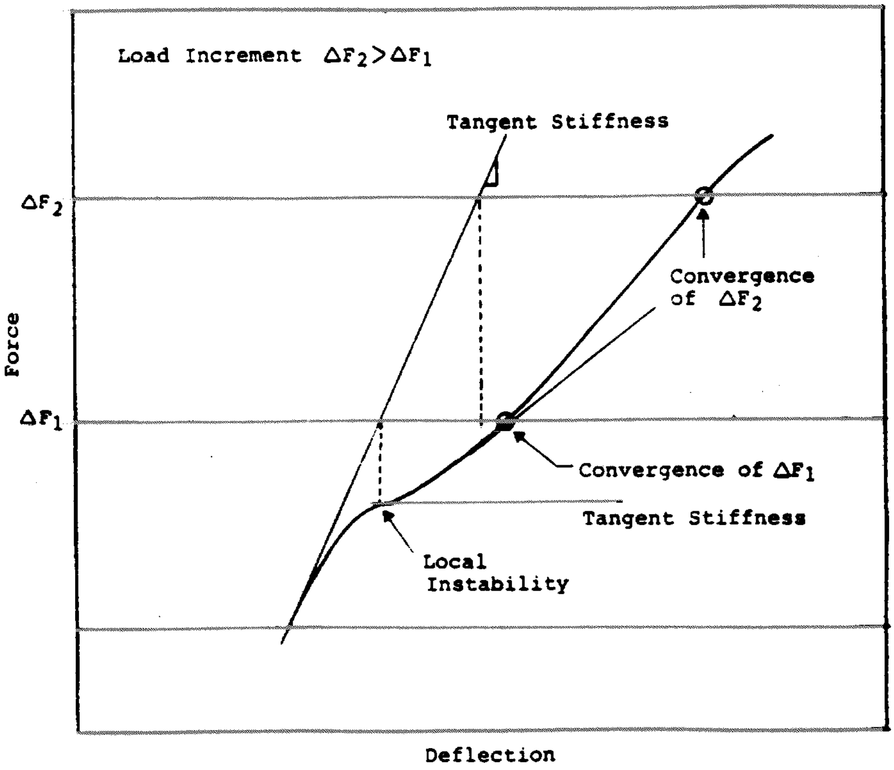

Figure 6. Effect of Load Increment on Convergence