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PIPE5 Finite Element Analysis for Buried Structures

David Aldous

Utah State University

PIPE5 FINITE ELEMENT ANALYSIS

FOR BURIED STRUCTURES

by

David Charles Aldous

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Approved:

Dr. Steven Folkman Major Professor	Dr. Alma P. Moser Committee Member
Dr. Barton Smith Committee Member	Dr. Byron Burnham Dean of Graduate Studies

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ABSTRACT

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by

David C. Aldous, Master of Science

Utah State University, 2008

Major Professor: Dr. Steven L. Folkman
Department: Mechanical and Aerospace Engineering

PIPE5 is a two-dimensional finite element analysis program for buried structure analysis. The program has gone through several changes over the years. Some of the features that were added in the latest revision are stress stiffening, corotational formulation, bandwidth minimization, residual monitoring, and dynamic memory allocation. Some parts of the program were also rewritten to make them clearer and improve their performance. After the modifications several comparisons were made to other programs and earlier versions of the program to test the accuracy of the program in its latest form.

(148 pages)

CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

PIPE5 is a finite element analysis (FEA) program designed to analyze buried pipes and culverts whose development was spearheaded by A. P. Moser. PIPE5 started as a modification of the program SSTIPN in 1981 so that the program could run in batch mode on a mainframe and was written in Fortran IV language. Various students made modifications to the original code making it compatible with personal computers and adding additional features. For more history on early PIPE5 developments see Moser [1]. In 2003 Mr. Merrill began a project of updating PIPE5. Mariner did extensive work on making the code compatible with the Fortran 90 standard and adding a graphical user interface. While Mariner made significant modifications to PIPE5 there are still elements of the program that could be updated.

PIPE5 has been improved many times since its creation. For the sake of clarity the program before Mariner's modifications will be referred to as PIPE5v1. The program as Mariner left it will be called PIPE5v2. The program in its current form with the improvements detailed in this thesis will be known as PIPE5v3.

This thesis will document the changes to PIPE5v2 that produced PIPE5v3. The following list of objectives covers most of the changes made to PIPE5v2.

OBJECTIVES

1. Completing PIPE5v2 in a more modern style.

2. Replace the gap or interface elements part of the code with the procedure outlined by Katona [2].

3. Modify the PIPE5v2 program to accommodate large displacement calculations in a single load step by applying corotational theory.

4. Clarify the application of the Duncan soil model in the code to make it well documented and easy to understand.

5. Modify the file input scheme to support Nastran gap elements and use physical property cards to assign soil layers.

6. Implement an option for stress stiffening in beam elements.

7. Implement a scheme to monitor residuals and determine when the finite element solution has converged for each increment.

8. Include dynamic memory allocation.

9. Include bandwidth minimization and a new solver that is designed for sparse matrices to reduce the amount of time required to reach a solution.

10. Compare PIPE5v3 to other FEA programs.

LITERATURE REVIEW

Duncan Soil Model

Soil does not behave like most solid materials. As Duncan et al. [3] describes them, soils are, “nonlinear, inelastic and highly dependent on the magnitude of stresses in the soil.” Only a few finite element analysis programs provide a Duncan material model. These programs include CANDE, PLAXIS, and PIPE5. In the Duncan soil model traditional linear relationships between stress and strain are used. These relationships are made nonlinear by changing the Young’s Modulus (*E*) and bulk modulus (*B*) at each iteration. This allows a more accurate simulation of soil properties without reinventing the stress strain relationships.

The Duncan model is based on the following linear plane strain relationship between stress and strain, Eq. (1).

$$\begin{Bmatrix} \Delta\sigma_x \\ \Delta\sigma_y \\ \Delta\tau_{xy} \end{Bmatrix} = \frac{3B}{9B-E} \begin{bmatrix} (3B+E) & (3B-E) & 0 \\ (3B-E) & (3B+E) & 0 \\ 0 & 0 & E \end{bmatrix} \begin{Bmatrix} \Delta\varepsilon_x \\ \Delta\varepsilon \\ \Delta\gamma_{xy} \end{Bmatrix} \qquad (1)$$

Where:
$\Delta\sigma_x$ = the change in stress in the x direction
$\Delta\sigma_y$ = the change in stress in the y direction
$\Delta\tau_{xy}$ = the change in shear stress
B= bulk modulus
E= Young’s modulus
$\Delta\varepsilon_x$ = the change in strain in the x direction
$\Delta\varepsilon_y$ = the change in strain in the y direction
$\Delta\gamma_{xy}$ = the change in shear strain

In materials like metals the values of *B* and *E* can accurately be approximated as constant but for soils they are variable. Their values are based mostly on the stresses and confining pressure applied to the soil so equations defining the modulus in terms of the applied stresses are used. An initial Young's modulus can be estimated using Eq. (2).

$$E_i = KP_a\left(\frac{\sigma_3}{P_a}\right)^n \tag{2}$$

Where:
E_i = initial Young's modulus
K= modulus number (dimensionless)
P_a = atmospheric pressure
σ_3 = the minimum principal stress in the soil
n= modulus exponent (dimensionless)

The atmospheric pressure is added into Eq. (2) to allow an easy transition between systems of units. The value of K and n are not dependent on the system of units used and, the output of the equation will have the same units as the atmospheric pressure.

After the first iterative solution estimates of the state of stress is available and Eq. (3) can be used to find the tangent modulus or instantaneous Young's modulus.

$$E_t = \left[1 - \frac{R_f(1-\sin\phi)(\sigma_1-\sigma_3)}{2c\cos\phi + 2\sigma_3\sin\phi}\right]^2 KP_a\left(\frac{\sigma_3}{P_a}\right)^n \tag{3}$$

Where:
E_t = the tangent Young's modulus
P_a = atmospheric pressure
R_f = the failure ratio
c= cohesion intercept
ϕ = the soil friction angle
σ_1 = the maximum principal stress
σ_3 = the minimum principal stress

In addition to the tangent modulus the bulk modulus must be calculated. The bulk modulus changes with the confining pressure and is defined in Eq. (4).

$$B = K_b P_a \left(\frac{\sigma_3}{P_a} \right)^m \tag{4}$$

Where:
B= the bulk modulus
K_b = bulk modulus number (dimensionless)
m= bulk modulus exponent (dimensionless)

Once values for E_t and B have been determined a value for Poisson's ratio can be obtained using Eq. (5).

$$\nu_t = \frac{1}{2} - \frac{E_t}{6B} \tag{5}$$

Where:
ν_t = the tangent Poisson's ratio

Poisson's ratio must always be greater than or equal to zero and less than one half. There exist situations where the result of Eq. (5) produces values that are outside of the allowable range. This is caused by the empirical basis for Eq. (3) and Eq. (4). In this situation the following corrective actions are taken. In the cases where ν_t is less than zero setting $B = \frac{E_t}{3}$ which makes Poisson's ratio equal to zero. When ν_t is greater than one half, the value of the bulk modulus can be changed to $B = 17E_t$ to keep the ratio slightly less than 0.5. One last value that must be calculated is the tangent shear modulus G_t shown here in Eq. (6).

$$G_t = \frac{E_t}{2(1+\nu_t)} \tag{6}$$

With these new values for the Young's modulus, bulk modulus, shear modulus and Poisson's ratio a better approximation of actual soil behavior can be achieved.

Predicting shear failures is an important function of the soil model. Shear failures occur when the principal stress σ_1 becomes large in relation to the confining stress σ_3. When this occurs the value of E_T calculated in Eq. (3) decreases rapidly. This reduction in the tangent modulus reduces the simulated soil stiffness so the model behaves like there has been a shear failure.

Interface Elements

When a pipe and soil are loaded, the soil can slip along the pipe surface. In PIPE5, the pipe is usually modeled using beam elements and the soil is modeled using four node quadrilateral elements. Interface elements are placed between the two types of elements. Interface (also called gap) elements allow for several possible conditions other than a solid connection between elements. According to Katona [2] there are three possible states of an interface element. First fixed where the two surfaces are in contact with each other and not moving. The second state is sliding where the two surfaces are moving past one another. And third free where a gap has formed between the two surfaces. Interface elements work by measuring the change in gap size and forces between two nodes in a finite element mesh in both the normal and tangential directions. The forces are denoted by λ_n for the normal force and λ_s for the shear force. The maximum friction force before slipping is represented by *F*, and the distance that the interface slipped is represented by Δ_s. Depending on how these gaps and forces are changing, the state of the interface element can be determined. Table 1 from Katona [2] shows how decisions are made about the state of the interface based on the values of λ_n, λ_s, F, and Δ_s. The left column is the three possible states for the last iteration. By

Table 1. Possible States for Interface Elements

Iteration ►i ▼i-1	Fix	Slip	Free
Fix	$\lambda_n^k < 0$ and $\lambda_s^k < F^k$	$\lambda_n^k < 0$ and $\lambda_s^k > F^k$	$\lambda_n^k > 0$
Slip	$\lambda_n^k < 0$ and $\Delta_s F^k < 0$	$\lambda_n^k < 0$ and $\Delta_s F^k > 0$	$\lambda_n^k > 0$
Free	$\lambda_n^k < 0$		$\lambda_n^k > 0$

examining the interface forces and displacement predicted for the next iteration, the state of the interface element can change.

Initially it is assumed that the interface elements are all fixed. Once an iteration is finished the forces and movements are analyzed to determine their new state based on Table 1.

Large Displacements (Corotational Theory)

Most of the equations used in Finite Element Analysis (FEA) are based on the assumption that the displacements are small. If the object being analyzed is not being deformed excessively the results can be trusted. When the deformations get larger the results are less reliable. The idea behind corotational theory is to break up the large displacements into two components; rigid body motions and elastic deformations.
If the elastic deformations and strains remain small, corotational theory can accurately predict large displacements. The iterative procedure has been well documented by Cook et al. [4], Felippa [5], Chrisfield and Moita [6], Jetteur and Crescotto [7], and Wempner [8].

Stress Stiffening

Thin walled structures like pipes can experience a phenomenon called stress stiffening. This happens when there is a combination of a longitudinal force and a transverse force. If a structure experiences a tensile force the effect of a transverse force will be diminished. If the same structure has a compressive force applied to it there will be more displacement in the direction of the transverse force. Stress stiffening can make pipes stiffer when there is internal pressure or can be less stiff if the pipe experiences external pressure from the installation.

Bandwidth and Sparse Matrices

The calculations involved in Finite Element Analysis are based on matrix mathematics. If a model that is being analyzed has more than a few nodes the matrices become very large. The matrices are also very sparse. If a FEA matrix is created with random node numbering, the nonzero values will often be scattered throughout the matrix. This significantly increases the semi-bandwidth of the matrix. This can be a significant disadvantage because an opportunity is lost to be able to minimize the memory consumed by the matrix and the number of operations required to solve the matrix is proportional to the square of the semi-bandwidth. When the stiffness matrix is formed using the principal of virtual work it will always be diagonally symmetric. One method of reducing the bandwidth was presented in a paper by Cuthill and McKee [9]. If a stiffness matrix has its bandwidth minimized the programmer can exploit this and minimize the amount of memory required to store the stiffness matrices and the time required to solve the problem.

Spaghetti Code

The program now known as PIPE5 was originally based on a program called SSTIPN. This original program was written in the Fortran IV syntax. While the FORTRAN IV code functions properly it leaves some things to be desired. One of the biggest problems is the use of GOTO statements. These statements were used because the language did not support IF, DO WHILE and ELSE statements at that point. The later versions of Fortran (77, 90, and 95) incorporate these types of statements. The use of GOTO statements in the Fortran IV codes makes them very confusing to follow because of their discontinuous nature. The additional types of statements allow programmers to avoid the use of GOTO statements and the code becomes much easier to understand, document and revise.

PROCEDURE

Dynamic Memory Allocation

Changes were made to the code to complete the work Mr. Merrill started in updating the style of the program. One of the largest tasks to update the style of the program was to eliminate the GOTO statements that make the code so hard to follow. The Fortran 90 standard includes dynamic memory allocation which allows the program to make the arrays the size it needs instead of a fixed array size. The scheme to read in an input file was modified to allow the number of nodes and elements to be counted and then arrays for storing the input data and results were dynamically allocated. PIPE5v3 model sizes are only limited by the available memory on the computer. Other style changes were also made to make the code easier to follow.

Interface Elements

The entire subroutine for interface elements was rewritten for PIPE5v3. The routine was written following the procedures outlined in Katona [2]. The new subroutine does not encounter the same troubles with convergence that the previous version of PIPE5 suffered. There are some guidelines that must be followed to have programs run properly when interface elements are used. The nodes in the beam and soil that define the interface element cannot be coincident but should be very closely spaced. These two nodes are used to define the orientation of the interface element. A line between the two elements should be perpendicular to the surface of the interface. The interface elements were used in several of the test cases including those to test the Duncan soil model and the simulations that were compared to soil cell tests. In Burns and Richardson [10] there is an exact elastic solution for a circular pipe in an infinite medium with a pressure load applied. Figure 1 shows the comparison of the Burns and Richardson theory to the results of an interface element test case. In Fig. 1 the solid lines are Burns and Richardson results and the markers show the finite element results. The Burns and Richardson solution is only possible for linear elastic models with either a no slip condition ($\mu=\infty$) or a full slip condition ($\mu=0$). The finite element solutions shown in Fig. 1 are for the three friction conditions $\mu=\infty$, $\mu=0$, and $\mu=.25$. The results are plotted as a function of orientation angle defining the location of the interface element, where zero degrees represents the spring line, 90 degrees the crown, and -90 for the invert.

The interface elements compare fairly well with the theoretical results. The pressures are a little lower for the interface elements with no slip when compared to the theoretical results with no slip. With additional mesh refinement, better agreement would occur. The shear stress with a friction coefficient of .25 lie between the slip and no slip conditions and shows that slippage is occurring just about everywhere around the pipe except for the crown, invert and spring lines.

Corotational Formulation

To test the corotational formulation in PIPE5v3, its results were compared to results from a NX NASTRAN [11] model. To select corotational formulation in NASTRAN, the nonlinear solver (solution 601) was selected as well as the PARAM's LGDISP=1 and LGSTRN=0. This selects the Adina solver and turns on large displacements but leaves large strains off. Both Adina and PIPE5v3 used the plane stress formulation to solve these models. Three different models were tested to show that the

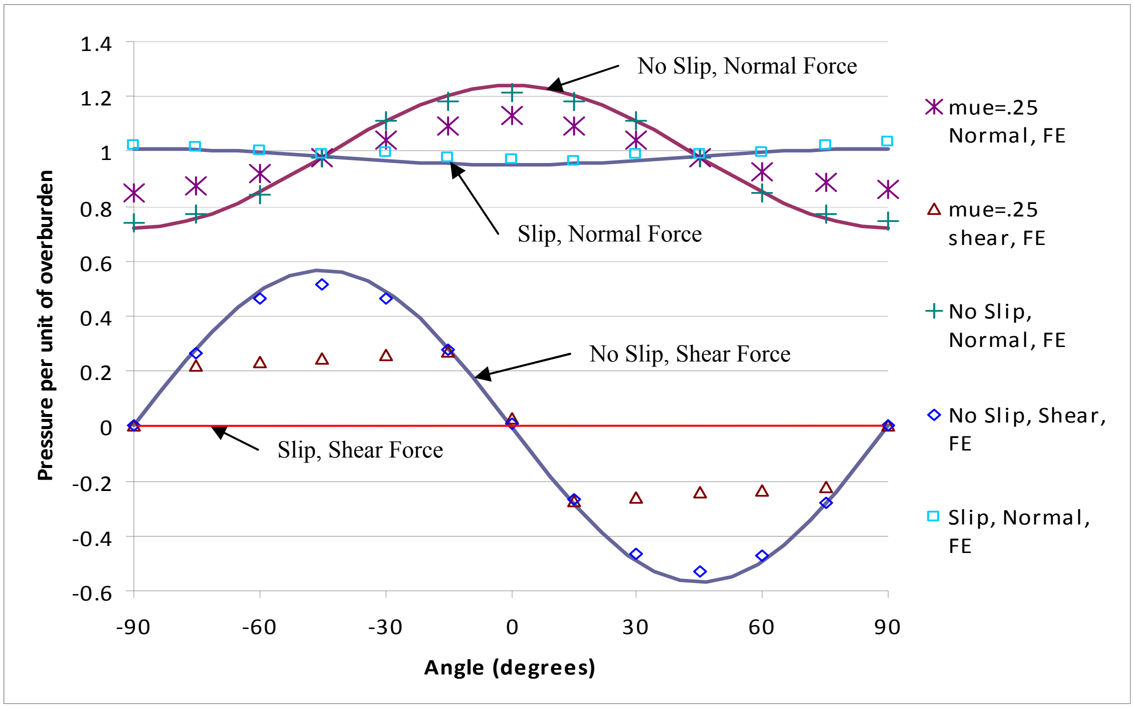

Figure 1. Interface element comparison to Burns and Richardson.

formulation is working in three different element types. The same overall shape was used for models with beam elements, constant strain triangles and QM6 elements. Figure 2 shows the deformed and original meshes of the QM6 version of the model.

The displacements in Table 2 are from the nodes at the top end of the model. These nodes were the ones that experienced the largest displacements in the model. Both with the large displacements turned on and off there is exceptionally good agreement between the two programs. Comparing the displacements with corotational formulation to the displacements without it there is a significant difference. For example with the beam elements the x direction displacement is 58% greater when the large displacements are used. Also note that the displacements for the constant strain triangle element models are much smaller compared with the beam and QM6 element formulations. This is caused by the overly stiff element formulation for constant strain triangle elements.

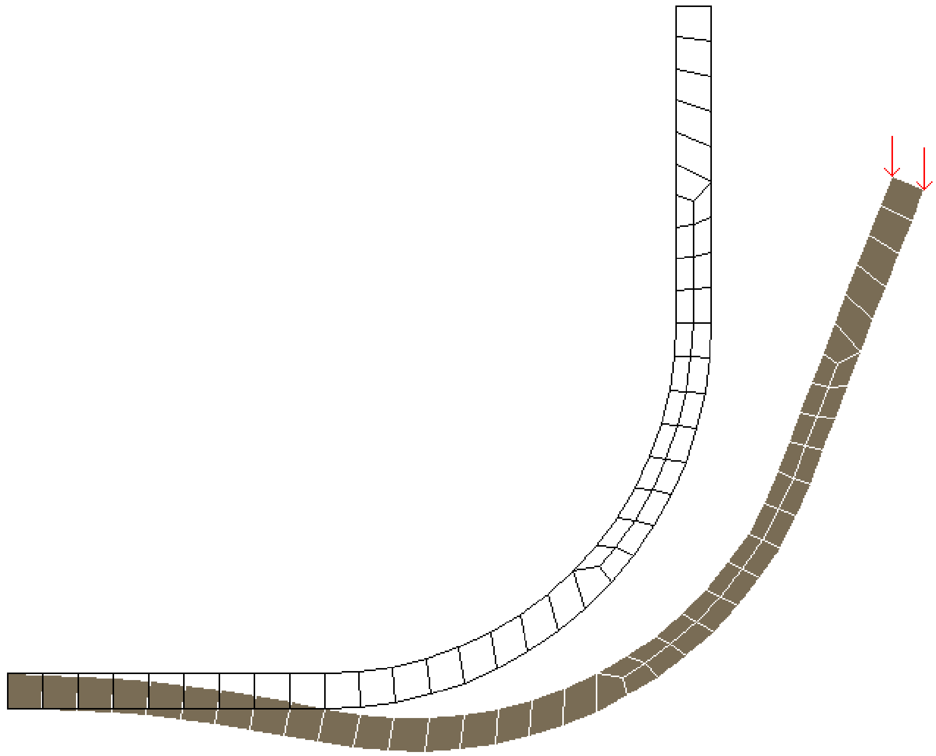

Figure 2. QM6 mesh before and after loading.

File Input Scheme

PIPE5v1 has gone through several changes in the input format over the years. The initial format was strictly line upon line of values with no labels to help the user understand what the values represent. Later, Mariner changed the input format to be largely based on the standard NASTRAN format. This new style of input improved things from the original because the input was organized into cards that helped them be identified. This also had the advantage of letting an existing meshing program like IDEAS [12] or FEMAP [13] create the file and eliminated some of the tedious hand input.

Table 2. Corotational Formulation Comparison

With corotation (large displacements turned on)				
node	direction	NASTRAN	PIPE5v3	%difference
	Beam Elements			
36	X	69.45589	69.453	0.00416
36	Y	-59.8251	-59.825	0.00017
	Constant Strain Triangles			
2	X	12.27078	12.274	0.0262
2	Y	-7.70183	-7.7049	0.0399
3	X	12.24871	12.242	0.0548
3	Y	-8.370444	-8.3736	0.0377
	QM6 elements			
2	X	69.1413	69.176	0.0502
2	Y	-57.0839	-57.095	0.0194
3	X	68.2227	68.257	0.0503
3	Y	-61.27116	-61.283	0.0193
Without corotation (large displacements turned off)				
node	direction	NASTRAN	PIPE5v3	%difference
	Beam Elements			
36	X	43.89439	43.894	0.00089
36	Y	-29.0681	-29.068	0.00034
	Constant Strain Triangles			
2	X	10.89484	10.896	0.0106
2	Y	-6.664315	-6.6651	0.0118
3	X	10.89512	10.896	0.0081
3	Y	-7.238981	-7.2398	0.0113
	QM6 elements			
2	X	43.69946	43.71	0.0241
2	Y	-27.86729	-27.872	0.0169
3	X	43.69974	43.711	0.0258
3	Y	-30.15644	-30.153	0.0114

Appendix A documents the current PIPE5v3 input file format and Appendix B contains examples of input files. PIPE5v2 converted the input scheme to a largely NASTRAN based card input system. Many of the cards went unchanged in the transition to PIPE5v3. In the newer version the 9LAYER cards went through a significant change. PIPE5v3 allows soil layers to be added as separate load steps and the 9LAYER and designates which soil layers a soil element is associated with. In the earlier version there was a 9LAYER card for each element that defined which soil layer the element was a part of. Since 9LAYER cards are not a NASTRAN feature each 9LAYER card had to be manually created. Now the program has been modified so that the 9LAYER cards refer to physical property numbers used in a PSHELL card. Since each soil element card refers to a particular PSHELL card, now each soil layer can be defined by a separate PSHELL card. The PSHELL cards then specify a material id number. This makes the creation of a PIPE5v3 input file much simpler because there are not a huge number of 9LAYER cards to create by hand after the standard NASTRAN model is generated by another program. This also eliminates many opportunities for user error while setting up the input.

Method of Solution and Residuals

PIPE5 seeks solutions to nonlinear elastic problems. Each iteration provides changes in the stiffness matrix being solved. The method used in PIPE5v3 to obtain a solution is summarized as follows. At the start of the first load step, the initial stiffness matrix $[K]$ is formed. With the external load vector $\{F\}$ known, $[K]\times\{D\}=\{F\}$ can be solved for displacement $\{D\}$. The stresses in each element are computed and a revised stiffness matrix $[K]_2$ is formed. A nodal force balance (or force residual) is computed using $\{R\}_1=\{F\}-[K]_2\{D\}_1$. Solving $[K]_2\{D\}_2=\{R\}_1$ for $\{D\}_2$ gives residual displacements. The residual displacements are summed to obtain the total displacement $\{D\}=\{D\}_s+\{D\}_i$. The stiffness matrix can again be updated and the process reported. If the solution is converging, the changes in the predicted displacements and errors in the resulting force balance must become smaller. These changes in displacement and force balance errors are called residuals. Instead of running the program for a fixed number of iterations, as was done in PIPE5v2 PIPE5v3 iterates until the residuals reach the user input convergence criteria. The displacement and force residuals were monitored. The default setting of .001% for the displacement residual and .05% for the force residual appear to allow the program to converge for most cases. For cases with exceptionally high loading where significant soil shear failures are occurring the residuals had to be raised slightly to prevent the program from requiring more than 100 iterations. The user can input a maximum number of iterations that it will perform even if the residual threshold has not been reached. If the program reaches this limit it will stop the solution and inform the user that the solution has not converged.

Stress Stiffening

To test the accuracy of the stress stiffening feature that was added to PIPE5v3 several test cases were run in both PIPE5 and IDEAS. The tests simulated a 1 mm by 1 mm beam that was 100 mm in length. Three cases were run with and without stress stiffening in each program. Case 1 had a horizontal beam with a 2 N compressive load and a 1 N transverse load. Case 2 had a horizontal beam with a 2 N tensile load and a 1 N transverse load. In Case 3 the beam was inclined 30 degrees with a 2 N tensile load and 1 N transverse load. Figure 3 shows case number two after the analysis. The dashed line represents the original mesh.

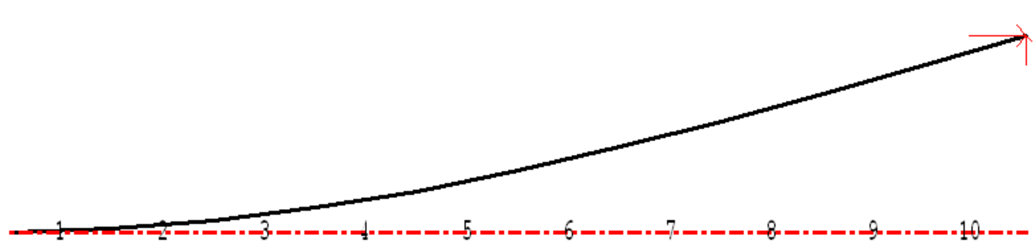

Figure 3. Case number two after loading.

Table 3. Tip Deflection Comparison

	Max tip deflection in y direction			
Case:	IDEAS results (mm)		Pipe 5 results (mm)	
	w/out SS	w/ SS	w/out SS	w/ SS
1	19.344	36.224	19.344	36.289
2	19.344	13.242	19.344	13.233
3	20.639	36.504	20.639	36.562

Table 3 shows the results of the simulations. For all three cases the tip deflection had identical results when stress stiffening was not used. Both the PIPE5v3 and IDEAS results showed increased deflection under compressive loads and decreased deflection under tensile loads. The results for the simulations with stress stiffening agree to three digits between the two programs. An attempt was made to compare the results from these two programs to the results of the same cases in NASTRAN but there was no option to switch just stress stiffening on without including large displacements and no reasonable comparison could be made.

Duncan Soil Model

After rewriting the subroutines associated with the Duncan Soil model it was necessary to compare the outputs with a trusted source. The main competing program of PIPE5 is CANDE [14]. Both were offshoots of the original STIPIN program. CANDE has been extensively tested and used in the industry while PIPE5 has only been used at USU. An opportunity to beta test a new version of CANDE presented itself as an ideal method of verifying the Duncan subroutines in PIPE5v3.

The first comparisons were done with a simple patch test of one quadrilateral soil element, illustrated in Fig. 4. The soil element was square and the loads in the x and y directions were equal. This hydrostatic loading has zero shearing stresses. When shearing stresses are high, soil failure can occur and the Duncan soil model becomes more complicated. The hydrostatic loading in Fig. 4 allows one to compute the soil modulus directly from Eq. (3). This simple model was analyzed in both PIPE5v3 and CANDE. Excellent agreement between Eq. (3) and PIPE5v3 were obtained. The results of CANDE for the patch test showed that the displacements were almost twice as large as the displacements in PIPE5v3 and the results of Eq. (3). After looking closely at the way the two programs reach convergence it became clear why the two programs disagreed. CANDE iterates until the tangent modulus is no longer changing and then uses the average of the tangent modulus from the previous load step and the one from the current step to calculate displacements. This is known as using a secant or cord modulus. PIPE5v3 makes a prediction of the soil properties for a given load and calculates the displacements. Then on each subsequent iteration it makes a correction on the soil properties based on currently predicted soil stresses. When the solution is converged, the soil modulus will reach the value predicted by Eq. (3). The CANDE method of reaching convergence was typical when it was written but requires multiple load steps to get reasonable results. By using small load steps, particularly at the beginning of the loading process, the CANDE model results began to approach the results from PIPE5v3.

Another PIPE5v3 test case was converted into the format of the CANDE input so that the mesh and boundary conditions would be identical. The mesh used in the two programs is shown in Fig. 5.

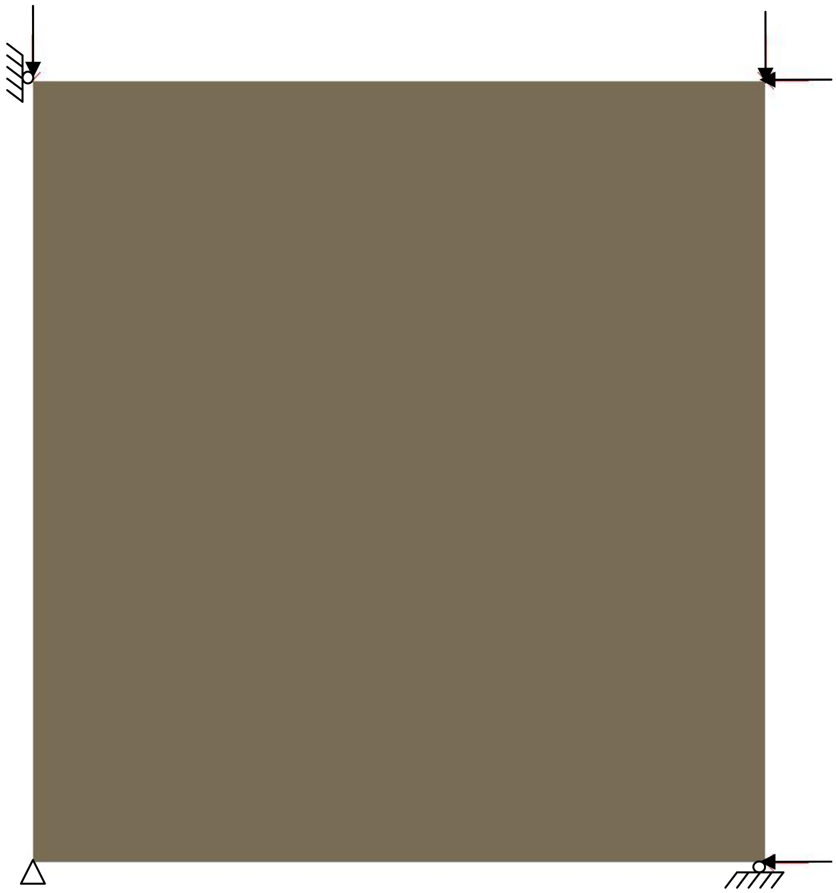

Figure 4. Patch test mesh.

The left edge of Fig. 5 is a symmetry boundary. The pipe diameter is 24 inches with 22 inches of soil cover above the crown of the pipe. The beam elements were made to simulate a 1 inch solid wall pipe. All of the cases were restrained the same way with horizontal restraints along the sides, horizontal and vertical restraints on the bottom, and the crown and invert of the pipe were restrained from z axis rotation. The loading was set up to simulate 9 psi of pressure over the top surface of the soil. Three sets of comparisons were made. First PIPE5v3 and IDEAS were run with a linear elastic soil model using plane stress. Next CANDE and PIPE5v3 were run with the same model but

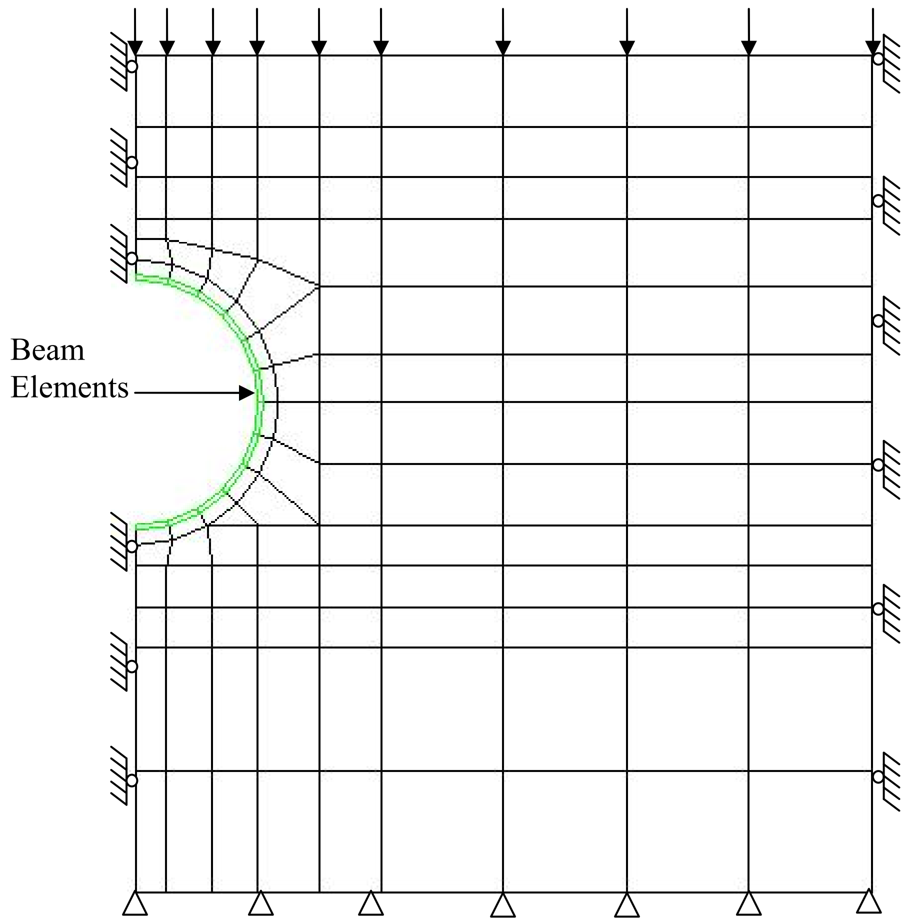

Figure 5. CANDE and PIPE5v3 comparison mesh.

in plane strain. Finally CANDE and PIPE5v3 were run using a Duncan soil model. Plane stress is used in the first simulations because IDEAS does not support interface elements in plane strain. Plane strain is used in the other two models because CANDE only supports plane strain. The models used a soil type called silty sand with varying levels of compaction. The first layer (i.e. the native soil beneath the pipe) was SM100 followed by two layers of SM90. The last two layers of soil were SM85. A more detailed description of the soil properties that those designations specify is included in

Appendix C and in the section on comparisons to the soil cell. They were also done with and without interface elements between the pipe and soil elements. The results of the various simulations are shown in Tables 4 through 6. In the Tables 4 through 6, node 76 or 88 refers to the spring line or the side of the pipe, 84 or 98 refers to the crown, the top of the pipe, and 142 or 168 refers to the node at the top of the soil directly above the pipe.

Table 4. PIPE5v3 and IDEAS Comparison

linear elastic no interface elements				
displacements (in)				
node	Direction	PIPE5v3	IDEAS	% difference
76	X	0.0536	0.0536	0.013
84	Y	-0.28328	-0.28327	0.004
142	Y	-0.3657	-0.3657	0.000
linear elastic with interface elements				
displacements (in)				
node	Direction	PIPE5v3	IDEAS	% difference
88	X	0.0656183	0.06616	0.83
98	Y	-0.30483	-0.30573	0.30
168	Y	-0.38949	-0.39	0.13

Table 5. PIPE5v3 and CANDE Linear Elastic Comparison

linear elastic no interface elements				
displacements (in)				
node	Direction	PIPE5v3	CANDE	% difference
76	X	0.0493	0.0493	0.05
84	Y	-0.26757	-0.2658	0.66
142	Y	-0.3457	-0.3439	0.52
linear elastic with interface elements				
displacements (in)				
node	Direction	PIPE5v3	CANDE	% difference
88	X	0.059174	0.06338	7.11
98	Y	-0.28574	-0.2895	1.32
168	Y	-0.36625	-0.3703	1.11

Table 6. PIPE5v3 and CANDE Duncan Soil Model Comparison

Duncan without interface				
displacements (in)				
Node	direction	PIPE5v3	CANDE	% difference
76	x	0.11194	0.1043	6.83
84	y	-0.61523	-0.5841	5.06
142	y	-0.88733	-0.8912	0.44
Duncan with interface elements				
displacements (in)				
Node	direction	PIPE5v3	CANDE	% difference
88	x	0.11493	0.119	3.54
98	y	-0.62802	-0.6261	0.31
168	y	-0.90005	-0.9485	5.38

The differences between IDEAS and PIPE5v3 are shown in Table 4. When there are no interface elements there is practically no difference. The differences increase when interface elements are added but they are still small enough to be inconsequential.

The differences shown in Table 5 are still small but they are not as small as the differences between PIPE5v3 and IDEAS. When interface elements are added the percent difference reached 7% for one of the nodal displacements.

Table 6 shows the differences between the two programs when Duncan soil models are used. The differences are slightly smaller when the interface elements are used.

When the PIPE5v3 Duncan simulations were examined it was found that several of the elements experienced shear failures during the solution process. The fact that the program can encounter shear failures and cope with them is a good indication that the Duncan subroutines are functioning properly. It was also found that elements in the same locations in the CANDE model were also experiencing high vertical stresses with fairly low horizontal stresses which would indicate they could be in a shear failure as well.

When the programs were both doing a strictly linear elastic solution they agree almost exactly. When the interface elements or hyperbolic soil model were added the programs did not agree as well but were still reasonably close. Katona spearheaded the development of CANDE and the interface elements in PIPE5v3 are based off of his work. Interface elements are equivalent to gap elements in IDEAS and the excellent agreement between IDEAS and PIPE5v3 would indicate that PIPE5v3 has a correct implementation. The way that the two programs arrive at a converged solution for the soil properties while applying the Duncan model could account for the differences in the programs results when the soil model was used.

Bandwidth Minimization

An algorithm for bandwidth minimization was used to help speed up the solution process when the model was large. Cuthill and McKee developed an algorithm for bandwidth minimization that is a part of the public domain. This algorithm was integrated into PIPE5v3. Also implemented was a public domain sparse matrix solver which is offered as an optional solution method along with Gauss elimination and Gauss elimination with pivoting solutions. There is a significant difference in solution time with large models when the Cuthill/McKee algorithm is used along with the sparse matrix solver.

Soil Cell Comparison

To test PIPE5v3 against some real world data some cases were run to simulate some soil cell tests. Utah State University has one of the two operational soil test cells in the United States. Figure 6 is a photograph of a pipe installed in the soil cell. The fifty hydraulic cylinders on top of the soil cell can apply a load simulating deeper burial depths. The tests used several different pipe profiles and different compaction of the surrounding soil. The profiles of the pipe are all based on a typical corrugated polyethylene pipe. For some of the pipes a third wall was added with either a convex, concave, or smooth outer surface. The profiles are shown in Fig. 7. The third wall adds a considerable amount of stiffness to the pipe.

Figure 8 illustrates the finite element mesh used to model the soil cell test. The FEA models used both standard corrugated and concave triple wall pipe stiffness data. The pipe stiffness values were measured in parallel plate tests conducted at Utah State University. The area moment of inertia of the beam elements used in the finite element models of the soil cell tests were backed out from measured pipe stiffness values. The pipe being tested has a 30-inch internal diameter. Interface elements were placed between the beam elements that represent the pipe and the soil elements. To accurately predict the performance of the pipe a row of beam elements were used to represent the pipe. The beam elements were located along a half circle with a radius of the internal diameter plus the distance to the centroid of the cross section of the pipe profile. Table 7 shows the properties used for the two different pipe profiles used in the models. Only the typical corrugated pipe and the concave triple wall pipe were used in the simulations. They were chosen because they were tested in the soil cell at the same time and because the stiffness difference between the triple wall pipes is not very large. The pipe performance is more dependent on the installation than on pipe stiffness so it is more reasonable to compare the two pipes that were buried at the same time. For the plastic properties a Young's modulus of 110000 and a Poisson's ratio of .3 were used.

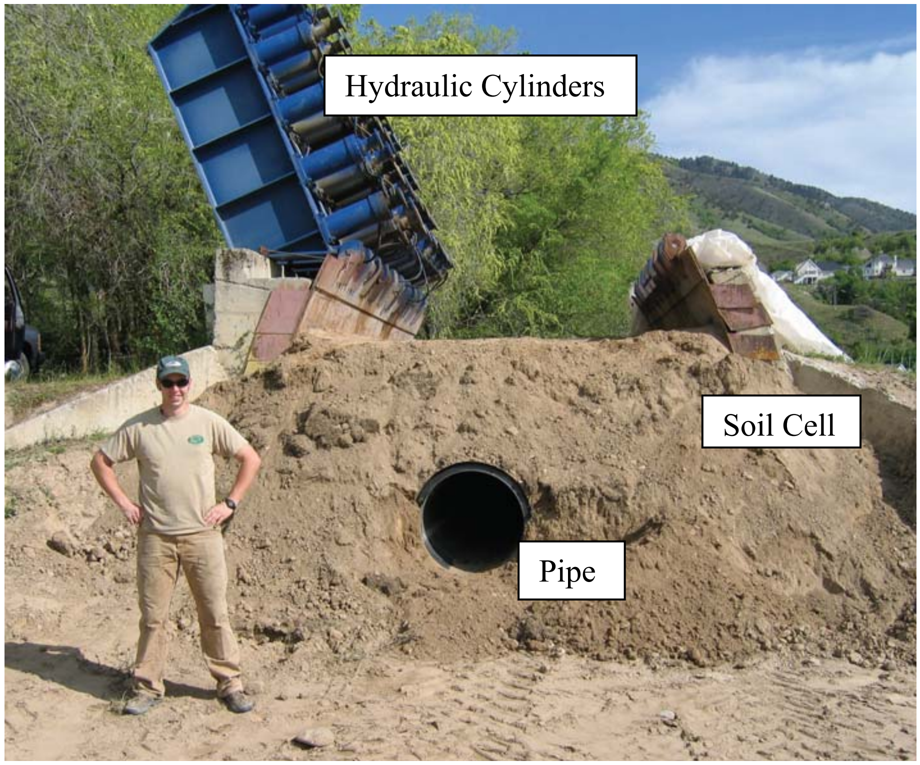

Figure 6. Soil cell with pipe installed.

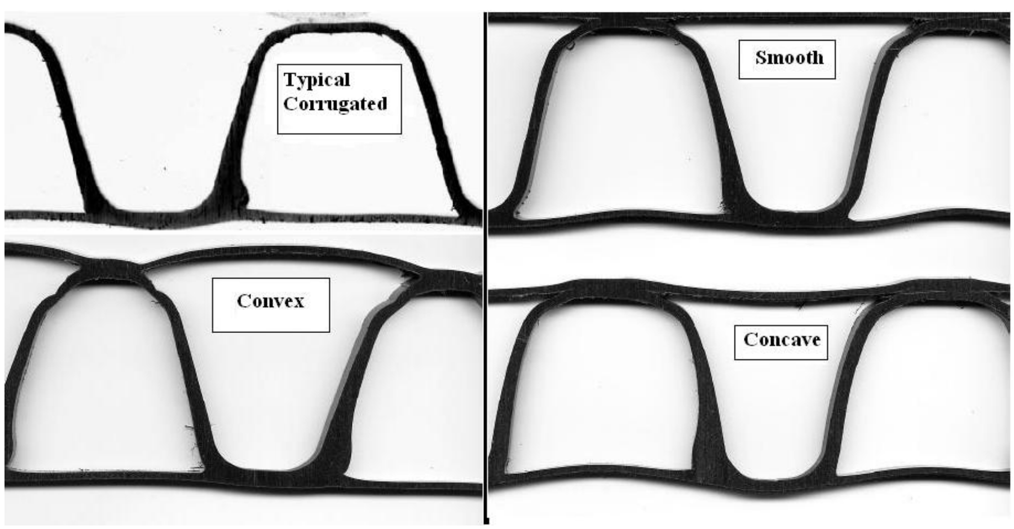

Figure 7. Corrugated pipe cross-sections.

Table 7. Pipe Properties

Profile	corrugated	Concave triple wall
Diameter	30	30
Area	1.602	1.971
Centroid	0.857	1.256
moment of inertia	1.137	1.706
I per unit length	0.278	0.434
Height	2.507	2.535

To represent the soil quadrilateral elements were used. The model was divided up into several regions to allow for different soil properties in the different areas. The soil being modeled is classified as silty sand. Appendix C lists the properties used to represent silty sand depending on the level of compaction. When silty sand is being referred to in this paper it will be written as SM followed by the percentage of compaction. For example a silty sand that was compacted 95% will be known as SM95. Soil cell tests were conducted at soil compaction levels of 100%, 95%, 85%, and 75%. Since there were no tabulated values for the properties of a SM75 soil the values were extrapolated from the 95% and 85% compaction soil properties. The first layer of the model is the base layer. For all models this was represented by a SM100 type of soil. This simulated the very well compacted layer of soil that has been at the bottom of the soil cell for several years. On the under side of the pipe is the haunch region. This was represented as a soft linear elastic material (E=400psi) in the 75% and 85% compaction models and as a SM95 in the 95% and SM100 in the 100% models. The reason for this is on the higher compaction test the haunches are compacted but in the lower compaction tests they are not. The region on the sides of the pipe was a SM75 for the 75% test, SM85 for the 85%, SM95 for the 95% test, and SM100 for the 100% test case. The top layer of soil was SM90 for the 85% and 75% compaction cases, SM95 for the 95% case and SM100 for the 100% compaction. The soil in the actual test needed to be compacted more in the top layers so that the plate that distributes the force in a soil cell test does not sink too far into the soil during the test. Even though the soil used in the soil cell tests is classified as silty sand there can be significant variation of actual soil properties even within a certain soil type. The Duncan soil parameters given in Appendix C will only give a reasonable estimate of the soil behavior but cannot be expected to exactly mimic the performance in the soil cell because the soil properties are based on tests of soil with similar but not identical properties. Furthermore actual soil compaction achieved in the soil cell is also only approximate.

Figure 8 shows the mesh distributed loads that produce an even pressure on the top surface. The sides of the model are restrained from horizontal movement and free to move in the vertical direction to simulate slippage against the soil cell walls. The beam elements nodes on the centerline of the model are also restrained to prevent rotation in the z direction. The bottom edge is restrained both for horizontal and vertical motion.

In the legends in Figs. 9-16 the lines are identified by three letters. The first one is either an s or an r. S stands for simulation and r stands for real measured data. The next letter will be n for a typical corrugated profile, c for a concave profile, s for a smooth profile, or x for a convex profile. The last letter is h or v for horizontal and vertical displacements.

The physical tests when the target compaction was 95% gave some very different results. By placing two different pipe samples end-to-end in the soil cell, one soil cell test could give the results for both pipe designs. The pairs of pipe that were tested

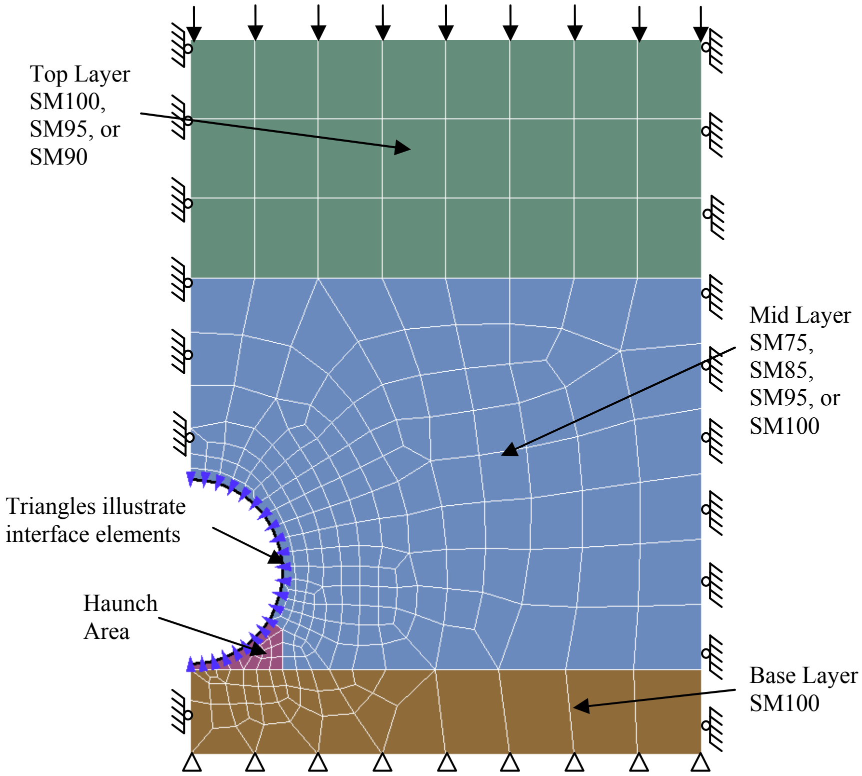

Figure 8. Mesh for soil cell simulation.

together performed similarly despite significant differences in stiffness. Figure 9 and Fig. 10 have the results of the 95% compaction physical tests as well as the simulations.

Figure 9 and Fig. 10 show that the simulated model deflected significantly more at each load step than the actual tests. Note the curves labeled rnh and rch which are both approximately vertical are for the first physical test conducted and the curves labeled rxh and rsh are from the second physical test. The difference between these two is primarily due to errors in compaction measurement. The vertical behavior of the two curves in Fig. 8 is characteristic of compaction in excess of 100%. The simulations were duplicated with a 100% compaction instead of 95% to see if they agreed better. Figure 11 and Fig. 12 show the results of the 100% compaction simulations with the same soil cell results.

Better agreement was now achieved although predicted displacements are still much greater than the measured.

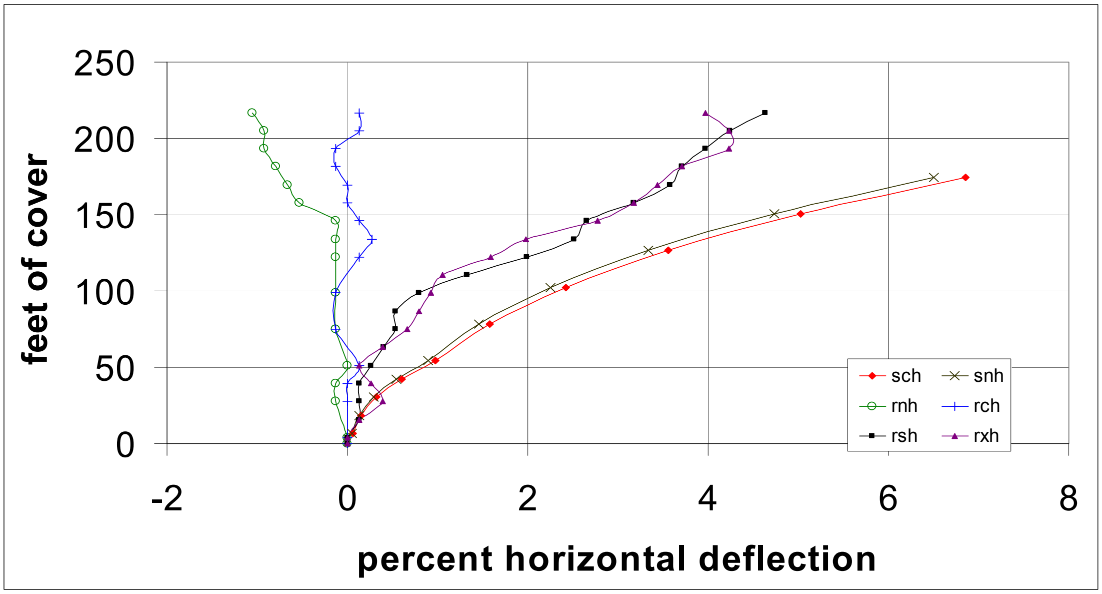

Figure 9. Horizontal deflection for the 95% compaction tests.

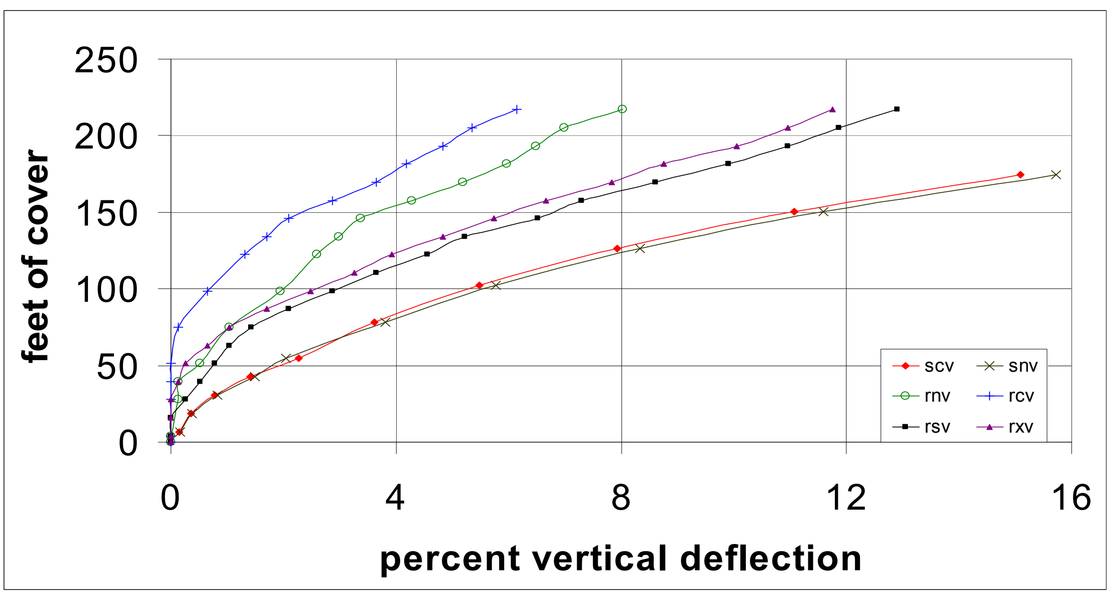

Figure 10. Vertical deflection for the 95% compaction tests.

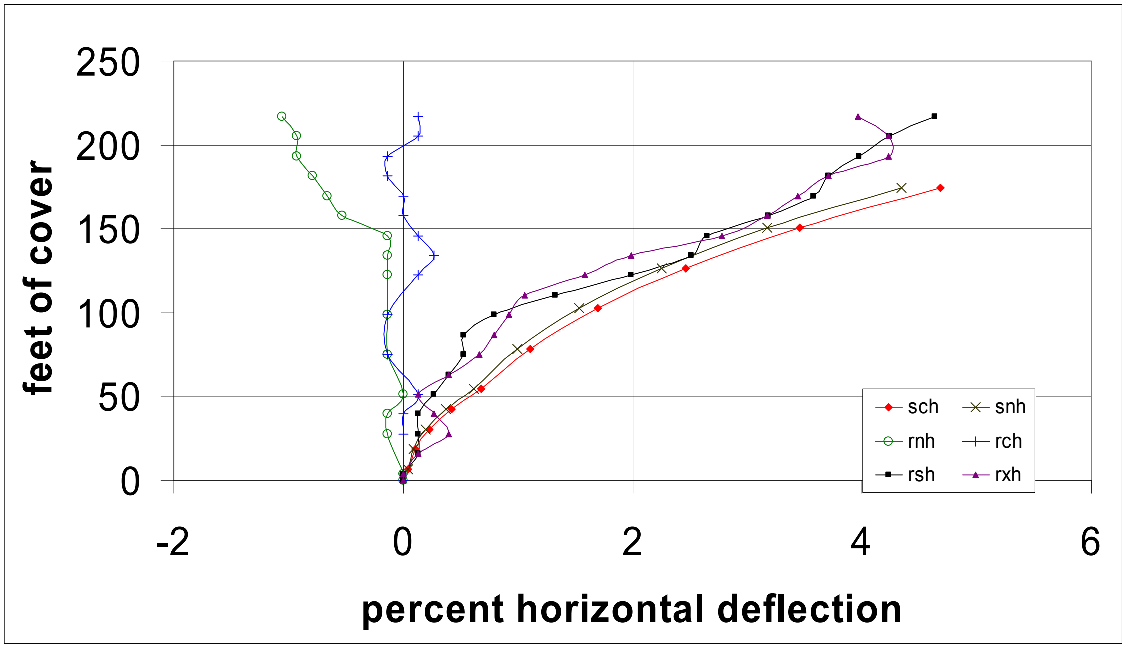

Figure 11. Horizontal deflection for the 100% compaction tests.

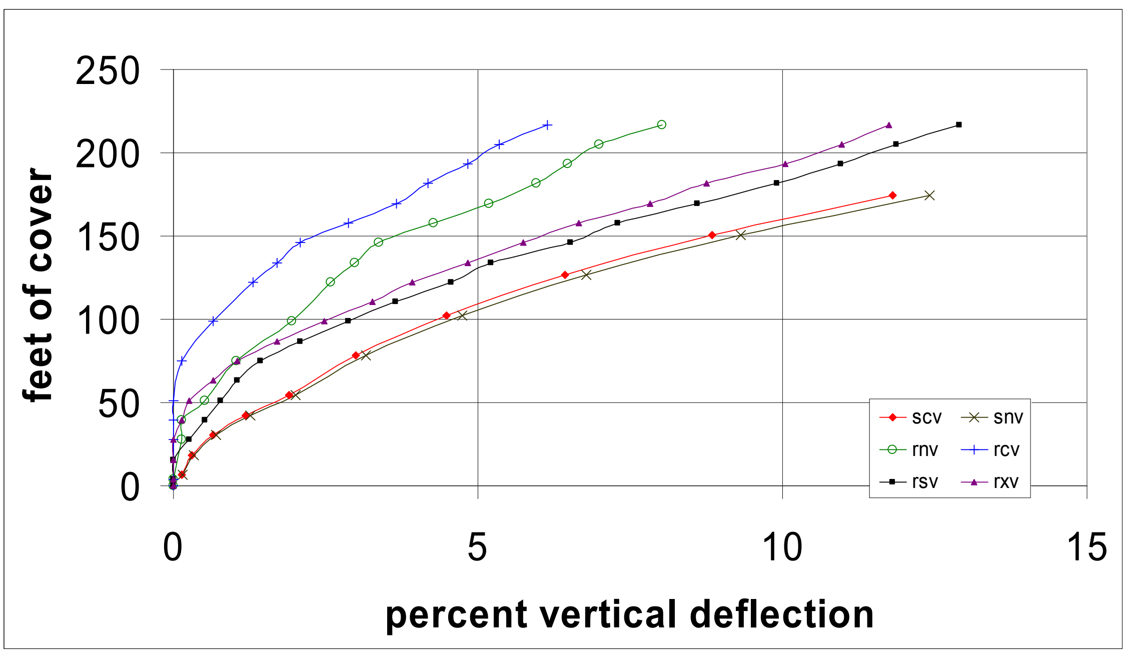

Figure 12. Vertical deflection for the 100% compaction tests.

For the 85% compaction tests the results matched very well between the simulation and real life tests as shown in Fig. 13 and Fig. 14. The vertical deflections matched better than the horizontal deflections. PIPE5v3 does not have buckling prediction built into it so it did not predict the buckling failure seen in the horizontal deflection graph.

The 75% compaction tests were not expected to perform particularly well because the soil parameters were obtained by extrapolation from higher compaction data. In the actual soil cell the more highly compacted soil on the top layers appears to hang up on the sides of the cell in the first part of the test. The simulation did not to account for this so the relatively good agreement, shown in Fig. 15 and Fig. 16, between the simulations and actual tests was surprising.

Soil properties are very difficult to predict accurately. The classification of silty sand encompasses a range of soil compositions with varying properties. It is unlikely that a published set of soil properties for a soil type will exactly match the actual performance of the soil in an actual test. Also the soil in a test situation will have variations in the compaction along the length of the pipe and also through the depth of the burial. The lack of a buckling model also accounts for some of the discrepancies between the simulated pipe behavior and the real pipe behavior. The agreement of the simulated results to the real results is quite good considering the potential for different results.

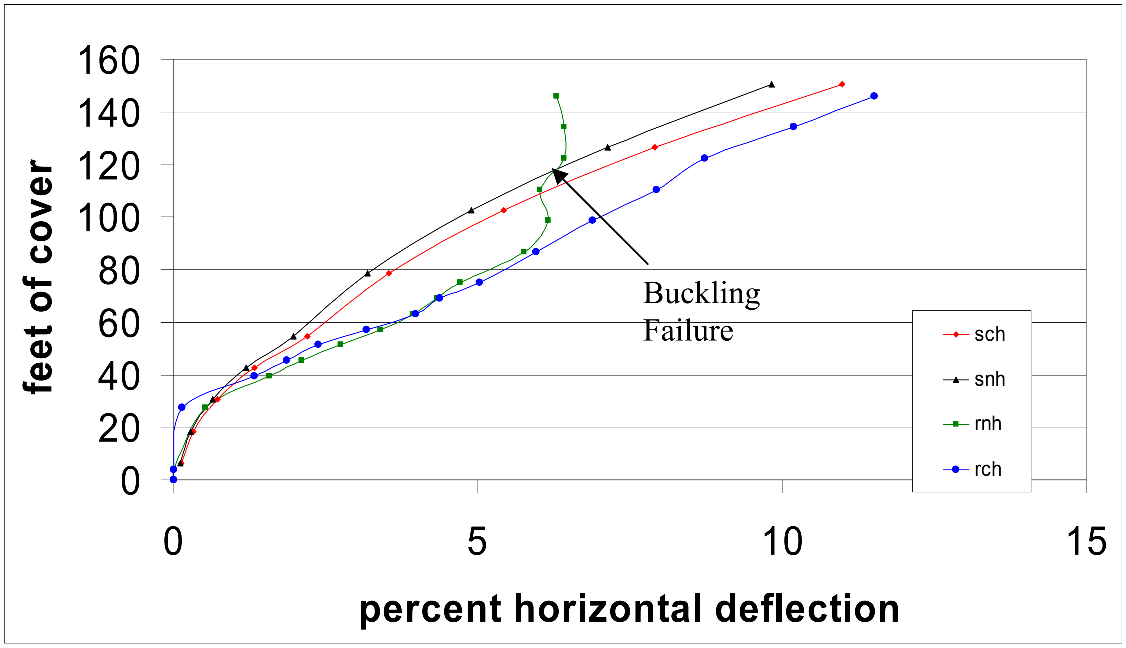

Figure 13. Horizontal deflection for the 85% compaction tests.

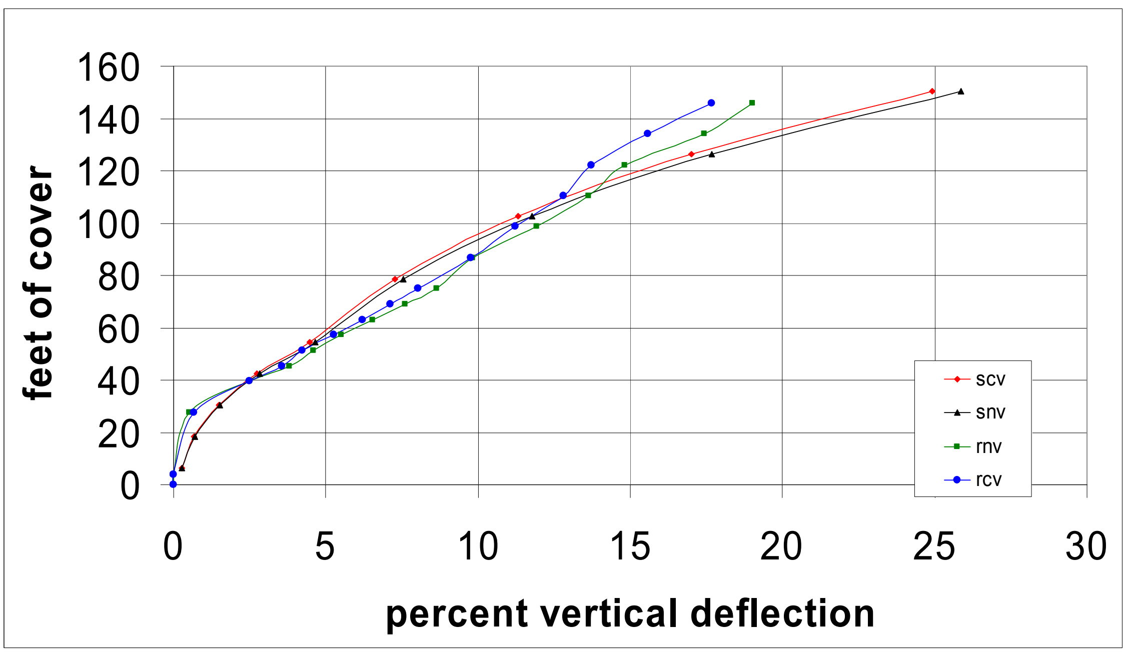

Figure 14. Vertical deflection for the 85% compaction tests.

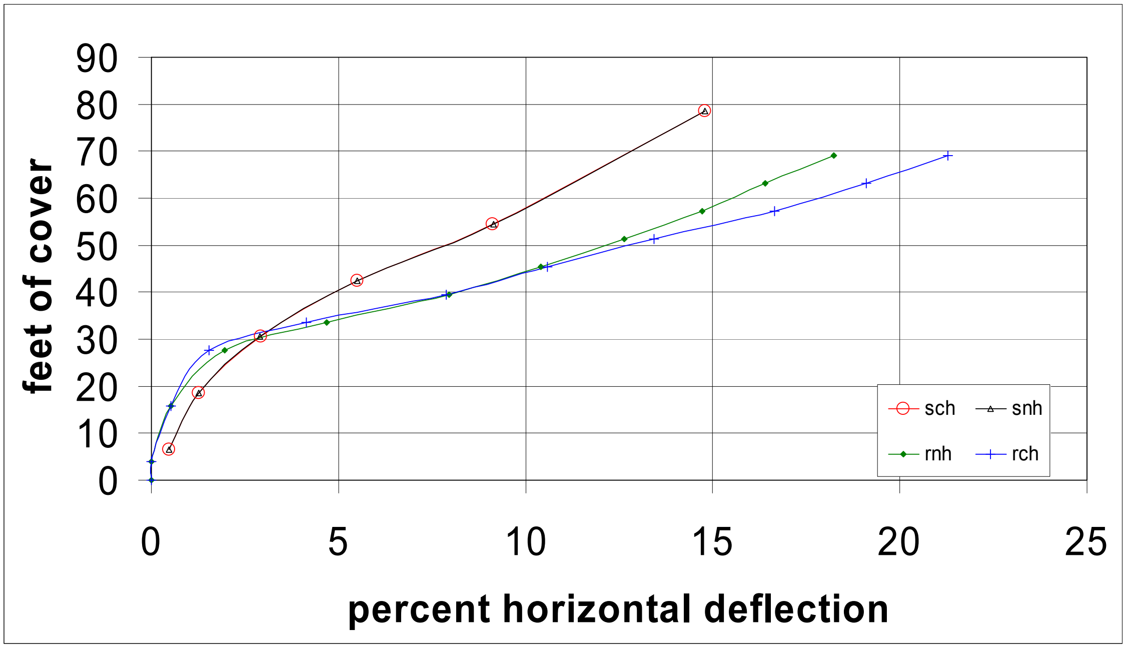

Figure 15. Horizontal deflection for the 75% compaction tests.

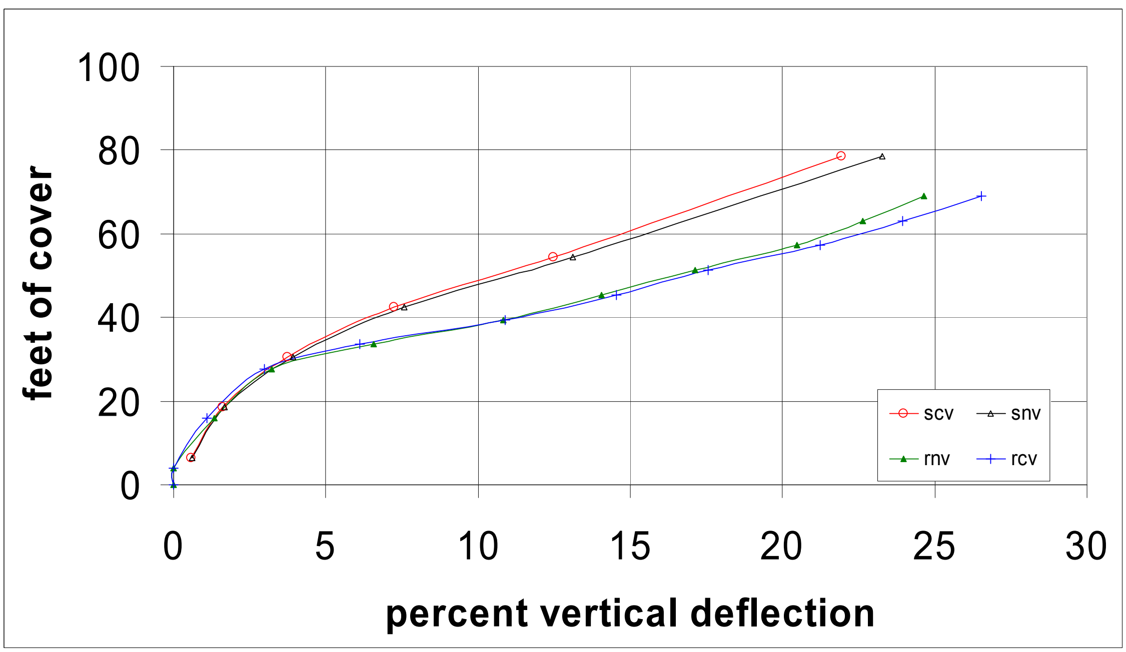

Figure 16. Vertical deflection for the 75% compaction tests.

Comparison to Previous PIPE Versions

While Mr. Merrill made significant changes to the style of the programming in PIPE5v2, he left the numerical parts largely untouched. Numerically, his only significant change was to rewrite the element formulations. When he made those changes, he compared the results of PIPE5v2 with PIPE5v1 and found the differences were minute. It was decided that if PIPE5v3 compared well with PIPE5v2 favorably it could be inferred that it would five similar results to PIPE5v1.

The model that was used for comparison had a 36-inch pipe that was buried 48 inches beneath the surface. Identical Duncan soil parameters were used in both simulations. An even pressure load was applied to the top surface. The mesh is shown in Fig. 17. Table 8 shows the differences in the results of the two programs with both the displacements and stresses at several locations.

The displacements were compared at several nodes. Node 63 is on the invert of the pipe and there was a 5% difference between the two simulations. Node 84 is the crown of the pipe and there was only a 2.5% difference in movement at that node. Node 76 is at the spring line of the pipe. The displacements in the x direction only differed by .7% while the y displacements differed by a little over 3%. The y displacement at node 142 at the soil surface was 10.3% different. The stresses in the beam elements had differences of 10% or less at the crown, invert, and spring lines.

It was expected that the results would not be exactly the same between the programs because of all the changes to the soil model. Also PIPE5v2 can only be run a

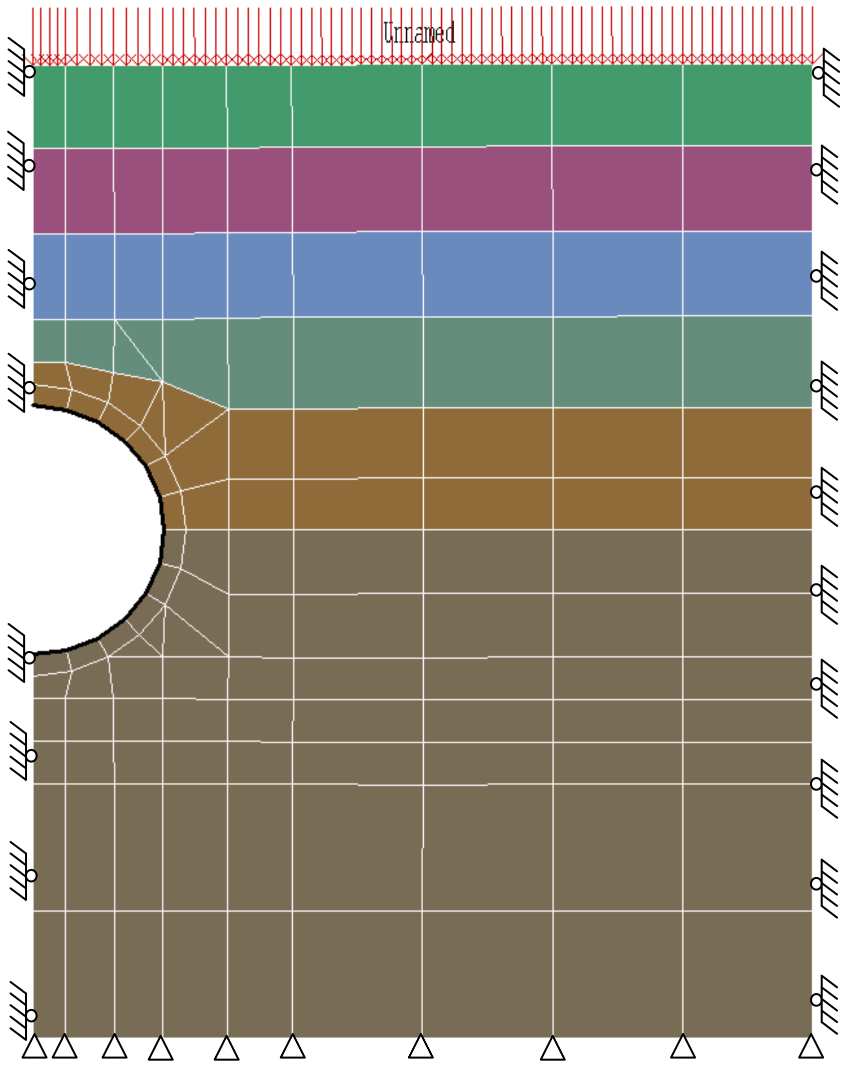

Figure 17. PIPE5v2 mesh.

certain number of iterations instead of stopping the iterating process when a set of residuals has reached a predetermined limit. Several iterations were performed to give a reasonable expectation of convergence. Considering the changes that have been made to the program the differences between the results are very reasonable.

Table 8. Comparison of PIPE5v3 to PIPE5v2

displacements					
node	direction	PIPE5v3	PIPE5v2	% difference	
63	Y	-0.3512	-0.37042	5.189	
84	Y	-1.1317	-1.1613	2.549	
76	X	0.12573	0.12486	0.697	
76	Y	-0.7202	-0.74345	3.127	
142	Y	-1.5696	-1.7498	10.298	
beam element stresses					
element	node	Direction	PIPE5v3	PIPE5v2	% difference
127	84	X	259.26	272.8	4.963
		Y	-31.894	-34.818	8.398
		moment z	-153.81	-155.1	0.832
132	76	X	-65.099	-68.14	4.463
		Y	436.48	451.81	3.393
		moment z	-130.03	-137.85	5.673
138	63	X	246.11	261.52	5.892
		Y	27.741	30.606	9.361
		moment z	106.99	107.05	0.056

CONCLUSION

PIPE5v3 is the result of several improvements to PIPE5v2, some of which were the numerical parts others dealt with ease of use and clarity of the coding. New functions were added to help performance or fixed bugs in previous versions.

Three changes were made to improve the numerical aspects of the program. Instead of running the program for a set number of iterations a scheme to monitor the changes in displacements and stresses was added. This way the program can run until the changes in the model become minimal and not waste time iterating while basically no change is occurring. Dynamic memory allocation was incorporated to allow the program to tailor the array size to its needs. Also a new bandwidth minimizer and sparse matrix solver was incorporated which significantly shortened the computational times for large models.

The program was updated to a Fortran 90 style of programming which makes it easier to follow and understand if changes need to be made in the future. The subroutines related to the Duncan soil model and the interface elements were rewritten to make them clearer and assure that they function correctly. The program input scheme was also simplified so it required less user modification from a standard NASTRAN deck.

The features that were added to PIPE5v3 include stress stiffening and corotational formulation. Stress stiffening allows the effect of transverse forces on beams to be accounted for without going to a full nonlinear solution scheme. The corotational formulation allows for large displacements in a given load step provided the strains remain small.

To assure that the program was giving good results after all of the modifications several comparisons were made to existing programs. Comparisons were made to IDEAS, NASTRAN, CANDE, and PIPE5v2 as well as some comparisons to theoretical results. PIPE5v3 compared favorably with the other programs.

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[11] NX Nastran is a product of UGS software, http://www.plm.automation.siemens.com/en_us/products/nx/simulation/nastran/index.shtml

[12] IDEAS is a product of UGS software,
http://www.plm.automation.siemens.com/en_us/products/nx/ideas/index.shtml

[13] FEMAP is a product of UGS software,
http://www.plm.automation.siemens.com/en_us/products/velocity/femap/index.shtml

[14] CANDE is being upgraded under the Transportation Research Board,
http://www.trb.org/TRBNet/ProjectDisplay.asp?ProjectID=408

APPENDICES

Appendix A. PIPE5 Input Card Descriptions

INPUT DATA SUMMARY FOR THE PIPE5 PROGRAM
The following sheets were adapted from MSC/NASTRAN input guidelines. The NASTRAN input format has been followed in general but some changes have been made. The following MSC/Nastran input rules are followed:

Executive Control Deck

If an executive control deck is present (it is optional) the only item stored is an ID record with a title of the analysis being performed.

Case Control Deck

If a case control deck is present (it also is optional), the only item stored a TITLE record with a title of the analysis. If both an ID and TITLE records are present, the contents of the TITLE record is stored.

Bulk Data Deck

Note that:

1. Each input record is divided into 10 fields, where each field is 8 characters wide. Input data for a given field can be located anywhere inside a field (i.e. it need not be right or left justified).
2. All records which begin with a $ in column 1 are treated as a comment and thus ignored by the program.
3. All grid point (nodes), element physical property, and material property ID's must be values greater than zero. Internally, the ID's are renumbered.
4. A "+" character in field 10 indicates the next line is continued input for this item. The next line must also have a + in field 1.
5. Arrays for storing information are dynamically allocated. The only limitation on problem size is the amount of memory available at run time.

Nastran Bulk Data items read in by this program are listed below. If the program encounters an item not listed below, the input is ignored and a warning message displayed.

CBAR Simple Beam Element

Description: Defines a simple beam element (BAR) of the structural model.

Format and Example:

1	2	3	4	5	6	7	8	9	10
CBAR	EID	PID	GA	GB	X1	X2	X3		
CBAR	3	2	7	3	0.0	1.0	0.0		

Field Contents

EID Unique element identification number (INTEGER and >0).

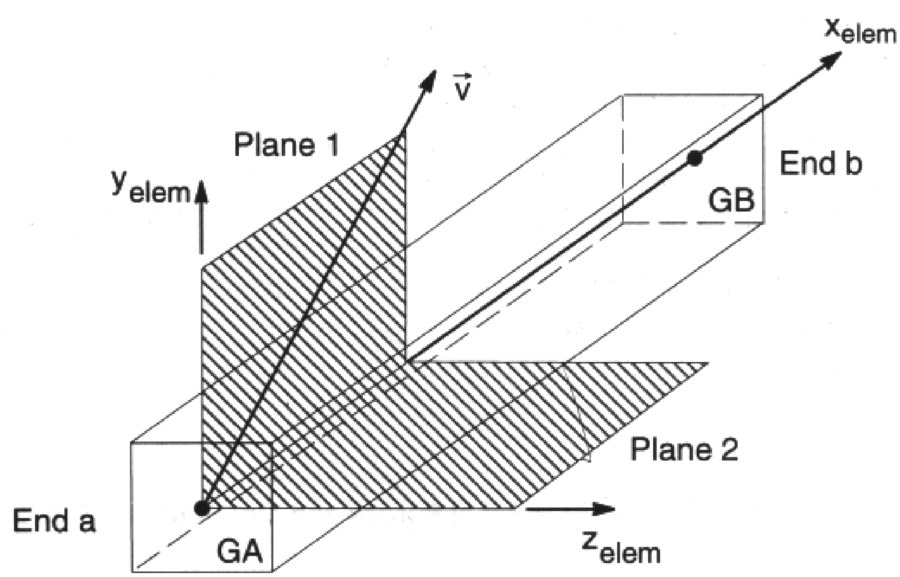
PID Identification number of a PBAR property card (INTEGER and >0).

GA, GB Grid point identification numbers of connection points (INTEGER and >0).

X1, X2, X3 Components of orientation vector v, from GA, in the displacement coordinate system of GA (REAL).

Remarks:

1. Orientation vector ignored for a planar model.



CGAP Gap Element Connection

Description: Defines a gap or friction element.

Format and Example:

1	2	3	4	5	6	7	8	9	10
CGAP	EID	PID	GA	GB	X1	X2	X3	CID	
CGAP	77	20	17	129	0.0	1.0	0.0		

Field Contents

EID Unique element identification number (INTEGER and >0).

PID Identification number of a PBAR property card (INTEGER and >0).

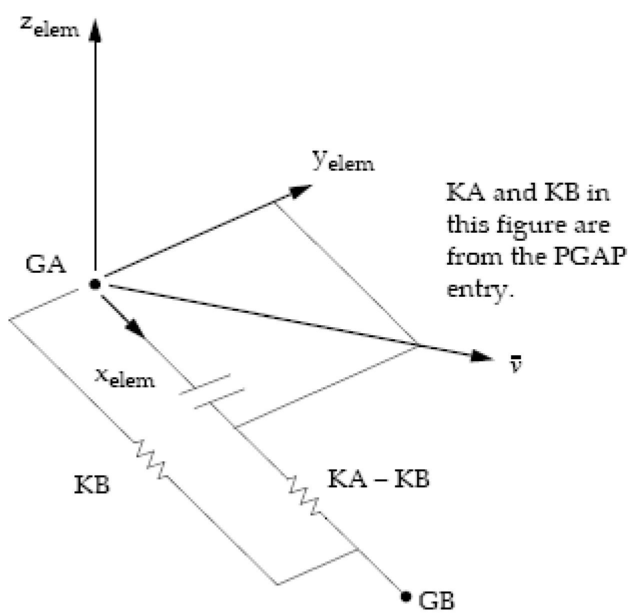
GA, GB Grid point identification numbers of connection points (INTEGER and >0).

X1, X2, X3 Components of orientation vector v, from GA, in the displacement coordinate system of GA (REAL).

CID Element coordinate system identifier.

Remarks:

1. This program ignores X1, X2, X3, and CID.
2. The nodes GA and GB should not be coincident. The X axis of the gap element coordinate system will be aligned with a vector from GA to GB. This will be the contact direction. The interface can slide in a direction 90 degrees from the X axis of the gap element. If the distance between GA and GB is less than 0.01% largest dimension of the structure being analyzed (in the X or Y directions), then the nodes will be considered coincident.



CORD2R Rectangular Coordinate System Definition, Form 2

Description: Defines a rectangular coordinate system using the coordinates of three points.

Format and Example:

1	2	3	4	5	6	7	8	9	10
CORD2R	CID	RID	A1	A2	A3	B1	B2	B3	+
+	C1	C2	C3						
CORD2R	2	0	1.0	1.0	1.0	1.0	1.0	2.0	+
+	1.0	1.0	0.0						

Field Contents

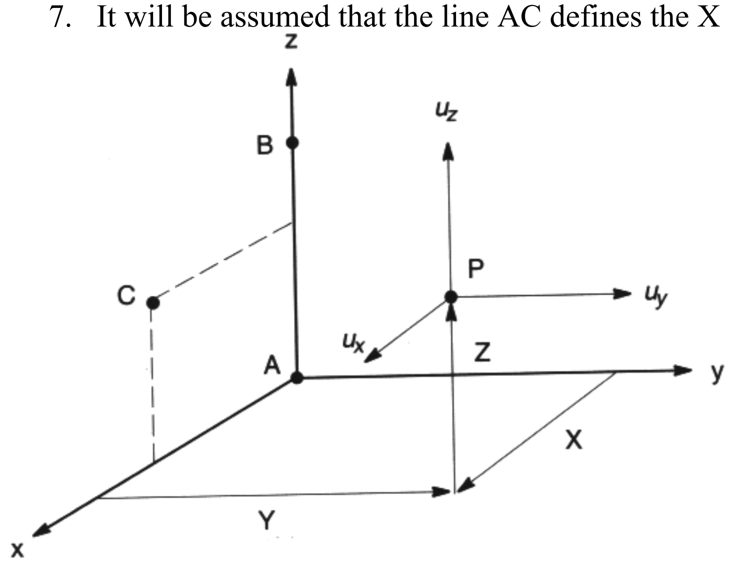
CID Coordinate System Identification number (INTEGER).

RID Reference Coordinate System Identification number used to define A1, B1, and C1 (INTEGER).

A1, B1, C1 Three points used to define the new coordinate system (REAL)

Remarks:

1. We will allow up to 5 coordinates system to be read in.
2. The RID must be 0 (the global coordinate system).
3. The origin of the new coordinate system is located at point A.
4. A vector from point A to point B defined the Z axis of the new coordinate system
5. Point C and the Z axis define the XZ plane.
6. A maximum of five new coordinate systems can be defined.
7. It will be assumed that the line AC defines the X axis



CQUAD4 Quadrilateral Plate Element

Description: Defines an isoparametric quadrilateral plate element.

Format and Example:

1	2	3	4	5	6	7	8	9	10
CQUAD4	EID	PID	G1	G2	G3	G4			
CQUAD4	4	2	8	6	12	14			

Field Contents

EID Unique element identification number (INTEGER and >0).

PID Identification number of a PSHELL property card (INTEGER and >0).

G1, G1, G3, G4 Grid point identification numbers of connection points (INTEGER and >0).

CROD Simple Rod Element

Description: Defines a tension-compression-torsion element.

Format and Example:

1	2	3	4	5	6	7	8	9	10
CROD	EID	PID	G1	G2					
CROD	3	2	7	3					

Field Contents

EID Unique element identification number (INTEGER and >0).

PID Identification number of a PROD property card (INTEGER and >0).

G1, G1 Grid point identification numbers of connection points (INTEGER and >0).

CTRIA3 Triangular Plate Element

Description: Defines an isoparametric triangular plate element.

Format and Example:

1	2	3	4	5	6	7	8	9	10
CTRIA3	EID	PID	G1	G2	G3				
CTRIA3	3	2	7	3	12				

Field Contents

EID Unique element identification number (INTEGER and >0).

PID Identification number of a PSHELL property card (INTEGER and >0).

G1, G1, G3 Grid point identification numbers of connection points (INTEGER and >0).

FORCE Static Load

Description: Defines a static load at a grid point by specifying a vector.

Format and Example:

1	2	3	4	5	6	7	8	9	10
FORCE	SID	G	CID	F	N1	N2	N3		
FORCE	1	1	1	200.	1.	0.5	0.0		

Field	Contents
SID	Load set identification number (INTEGER and >0)
G	Grid point identification number where load is applied (INTEGER and >0).
CID	Coordinate system identification number (INTEGER and >0)
F	Scale factor (Real).
N1	X component of the force (REAL)
N2	Y component of the force (REAL)
N3	Z component of the force (REAL)

Remarks:

1. The total force in the X direction is F*N1. The total force in the Y direction is F*N2. For planar problems N3 will be ignored.
2. SID and CID will be ignored.

GRAV Gravity Vector

Description: Used to define the gravity vector for gravity loading.

Format and Example:

1	2	3	4	5	6	7	8	9	10
GRAV	SID	CID	A	N1	N2	N3			
GRAV			32.2	0.0	-1.0				

Field	Contents
SID	Load set identification number (INTEGER and >0)
CID	Coordinate system identification number (INTEGER and >0)
A	Gravity acceleration vector scale factor (REAL).
N1	X component of the gravity vector (REAL)
N2	Y component of the gravity vector (REAL)
N3	Z component of the gravity vector (REAL)

Remarks:

1. Internally, the program will always apply a gravity load of 1.0 G. The total gravity in the X direction is A*N1. The total vector in the Y direction is A*N2. N3 is ignored. The program will convert the input into two unit vector components using:

$$g_x = \frac{A \cdot N1}{\sqrt{(A \cdot N1)^2 + (A \cdot N2)^2}} \qquad g_y = \frac{A \cdot N2}{\sqrt{(A \cdot N1)^2 + (A \cdot N2)^2}}$$

1. Given the above statement, the net acceleration input units are just the components of a 1 G unit vector. Warning: this is different than standard Nastran input.
2. CID is ignored.

GRID Grid Point

Description: Defines the location of a geometric grid point of the structural model and its permanent single point constraints.

Format and Example:

1	2	3	4	5	6	7	8	9	10
GRID	ID	CP	X	Y	Z	CD	PS		
GRID	2		1.0	-2.0	0.0		12		

Field Contents

ID Grid Point identification number (INTEGER and >0).

CP Coordinate system ID used to define the node location (INTEGER or blank)

X, Y, Z Location of the grid point (REAL)

CD Coordinate system ID used to define the displacements (INTEGER or blank)

PS Permanent single-point constraints associated with grid point (any of the digits 1-6 with no embedded blanks) (INTEGER or blank)

Remarks:

1. All grid point identification numbers must be unique with respect to all other points.
2. CP is ignored.
3. Z is ignored.

MAT1 Material Property Definition

Description: Defines the material properties for linear isotropic materials.

Format and Example:

1	2	3	4	5	6	7	8	9	10
MAT1	MID	E	G	NU	RHO	A	TREF	GE	+
+	ST	SC	SS	MCSID					
MAT1	1	10.E6		0.3	.2E-4	.5E-6	250.		+
+	35000.	35000.	42000.						

Field Contents

MID Unique material identification number (INTEGER).

E Young's modulus (REAL).

G Shear modulus

NU Poisson's Ratio (REAL).

RHO Weight Density (REAL). Warning: conventional Nastran input is a mass density. Since load (if present) is always 1.0 G's, this input must be a weight density.

A Thermal Expansion Coefficient (REAL).

TREF Reference Temperature (REAL)

GE Structural element damping coefficient (REAL)

ST, SC, SS Stress limits for tension, compression and shear (REAL)

MCSID Material coordinate system identification number (INTEGER)

Remarks:

1. This program ignores GE, ST, SC, SS, and MCSID will be ignored.

PBAR Simple Beam Property

Description: Defines the properties of a simple beam (bar) which is used to create bar elements via the CBAR card.

Format and Example:

1	2	3	4	5	6	7	8	9	10
PBAR	PID	MID	A	I1	I2	J	NSM		+
+	C1	C2	D1	D2	E1	E2	F1	F2	+
+	K1	K2	I12						
PBAR	3	1	0.50	0.041	0.010	0.028			+
+	0.8	0.7	-0.8	0.7	-0.8	-0.7	0.8	-.07	+
+	0.12	0.43	0.0						

Field	Contents
PID	Property identification number (INTEGER).
MID	Material identification number (INTEGER).
A	Area of bar cross section (REAL).
I1	Area moment of inertia for bending in the 1 plane (REAL)
I2	Area moment of inertia for bending in the 2 plane (REAL)
J	Polar moment of inertia (REAL)
NSM	Nonstructural Mass (REAL)
C1	Distance in the 1 direction from the neutral axis for stress calculations (REAL).
C2	Distance in the 2 direction from the neutral axis for stress calculations (REAL).
D1, D2	Another coordinate point for stress calculation (REAL)
E1, E2	Another coordinate point for stress calculation (REAL)
F1, F2	Another coordinate point for stress calculation (REAL)
K1	Area Factor for shear in the 1 direction (REAL)
K2	Area Factor for shear in the 2 direction (REAL)
I12	Product of Inertia (REAL)

Remarks:

1. This program ignores I2, J, NSM, C2, D2, E2, F2, K2, and I12. Bending stiffness is based only on I1.
2. For stress calculations, use the largest (most positive) and smallest (most negative) values from C1, C2, C3, and C4.

PGAP Gap Element Property

Description: Defines the properties of the gap element (CGAP entry).

Format and Example:

1	2	3	4	5	6	7	8	9	10
PGAP	PID	U0	F0	KA	KB	KT	MU1	MU2	+
+	TMAX	MAR	TRMIN						
PBAR	3	1	0.50	0.041	0.010	0.028			+
+	0.8	0.7	-0.8	0.7	-0.8	-0.7	0.8	-.07	+

Field Contents

PID Property identification number (INTEGER).

U0 Initial gap opening (REAL).

F0 Preload (REAL).

KA Axial stiffness for the closed gap (REAL)

KB Axial stiffness for the open gap (REAL)

KT Shearing stiffness for a closed gap (REAL)

MU1 Coefficient of static friction (REAL)

MU2 Coefficient of kinetic friction (REAL)

TMAX Maximum allowable penetration (REAL)

MAR Maximum allowable adjustment ratio for adaptive penalty value (REAL)

TRMIN Fraction of TMAX defining the lower bound for the allowable penetration.

Remarks:

1. This program ignores U0, F0, KA, KB, KT MU2, TMAX, MAR and TRMIN.
2. The gap opening U0 is always set to zero.
3. The preload in the gap element is always set to zero.

PROD Physical Properties of a Rod Element

Description: Defines physical properties of a rod (CROD).

Format and Example:

1	2	3	4	5	6	7	8	9	10
PROD	PID	MID	A	J	C	NSM			
PROD	3	2	0.534	0.123					

Field Contents

PID Property identification number (INTEGER).

MID Material Property Identification number (INTEGER)

A Area of the rod (REAL)

J Torsional Constant (REAL)

C Coefficient to determine torsional stress (REAL)

NSM Nonstructural mass (REAL)

Remarks:

1. This program ignores J, C, and NSM.

PSHELL Shell Element Property

Description: Defines the membrane, bending, transverse shear, and coupling properties of thin shell elements.

Format and Example:

1	2	3	4	5	6	7	8	9	10
PSHELL	PID	MID	T	MID2	12I/T^3	MID3	TS/T	NSM	
PSHELL	11	2	0.125						

Field Contents

PID Property identification number (INTEGER)

MID Material identification number for the membrane (INTEGER)

T Default membrane thickness for the element

MID2 Material identification number for bending (INTEGER)

12I/T^2 Bending moment of inertia ratio. (REAL)

MID3 Material identification number for transverse shear (INTEGER)

TS/T Transverse shear thickness ratio (default = 0.833333) (REAL)

NSM Nonstructural mass per unit area. (REAL)

Remarks:

1. This program ignores T, MID2, 12I/T^3, MID3, TS/T, and NSM.
2. The thickness of the plane strain elements is always assumed to be unity.

SPC Single Point Constraint

Description: Defines the location of a geometric grid point of the structural model and its permanent single point constraints.

Format and Example:

1	2	3	4	5	6	7	8	9	10
SPC	SID	G1	C1	D1	G2	C2	D2		
SPC	2	1	123456	0.0	2	1	0.0		

Field Contents

SID Identification number of the single point constraint set (INTEGER and >0).

G1 Grid point identification number (INTEGER)

C1 Component number. (any of the digits 1-6 with no embedded blanks) (INTEGER)

D1 Value of enforced displacement

G2 Grid point identification number (INTEGER)

C2 Component number. (any of the digits 1-6 with no embedded blanks) (INTEGER)

D2 Value of enforced displacement

Remarks:

1. The SID is ignored.
2. An enforced displacement (other than zero) can be entered in values D1 and D2.
3. This program only considers C1 and C2 values of 1, 2, and 6 (for constraining displacements in the x and y directions and rotations about the z axis, respectively).

SPC1 Single Point Constraint, Alternate Form

Description: Defines the location of a geometric grid point of the structural model and its permanent single point constraints.

Format and Example:

1	2	3	4	5	6	7	8	9	10
SPC1	SID	C	G1	G2	G3	G4	G5	G6	
SPC1	2	12	23	33	37				
SPC1	2	123	12	THRU	22				

Field Contents

SID Identification number of the single point constraint set (INTEGER).

C Component number. (any of the digits 1-6 with no embedded blanks) (INTEGER)

G1 Grid point identification number (INTEGER)

G2 Grid point identification number (INTEGER)

G3 Grid point identification number (INTEGER)

G4 Grid point identification number (INTEGER)

G5 Grid point identification number (INTEGER)

G6 Grid point identification number (INTEGER)

Remarks:

1. The SID will be ignored.
2. The components C will always be constrained to a displacement of zero.
3. If G2 holds the string "THRU", then the constraint must be applied consecutively to nodes G2 through G4

TEMPD Grid Point Temperature Field Default

Description: Defines a temperature value for all grid points of the structural model that have not been given a temperature on a TEMP entry.

Format and Example:

1	2	3	4	5	6	7	8	9	10
TEMPD	SID1	T1	SID2	T2	SID3	T3	SID4	T4	
TEMPD	11	100.							

Field Contents

SID1 Temperature set identification number (INTEGER)

T1 Default temperature value (REAL)

Remarks:

1. SID1, SID2, T2, SID3, T3, SID4 and T4 will be ignored.

Input Data Unique to Pipe-6

The following input data descriptions are unique to the Pipe program. A Pipe program input is easily identified because the name (field 1 value) always begins with the digit "9".

9CONSTS Various Constants

Description: Defines various constants used by the Pipe program

Format and Example:

1	2	3	4	5	6	7	8	9	10
9CONSTS	ATM	GPUP	MUMIN	MI					
9CONSTS	14.7	0	0.1	5					

Field Contents

ATM Atmospheric Pressure (REAL)

GPUP Gap element orientation angle updating flag; blank or 0=no, 1=yes (INTEGER)

MUMIN Minimum value for Poisson's ration for Duncan materials (REAL)

MI Maximum number of iterations per load increment (INTEGER)

Remarks:

1. If a set of units other than inches are used for input, the ATM must be set to be conistent with the units used.
2. If GPUP is set to 1 and if the first node of a gap element is attached to a beam element, then the orientation angle of the gap element is updated each solution increment by rotations of the beam element.

9XPROPS Extra Beam Properties

Description: Defines pipe pitch

Format and Example:

1	2	3	4	5	6	7	8	9	10
9XPROPS	PID	PITCH							
9XPROPS	3	3.5							

Field Contents

PID Identification number of a PBAR property card (INTEGER and >0).

PITCH Pitch dimension of beam elements representing a pipe. The area and area moment of inertial value entered on the corresponding PBAR record are divided by this value (REAL)

Remarks:

1. The plane strain analysis always uses a thickness in the Z direction of 1. Frequently, profile pipe designs have property values for a given pitch dimension. This input allows those values to be internally modified.

<u>9DUNCAN</u> Duncan Soil Properties

Description: Defines soil properties needed in a Duncan Soil Model

Format and Example:

1	2	3	4	5	6	7	8	9	10
9DUNCAN	MID	GAMA	PHI	DPHI	C	K	N	RF	+
+	KB	M	K0	KUR	NUR				
9DUNCAN	3	0.065	30.0	0.0	8.3	480.	0.44	0.75	
+	80.0	0.38	0.48	720.	0.44				

Field Contents

MID Material identification number in a PSHELL property card (INTEGER and >0).

GAMA Unit weight (typically in units of lb/in^3) (REAL)

PHI Angle of internal friction (degrees) at 1 Atm (REAL).

DPHI Reduction in friction angle for a 10-fold increase in lateral pressure (REAL).

C Cohesion strength (REAL).

K Modulus number (REAL)

N Modulus exponent (REAL)

RF Failure ratio (REAL).

KB Bulk modulus number (REAL).

M Bulk modulus exponent (REAL).

K0 Lateral pressure coefficient (Rankine ratio) (REAL).

KUR Unload/reloading modulus number (REAL).

NUR Unload/reloading exponent number (REAL).

Remarks:

1. These parameters can be found in 'Finite Element Analysis of Buried Flexible Reinforced Plastic Pipe, Final Report.' Summer Program 1983 by Kevan D. Sharp, Loren R. Anderson, Alma P. Moser, Mark J. Warner, on page 154. Another source is the 1980 report by Duncan, et al.

9PRESS Static Pressure Load

Description: Defines soil properties needed in a Duncan Soil Model

Format and Example:

1	2	3	4	5	6	7	8	9	10
9PRESS	SID	G1	G2	F	P1	P2			
9PRESS	2	21	102	1.0	8.3	480.			

Field Contents

SID Load set identification number (INTEGER and >0).

G1 First node ID (INTEGER)

G2 Second node ID (INTEGER)

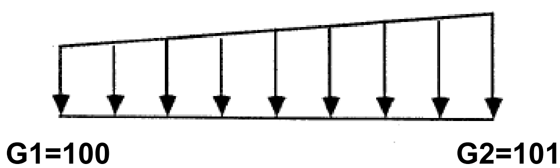
F A scale factor (REAL).

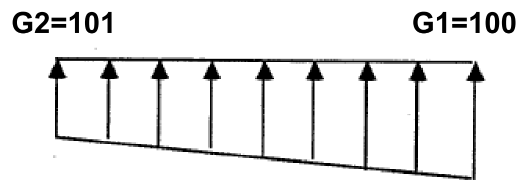
P1 Pressure at G1 (REAL).

P2 Pressure at G2 (REAL).

Remarks:

1. Nodes G1 and G2 must be attached to the same element and define the edge along the element where the pressure is applied.
2. Pressures will act perpendicular to the element edge. The direction the pressure acts is illustrated below where node 100 is assumed to be G1 and 101 is G2.





9LAYER Soil Layer Data

Description: Defines which elements are in a particular layer.

Format and Example:

1	2	3	4	5	6	7	8	9	10
9LAYER	LID	PID							
9LAYER	3	5							

Field Contents

LID Layer ID (INTEGER >= 0)

PID Physical Property ID whose elements are assigned to this layer (INTEGER>0)

Remarks:

1. Multiple physical property ID's can be assigned to the same layer by repeating this input and changing the PID value.
2. By default, all elements are assigned as LID=0. This input is only needed for element in higher layers.
3. LID=0 is the base layer. LID=1 would be the next soil element inserted (or the next lift).
4. LID values must be consecutive. That is, 0, 1, 2, 3 … You can not have a LID=3 without a LID=0, 1, and 2.
5. Normally, pipe elements are in LID=0.
6. Interface elements MUST have the same LID as the associated soil elements.

9ISTRESS Initial Soil Stress Data

Description: Defines which elements are in a particular layer.

Format and Example:

1	2	3	4	5	6	7	8	9	10
9ISTRESS	EID	S1	S2	S3	PP				
9ISTRESS	45	10.0	20.0	0.0	480.				

Field Contents

EID Element ID (INTEGER and >0).

S1 Preexisting normal stress in the X direction (REAL)

S2 Preexisting normal stress in the Y direction (REAL)

S3 Preexisting shearing stress in the XY direction (REAL)

PP Maximum Past Pressure (REAL).

Remarks:

1. S1, S2, S3, and PP are normally only used on preexisting elements (layer 0).

<u>9INC</u> Solution Increment Data

Description: Defines how soil layers and loads are applied.

Format and Example:

1	2	3	4	5	6	7	8	9	10
9INC	N	LAY	LID	SF					
9INC	1	1	1	2.0					

Field Contents

N Solution increment (INTEGER and >0).

LAY Layer ID (INTEGER)

LID Load ID (INTEGER)

SF Scale Factor to apply to loads (REAL)

Remarks:

1. This record will be repeated for solution increment. The first 9INC record must have N =1 and the subsequent solution increments have N incremented by 1.
2. The LAY value refers to the layer currently considered the top layer.
3. The LID value refers to either FORCE or 9PRESS identification numbers.
4. The SF multiplies all the applied loads.

Appendix B. Input Files

The following input files are the ones used for the test cases discussed in the previous thesis. Unless otherwise noted the cases were run using plane stress, small displacement assumption, and stress stiffening is turned off.

Candee3.dat
This case was compared to CANDE. It has a 24 inch pipe with linear elastic soil elements.

```
ID Pipe5 Reformatted File
$*  GRID CARDS
$*
GRID      1    0     0.0-48.0000     0.0      0
GRID      2    0 3.00000-48.0000     0.0      0
GRID      3    0 7.50000-48.0000     0.0      0
GRID      4    0 12.0000-48.0000     0.0      0
GRID      5    0 18.0000-48.0000     0.0      0
GRID      6    0 24.0000-48.0000     0.0      0
GRID      7    0 36.0000-48.0000     0.0      0
GRID      8    0 48.0000-48.0000     0.0      0
GRID      9    0 60.0000-48.0000     0.0      0
GRID     10    0 72.0000-48.0000     0.0      0
GRID     11    0     0.0-36.0000     0.0      0
GRID     12    0 3.00000-36.0000     0.0      0
GRID     13    0 7.50000-36.0000     0.0      0
GRID     14    0 12.0000-36.0000     0.0      0
GRID     15    0 18.0000-36.0000     0.0      0
GRID     16    0 24.0000-36.0000     0.0      0
GRID     17    0 36.0000-36.0000     0.0      0
GRID     18    0 48.0000-36.0000     0.0      0
GRID     19    0 60.0000-36.0000     0.0      0
GRID     20    0 72.0000-36.0000     0.0      0
GRID     21    0     0.0-24.0000     0.0      0
GRID     22    0 3.00000-24.0000     0.0      0
GRID     23    0 7.50000-24.0000     0.0      0
GRID     24    0 12.0000-24.0000     0.0      0
GRID     25    0 18.0000-24.0000     0.0      0
GRID     26    0 24.0000-24.0000     0.0      0
GRID     27    0 36.0000-24.0000     0.0      0
GRID     28    0 48.0000-24.0000     0.0      0
GRID     29    0 60.0000-24.0000     0.0      0
GRID     30    0 72.0000-24.0000     0.0      0
GRID     31    0     0.0-20.0000     0.0      0
GRID     32    0 3.00000-20.0000     0.0      0
GRID     33    0 7.50000-20.0000     0.0      0
GRID     34    0 12.0000-20.0000     0.0      0
GRID     35    0 18.0000-20.0000     0.0      0
GRID     36    0 24.0000-20.0000     0.0      0
GRID     37    0 36.0000-20.0000     0.0      0
GRID     38    0 48.0000-20.0000     0.0      0
```

```
GRID      39      0 60.0000-20.0000     0.0       0
GRID      40      0 72.0000-20.0000     0.0       0
GRID      41      0     0.0-16.0000     0.0       0
GRID      42      0 3.00000-16.0000     0.0       0
GRID      43      0 7.50000-16.0000     0.0       0
GRID      44      0 12.0000-16.0000     0.0       0
GRID      45      0 18.0000-16.0000     0.0       0
GRID      46      0 24.0000-16.0000     0.0       0
GRID      47      0 36.0000-16.0000     0.0       0
GRID      48      0 48.0000-16.0000     0.0       0
GRID      49      0 60.0000-16.0000     0.0       0
GRID      50      0 72.0000-16.0000     0.0       0
GRID      51      0     0.0-14.0000     0.0       0
GRID      52      0 3.62300-13.5230     0.0       0
GRID      53      0 7.00000-12.1240     0.0       0
GRID      54      0 9.89900-9.89900     0.0       0
GRID      55      0 12.0000-12.0000     0.0       0
GRID      56      0 12.1240-7.00000     0.0       0
GRID      57      0 18.0000-12.0000     0.0       0
GRID      58      0 24.0000-12.0000     0.0       0
GRID      59      0 36.0000-12.0000     0.0       0
GRID      60      0 48.0000-12.0000     0.0       0
GRID      61      0 60.0000-12.0000     0.0       0
GRID      62      0 72.0000-12.0000     0.0       0
GRID      63      0     0.0-12.0000     0.0       0
GRID      64      0 3.10600-11.5910     0.0       0
GRID      65      0 6.00001-10.3920     0.0       0
GRID      66      0 8.48500-8.48500     0.0       0
GRID      67      0 10.3920-6.00001     0.0       0
GRID      68      0 11.5910-3.10600     0.0       0
GRID      69      0 13.5230-3.62300     0.0       0
GRID      70      0 18.0000-6.00000     0.0       0
GRID      71      0 24.0000-6.00000     0.0       0
GRID      72      0 36.0000-6.00000     0.0       0
GRID      73      0 48.0000-6.00000     0.0       0
GRID      74      0 60.0000-6.00000     0.0       0
GRID      75      0 72.0000-6.00000     0.0       0
GRID      76      0 12.0000     0.0     0.0       0
GRID      77      0 14.0000     0.0     0.0       0
GRID      78      0 18.0000     0.0     0.0       0
GRID      79      0 24.0000     0.0     0.0       0
GRID      80      0 36.0000     0.0     0.0       0
GRID      81      0 48.0000     0.0     0.0       0
GRID      82      0 60.0000     0.0     0.0       0
GRID      83      0 72.0000     0.0     0.0       0
GRID      84      0     0.0 12.0000     0.0       0
GRID      85      0 3.10600 11.5910     0.0       0
GRID      86      0 6.00001 10.3920     0.0       0
GRID      87      0 8.48500 8.48500     0.0       0
GRID      88      0 10.3920 6.00001     0.0       0
GRID      89      0 11.5910 3.10600     0.0       0
GRID      90      0 13.5230 3.62300     0.0       0
GRID      91      0 18.0000 4.80000     0.0       0
GRID      92      0 24.0000 4.80000     0.0       0
GRID      93      0 36.0000 4.80000     0.0       0
```

GRID	94	0	48.0000	4.80000	0.0	0
GRID	95	0	60.0000	4.80000	0.0	0
GRID	96	0	72.0000	4.80000	0.0	0
GRID	97	0	0.0	14.0000	0.0	0
GRID	98	0	3.62300	13.5230	0.0	0
GRID	99	0	7.00000	12.1240	0.0	0
GRID	100	0	9.89900	9.89900	0.0	0
GRID	101	0	12.1240	7.00000	0.0	0
GRID	102	0	18.0000	11.4000	0.0	0
GRID	103	0	24.0000	11.4000	0.0	0
GRID	104	0	36.0000	11.4000	0.0	0
GRID	105	0	48.0000	11.4000	0.0	0
GRID	106	0	60.0000	11.4000	0.0	0
GRID	107	0	72.0000	11.4000	0.0	0
GRID	108	0	0.0	16.0000	0.0	0
GRID	109	0	3.00000	16.0000	0.0	0
GRID	110	0	7.50000	15.0000	0.0	0
GRID	111	0	12.0000	14.0000	0.0	0
GRID	112	0	0.0	18.0000	0.0	0
GRID	113	0	3.00000	18.0000	0.0	0
GRID	114	0	7.50000	18.0000	0.0	0
GRID	115	0	12.0000	18.0000	0.0	0
GRID	116	0	18.0000	18.0000	0.0	0
GRID	117	0	24.0000	18.0000	0.0	0
GRID	118	0	36.0000	18.0000	0.0	0
GRID	119	0	48.0000	18.0000	0.0	0
GRID	120	0	60.0000	18.0000	0.0	0
GRID	121	0	72.0000	18.0000	0.0	0
GRID	122	0	0.0	22.0000	0.0	0
GRID	123	0	3.00000	22.0000	0.0	0
GRID	124	0	7.50000	22.0000	0.0	0
GRID	125	0	12.0000	22.0000	0.0	0
GRID	126	0	18.0000	22.0000	0.0	0
GRID	127	0	24.0000	22.0000	0.0	0
GRID	128	0	36.0000	22.0000	0.0	0
GRID	129	0	48.0000	22.0000	0.0	0
GRID	130	0	60.0000	22.0000	0.0	0
GRID	131	0	72.0000	22.0000	0.0	0
GRID	132	0	0.0	27.0000	0.0	0
GRID	133	0	3.00000	27.0000	0.0	0
GRID	134	0	7.50000	27.0000	0.0	0
GRID	135	0	12.0000	27.0000	0.0	0
GRID	136	0	18.0000	27.0000	0.0	0
GRID	137	0	24.0000	27.0000	0.0	0
GRID	138	0	36.0000	27.0000	0.0	0
GRID	139	0	48.0000	27.0000	0.0	0
GRID	140	0	60.0000	27.0000	0.0	0
GRID	141	0	72.0000	27.0000	0.0	0
GRID	142	0	0.0	34.0000	0.0	0
GRID	143	0	3.00000	34.0000	0.0	0
GRID	144	0	7.50000	34.0000	0.0	0
GRID	145	0	12.0000	34.0000	0.0	0
GRID	146	0	18.0000	34.0000	0.0	0
GRID	147	0	24.0000	34.0000	0.0	0
GRID	148	0	36.0000	34.0000	0.0	0

```
GRID      149      0 48.0000 34.0000     0.0     0
GRID      150      0 60.0000 34.0000     0.0     0
GRID      151      0 72.0000 34.0000     0.0     0
$*
$*  ELEMENT CARDS
$*
CQUAD4     1   21   11    1    2   12   0.0
CQUAD4     2   21   12    2    3   13   0.0
CQUAD4     3   21   13    3    4   14   0.0
CQUAD4     4   21   14    4    5   15   0.0
CQUAD4     5   21   15    5    6   16   0.0
CQUAD4     6   21   16    6    7   17   0.0
CQUAD4     7   21   17    7    8   18   0.0
CQUAD4     8   21   18    8    9   19   0.0
CQUAD4     9   21   19    9   10   20   0.0
CQUAD4    10   21   21   11   12   22   0.0
CQUAD4    11   21   22   12   13   23   0.0
CQUAD4    12   21   23   13   14   24   0.0
CQUAD4    13   21   24   14   15   25   0.0
CQUAD4    14   21   25   15   16   26   0.0
CQUAD4    15   21   26   16   17   27   0.0
CQUAD4    16   21   27   17   18   28   0.0
CQUAD4    17   21   28   18   19   29   0.0
CQUAD4    18   21   29   19   20   30   0.0
CQUAD4    19   21   31   21   22   32   0.0
CQUAD4    20   21   32   22   23   33   0.0
CQUAD4    21   21   33   23   24   34   0.0
CQUAD4    22   21   34   24   25   35   0.0
CQUAD4    23   21   35   25   26   36   0.0
CQUAD4    24   21   36   26   27   37   0.0
CQUAD4    25   21   37   27   28   38   0.0
CQUAD4    26   21   38   28   29   39   0.0
CQUAD4    27   21   39   29   30   40   0.0
CQUAD4    28   22   41   31   32   42   0.0
CQUAD4    29   22   42   32   33   43   0.0
CQUAD4    30   22   43   33   34   44   0.0
CQUAD4    31   22   44   34   35   45   0.0
CQUAD4    32   22   45   35   36   46   0.0
CQUAD4    33   22   46   36   37   47   0.0
CQUAD4    34   22   47   37   38   48   0.0
CQUAD4    35   22   48   38   39   49   0.0
CQUAD4    36   22   49   39   40   50   0.0
CQUAD4    37   22   51   41   42   52   0.0
CQUAD4    38   22   63   51   52   64   0.0
CQUAD4    39   22   64   52   53   65   0.0
CQUAD4    40   22   52   42   43   53   0.0
CQUAD4    41   22   53   43   44   55   0.0
CQUAD4    42   22   55   44   45   57   0.0
CQUAD4    43   22   57   45   46   58   0.0
CQUAD4    44   22   58   46   47   59   0.0
CQUAD4    45   22   59   47   48   60   0.0
CQUAD4    46   22   60   48   49   61   0.0
CQUAD4    47   22   61   49   50   62   0.0
CQUAD4    48   23   65   53   54   66   0.0
CQUAD4    49   23   67   66   54   56   0.0
```

CTRIA3	50	23	55	54	53	0.0	
CQUAD4	51	23	57	56	54	55	0.0
CQUAD4	52	23	68	67	56	69	0.0
CQUAD4	53	23	69	56	57	70	0.0
CQUAD4	54	23	70	57	58	71	0.0
CQUAD4	55	23	71	58	59	72	0.0
CQUAD4	56	23	72	59	60	73	0.0
CQUAD4	57	23	73	60	61	74	0.0
CQUAD4	58	23	74	61	62	75	0.0
CQUAD4	59	23	76	68	69	77	0.0
CQUAD4	60	23	77	69	70	78	0.0
CQUAD4	61	23	78	70	71	79	0.0
CQUAD4	62	23	79	71	72	80	0.0
CQUAD4	63	23	80	72	73	81	0.0
CQUAD4	64	23	81	73	74	82	0.0
CQUAD4	65	23	82	74	75	83	0.0
CQUAD4	66	24	89	76	77	90	0.0
CQUAD4	67	24	90	77	78	91	0.0
CQUAD4	68	24	91	78	79	92	0.0
CQUAD4	69	24	92	79	80	93	0.0
CQUAD4	70	24	93	80	81	94	0.0
CQUAD4	71	24	94	81	82	95	0.0
CQUAD4	72	24	95	82	83	96	0.0
CQUAD4	73	24	88	89	90	101	0.0
CQUAD4	74	24	100	87	88	101	0.0
CQUAD4	75	24	99	86	87	100	0.0
CQUAD4	76	24	98	85	86	99	0.0
CQUAD4	77	24	97	84	85	98	0.0
CQUAD4	78	24	108	97	98	109	0.0
CQUAD4	79	24	109	98	99	110	0.0
CQUAD4	80	24	110	99	100	111	0.0
CQUAD4	81	24	101	102	111	100	0.0
CQUAD4	82	24	101	90	91	102	0.0
CQUAD4	83	24	102	91	92	103	0.0
CQUAD4	84	24	103	92	93	104	0.0
CQUAD4	85	24	104	93	94	105	0.0
CQUAD4	86	24	105	94	95	106	0.0
CQUAD4	87	24	106	95	96	107	0.0
CQUAD4	88	24	112	108	109	113	0.0
CQUAD4	89	24	113	109	110	114	0.0
CQUAD4	90	24	111	115	114	110	0.0
CQUAD4	91	24	115	111	102	116	0.0
CQUAD4	92	24	116	102	103	117	0.0
CQUAD4	93	24	117	103	104	118	0.0
CQUAD4	94	24	118	104	105	119	0.0
CQUAD4	95	24	119	105	106	120	0.0
CQUAD4	96	24	120	106	107	121	0.0
CQUAD4	97	25	122	112	113	123	0.0
CQUAD4	98	25	123	113	114	124	0.0
CQUAD4	99	25	124	114	115	125	0.0
CQUAD4	100	25	125	115	116	126	0.0
CQUAD4	101	25	126	116	117	127	0.0
CQUAD4	102	25	127	117	118	128	0.0
CQUAD4	103	25	128	118	119	129	0.0
CQUAD4	104	25	129	119	120	130	0.0

```
CQUAD4     105    25    130    120    121    131    0.0
CQUAD4     106    25    132    122    123    133    0.0
CQUAD4     107    25    133    123    124    134    0.0
CQUAD4     108    25    134    124    125    135    0.0
CQUAD4     109    25    135    125    126    136    0.0
CQUAD4     110    25    136    126    127    137    0.0
CQUAD4     111    25    137    127    128    138    0.0
CQUAD4     112    25    138    128    129    139    0.0
CQUAD4     113    25    139    129    130    140    0.0
CQUAD4     114    25    140    130    131    141    0.0
CQUAD4     115    25    142    132    133    143    0.0
CQUAD4     116    25    143    133    134    144    0.0
CQUAD4     117    25    144    134    135    145    0.0
CQUAD4     118    25    145    135    136    146    0.0
CQUAD4     119    25    146    136    137    147    0.0
CQUAD4     120    25    147    137    138    148    0.0
CQUAD4     121    25    148    138    139    149    0.0
CQUAD4     122    25    149    139    140    150    0.0
CQUAD4     123    25    150    140    141    151    0.0
CBAR     124    10    63    64-.130554.9914412    0.0
CBAR     125    10    64    65-.382749.9238524    0.0
CBAR     126    10    65    66-.608805.7933197    0.0
CBAR     127    10    66    67-.793320.6088052    0.0
CBAR     128    10    67    68-.923852.3827488    0.0
CBAR     129    10    68    76-.991441.1305538    0.0
CBAR     130    10    76    89-.991441-.130554    0.0
CBAR     131    10    89    88-.923852-.382749    0.0
CBAR     132    10    88    87-.793320-.608805    0.0
CBAR     133    10    87    86-.608805-.793320    0.0
CBAR     134    10    86    85-.382749-.923852    0.0
CBAR     135    10    85    84-.130554-.991441    0.0
$*
$*  MATERIAL CARDS
$*
$*  I-DEAS Material: 11   name: MAT1  11
MAT1      11110000.042307.69.3000000    0.0    0.0        0.0
MAT1      12  2000.0  840.34.190000.0000000    0.0        0.0
$*
$*
$*  RESTRAINT CARDS
$*
SPC       1    11     1    0.0
SPC       1    62     1    0.0
SPC       1    75     1    0.0
SPC       1    83     1    0.0
SPC       1   112     1    0.0
SPC       1   151     1    0.0
SPC       1    63    16    0.0
SPC       1    84    16    0.0
SPC1      1     1    20THRU       21
SPC1      1     1    30THRU       31
SPC1      1     1    40THRU       41
SPC1      1     1    50THRU       51
SPC1      1     1    96THRU       97
SPC1      1     1   107THRU      108
```

```
SPC1         1      1     121THRU        122
SPC1         1      1     131THRU        132
SPC1         1      1     141THRU        142
SPC1         1     12       1THRU         10
GRAV         0      0  1.0000 0.00000-1.00000 0.00000
$*  PROPERTY CARDS
PSHELL      21      121.000000     -1
PSHELL      22      121.000000     -1
PSHELL      23      121.000000     -1
PSHELL      24      121.000000     -1
PSHELL      25      121.000000     -1
PBAR        10      111.0000000.0833330.0000000.0000000.0000000.000000  +
   +    0.50    0.0000 -0.50    0.0000  0.0000  0.0000  0.0000  0.0000  +
   +   0.00E+000.00E+000.00E+00
FORCE        1    142          13.5      0     -1      0
FORCE        1    143         33.75      0     -1      0
FORCE        1    144          40.5      0     -1      0
FORCE        1    145         47.25      0     -1      0
FORCE        1    146            54      0     -1      0
FORCE        1    147            81      0     -1      0
FORCE        1    148           108      0     -1      0
FORCE        1    149           108      0     -1      0
FORCE        1    150           108      0     -1      0
FORCE        1    151            54      0     -1      0
 9XPROPS      10 1.00000
 9CONSTS  14.700    1    0.10000      50
9LAYER       1     24
9LAYER       2     25

9INC         1      2      1     1.0
```

Candee2.dat

This is similar to the previous test case but with interface elements added.

```
ID Pipe5 Reformatted File
$*  GRID CARDS
$*
GRID         1      0     0.0-48.0000     0.0       0
GRID         2      0 3.00000-48.0000     0.0       0
GRID         3      0 7.50000-48.0000     0.0       0
GRID         4      0 12.0000-48.0000     0.0       0
GRID         5      0 18.0000-48.0000     0.0       0
GRID         6      0 24.0000-48.0000     0.0       0
GRID         7      0 36.0000-48.0000     0.0       0
GRID         8      0 48.0000-48.0000     0.0       0
GRID         9      0 60.0000-48.0000     0.0       0
GRID        10      0 72.0000-48.0000     0.0       0
GRID        11      0     0.0-36.0000     0.0       0
GRID        12      0 3.00000-36.0000     0.0       0
GRID        13      0 7.50000-36.0000     0.0       0
GRID        14      0 12.0000-36.0000     0.0       0
GRID        15      0 18.0000-36.0000     0.0       0
GRID        16      0 24.0000-36.0000     0.0       0
GRID        17      0 36.0000-36.0000     0.0       0
GRID        18      0 48.0000-36.0000     0.0       0
GRID        19      0 60.0000-36.0000     0.0       0
```

```
GRID        20     0 72.0000-36.0000     0.0       0
GRID        21     0     0.0-24.0000     0.0       0
GRID        22     0 3.00000-24.0000     0.0       0
GRID        23     0 7.50000-24.0000     0.0       0
GRID        24     0 12.0000-24.0000     0.0       0
GRID        25     0 18.0000-24.0000     0.0       0
GRID        26     0 24.0000-24.0000     0.0       0
GRID        27     0 36.0000-24.0000     0.0       0
GRID        28     0 48.0000-24.0000     0.0       0
GRID        29     0 60.0000-24.0000     0.0       0
GRID        30     0 72.0000-24.0000     0.0       0
GRID        31     0     0.0-20.0000     0.0       0
GRID        32     0 3.00000-20.0000     0.0       0
GRID        33     0 7.50000-20.0000     0.0       0
GRID        34     0 12.0000-20.0000     0.0       0
GRID        35     0 18.0000-20.0000     0.0       0
GRID        36     0 24.0000-20.0000     0.0       0
GRID        37     0 36.0000-20.0000     0.0       0
GRID        38     0 48.0000-20.0000     0.0       0
GRID        39     0 60.0000-20.0000     0.0       0
GRID        40     0 72.0000-20.0000     0.0       0
GRID        41     0     0.0-16.0000     0.0       0
GRID        42     0 3.00000-16.0000     0.0       0
GRID        43     0 7.50000-16.0000     0.0       0
GRID        44     0 12.0000-16.0000     0.0       0
GRID        45     0 18.0000-16.0000     0.0       0
GRID        46     0 24.0000-16.0000     0.0       0
GRID        47     0 36.0000-16.0000     0.0       0
GRID        48     0 48.0000-16.0000     0.0       0
GRID        49     0 60.0000-16.0000     0.0       0
GRID        50     0 72.0000-16.0000     0.0       0
GRID        51     0     0.0-14.0000     0.0       0
GRID        52     0 3.62300-13.5230     0.0       0
GRID        53     0 7.00000-12.1240     0.0       0
GRID        54     0 9.89900-9.89900     0.0       0
GRID        55     0 12.0000-12.0000     0.0       0
GRID        56     0 12.1240-7.00000     0.0       0
GRID        57     0 18.0000-12.0000     0.0       0
GRID        58     0 24.0000-12.0000     0.0       0
GRID        59     0 36.0000-12.0000     0.0       0
GRID        60     0 48.0000-12.0000     0.0       0
GRID        61     0 60.0000-12.0000     0.0       0
GRID        62     0 72.0000-12.0000     0.0       0
GRID        63     0     0.0-12.0000     0.0       0
GRID        65     0     0.0-12.1000     0.0       0
GRID        66     0 3.10600-11.5910     0.0       0
GRID        68     0 3.13188-11.6876     0.0       0
GRID        69     0 6.00001-10.3920     0.0       0
GRID        71     0 6.05000-10.4786     0.0       0
GRID        72     0 8.48500-8.48500     0.0       0
GRID        74     0 8.55571-8.55571     0.0       0
GRID        75     0 10.3920-6.00001     0.0       0
GRID        77     0 10.4786-6.05000     0.0       0
GRID        78     0 11.5910-3.10600     0.0       0
GRID        80     0 11.6876-3.13188     0.0       0
```

```
GRID      81      0 13.5230-3.62300     0.0       0
GRID      82      0 18.0000-6.00000     0.0       0
GRID      83      0 24.0000-6.00000     0.0       0
GRID      84      0 36.0000-6.00000     0.0       0
GRID      85      0 48.0000-6.00000     0.0       0
GRID      86      0 60.0000-6.00000     0.0       0
GRID      87      0 72.0000-6.00000     0.0       0
GRID      88      0 12.0000     0.0     0.0       0
GRID      90      0 12.1000     0.0     0.0       0
GRID      91      0 14.0000     0.0     0.0       0
GRID      92      0 18.0000     0.0     0.0       0
GRID      93      0 24.0000     0.0     0.0       0
GRID      94      0 36.0000     0.0     0.0       0
GRID      95      0 48.0000     0.0     0.0       0
GRID      96      0 60.0000     0.0     0.0       0
GRID      97      0 72.0000     0.0     0.0       0
GRID      98      0     0.0 12.0000     0.0       0
GRID     100      0     0.0 12.1000     0.0       0
GRID     101      0 3.10600 11.5910     0.0       0
GRID     103      0 3.13188 11.6876     0.0       0
GRID     104      0 6.00001 10.3920     0.0       0
GRID     106      0 6.05000 10.4786     0.0       0
GRID     107      0 8.48500 8.48500     0.0       0
GRID     109      0 8.55571 8.55571     0.0       0
GRID     110      0 10.3920 6.00001     0.0       0
GRID     112      0 10.4786 6.05000     0.0       0
GRID     113      0 11.5910 3.10600     0.0       0
GRID     115      0 11.6876 3.13188     0.0       0
GRID     116      0 13.5230 3.62300     0.0       0
GRID     117      0 18.0000 4.80000     0.0       0
GRID     118      0 24.0000 4.80000     0.0       0
GRID     119      0 36.0000 4.80000     0.0       0
GRID     120      0 48.0000 4.80000     0.0       0
GRID     121      0 60.0000 4.80000     0.0       0
GRID     122      0 72.0000 4.80000     0.0       0
GRID     123      0     0.0 14.0000     0.0       0
GRID     124      0 3.62300 13.5230     0.0       0
GRID     125      0 7.00000 12.1240     0.0       0
GRID     126      0 9.89900 9.89900     0.0       0
GRID     127      0 12.1240 7.00000     0.0       0
GRID     128      0 18.0000 11.4000     0.0       0
GRID     129      0 24.0000 11.4000     0.0       0
GRID     130      0 36.0000 11.4000     0.0       0
GRID     131      0 48.0000 11.4000     0.0       0
GRID     132      0 60.0000 11.4000     0.0       0
GRID     133      0 72.0000 11.4000     0.0       0
GRID     134      0     0.0 16.0000     0.0       0
GRID     135      0 3.00000 16.0000     0.0       0
GRID     136      0 7.50000 15.0000     0.0       0
GRID     137      0 12.0000 14.0000     0.0       0
GRID     138      0     0.0 18.0000     0.0       0
GRID     139      0 3.00000 18.0000     0.0       0
GRID     140      0 7.50000 18.0000     0.0       0
GRID     141      0 12.0000 18.0000     0.0       0
GRID     142      0 18.0000 18.0000     0.0       0
```

```
GRID         143        0 24.0000 18.0000      0.0        0
GRID         144        0 36.0000 18.0000      0.0        0
GRID         145        0 48.0000 18.0000      0.0        0
GRID         146        0 60.0000 18.0000      0.0        0
GRID         147        0 72.0000 18.0000      0.0        0
GRID         148        0      0.0 22.0000      0.0        0
GRID         149        0 3.00000 22.0000      0.0        0
GRID         150        0 7.50000 22.0000      0.0        0
GRID         151        0 12.0000 22.0000      0.0        0
GRID         152        0 18.0000 22.0000      0.0        0
GRID         153        0 24.0000 22.0000      0.0        0
GRID         154        0 36.0000 22.0000      0.0        0
GRID         155        0 48.0000 22.0000      0.0        0
GRID         156        0 60.0000 22.0000      0.0        0
GRID         157        0 72.0000 22.0000      0.0        0
GRID         158        0      0.0 27.0000      0.0        0
GRID         159        0 3.00000 27.0000      0.0        0
GRID         160        0 7.50000 27.0000      0.0        0
GRID         161        0 12.0000 27.0000      0.0        0
GRID         162        0 18.0000 27.0000      0.0        0
GRID         163        0 24.0000 27.0000      0.0        0
GRID         164        0 36.0000 27.0000      0.0        0
GRID         165        0 48.0000 27.0000      0.0        0
GRID         166        0 60.0000 27.0000      0.0        0
GRID         167        0 72.0000 27.0000      0.0        0
GRID         168        0      0.0 34.0000      0.0        0
GRID         169        0 3.00000 34.0000      0.0        0
GRID         170        0 7.50000 34.0000      0.0        0
GRID         171        0 12.0000 34.0000      0.0        0
GRID         172        0 18.0000 34.0000      0.0        0
GRID         173        0 24.0000 34.0000      0.0        0
GRID         174        0 36.0000 34.0000      0.0        0
GRID         175        0 48.0000 34.0000      0.0        0
GRID         176        0 60.0000 34.0000      0.0        0
GRID         177        0 72.0000 34.0000      0.0        0
$*
$*  ELEMENT CARDS
$*
CQUAD4         1      21      11       1       2      12     0.0
CQUAD4         2      21      12       2       3      13     0.0
CQUAD4         3      21      13       3       4      14     0.0
CQUAD4         4      21      14       4       5      15     0.0
CQUAD4         5      21      15       5       6      16     0.0
CQUAD4         6      21      16       6       7      17     0.0
CQUAD4         7      21      17       7       8      18     0.0
CQUAD4         8      21      18       8       9      19     0.0
CQUAD4         9      21      19       9      10      20     0.0
CQUAD4        10      21      21      11      12      22     0.0
CQUAD4        11      21      22      12      13      23     0.0
CQUAD4        12      21      23      13      14      24     0.0
CQUAD4        13      21      24      14      15      25     0.0
CQUAD4        14      21      25      15      16      26     0.0
CQUAD4        15      21      26      16      17      27     0.0
CQUAD4        16      21      27      17      18      28     0.0
CQUAD4        17      21      28      18      19      29     0.0
```

CQUAD4	18	21	29	19	20	30	0.0
CQUAD4	19	21	31	21	22	32	0.0
CQUAD4	20	21	32	22	23	33	0.0
CQUAD4	21	21	33	23	24	34	0.0
CQUAD4	22	21	34	24	25	35	0.0
CQUAD4	23	21	35	25	26	36	0.0
CQUAD4	24	21	36	26	27	37	0.0
CQUAD4	25	21	37	27	28	38	0.0
CQUAD4	26	21	38	28	29	39	0.0
CQUAD4	27	21	39	29	30	40	0.0
CQUAD4	28	22	41	31	32	42	0.0
CQUAD4	29	22	42	32	33	43	0.0
CQUAD4	30	22	43	33	34	44	0.0
CQUAD4	31	22	44	34	35	45	0.0
CQUAD4	32	22	45	35	36	46	0.0
CQUAD4	33	22	46	36	37	47	0.0
CQUAD4	34	22	47	37	38	48	0.0
CQUAD4	35	22	48	38	39	49	0.0
CQUAD4	36	22	49	39	40	50	0.0
CQUAD4	37	22	51	41	42	52	0.0
CQUAD4	38	22	65	51	52	68	0.0
CQUAD4	39	22	68	52	53	71	0.0
CQUAD4	40	22	52	42	43	53	0.0
CQUAD4	41	22	53	43	44	55	0.0
CQUAD4	42	22	55	44	45	57	0.0
CQUAD4	43	22	57	45	46	58	0.0
CQUAD4	44	22	58	46	47	59	0.0
CQUAD4	45	22	59	47	48	60	0.0
CQUAD4	46	22	60	48	49	61	0.0
CQUAD4	47	22	61	49	50	62	0.0
CQUAD4	48	23	71	53	54	74	0.0
CQUAD4	49	23	77	74	54	56	0.0
CTRIA3	50	23	55	54	53	0.0	
CQUAD4	51	23	57	56	54	55	0.0
CQUAD4	52	23	80	77	56	81	0.0
CQUAD4	53	23	81	56	57	82	0.0
CQUAD4	54	23	82	57	58	83	0.0
CQUAD4	55	23	83	58	59	84	0.0
CQUAD4	56	23	84	59	60	85	0.0
CQUAD4	57	23	85	60	61	86	0.0
CQUAD4	58	23	86	61	62	87	0.0
CQUAD4	59	23	90	80	81	91	0.0
CQUAD4	60	23	91	81	82	92	0.0
CQUAD4	61	23	92	82	83	93	0.0
CQUAD4	62	23	93	83	84	94	0.0
CQUAD4	63	23	94	84	85	95	0.0
CQUAD4	64	23	95	85	86	96	0.0
CQUAD4	65	23	96	86	87	97	0.0
CQUAD4	66	24	115	90	91	116	0.0
CQUAD4	67	24	116	91	92	117	0.0
CQUAD4	68	24	117	92	93	118	0.0
CQUAD4	69	24	118	93	94	119	0.0
CQUAD4	70	24	119	94	95	120	0.0
CQUAD4	71	24	120	95	96	121	0.0
CQUAD4	72	24	121	96	97	122	0.0

CQUAD4	73	24	112	115	116	127	0.0
CQUAD4	74	24	126	109	112	127	0.0
CQUAD4	75	24	125	106	109	126	0.0
CQUAD4	76	24	124	103	106	125-1.000-3	
CQUAD4	77	24	123	100	103	124	0.0
CQUAD4	78	24	134	123	124	135	0.0
CQUAD4	79	24	135	124	125	136	0.0
CQUAD4	80	24	136	125	126	137	0.0
CQUAD4	81	24	127	128	137	126	0.0
CQUAD4	82	24	127	116	117	128	0.0
CQUAD4	83	24	128	117	118	129	0.0
CQUAD4	84	24	129	118	119	130	0.0
CQUAD4	85	24	130	119	120	131	0.0
CQUAD4	86	24	131	120	121	132	0.0
CQUAD4	87	24	132	121	122	133	0.0
CQUAD4	88	24	138	134	135	139	0.0
CQUAD4	89	24	139	135	136	140	0.0
CQUAD4	90	24	137	141	140	136	0.0
CQUAD4	91	24	141	137	128	142	0.0
CQUAD4	92	24	142	128	129	143	0.0
CQUAD4	93	24	143	129	130	144	0.0
CQUAD4	94	24	144	130	131	145	0.0
CQUAD4	95	24	145	131	132	146	0.0
CQUAD4	96	24	146	132	133	147	0.0
CQUAD4	97	25	148	138	139	149	0.0
CQUAD4	98	25	149	139	140	150	0.0
CQUAD4	99	25	150	140	141	151	0.0
CQUAD4	100	25	151	141	142	152	0.0
CQUAD4	101	25	152	142	143	153	0.0
CQUAD4	102	25	153	143	144	154	0.0
CQUAD4	103	25	154	144	145	155	0.0
CQUAD4	104	25	155	145	146	156	0.0
CQUAD4	105	25	156	146	147	157	0.0
CQUAD4	106	25	158	148	149	159	0.0
CQUAD4	107	25	159	149	150	160	0.0
CQUAD4	108	25	160	150	151	161	0.0
CQUAD4	109	25	161	151	152	162	0.0
CQUAD4	110	25	162	152	153	163	0.0
CQUAD4	111	25	163	153	154	164	0.0
CQUAD4	112	25	164	154	155	165	0.0
CQUAD4	113	25	165	155	156	166	0.0
CQUAD4	114	25	166	156	157	167	0.0
CQUAD4	115	25	168	158	159	169	0.0
CQUAD4	116	25	169	159	160	170	0.0
CQUAD4	117	25	170	160	161	171	0.0
CQUAD4	118	25	171	161	162	172	0.0
CQUAD4	119	25	172	162	163	173	0.0
CQUAD4	120	25	173	163	164	174	0.0
CQUAD4	121	25	174	164	165	175	0.0
CQUAD4	122	25	175	165	166	176	0.0
CQUAD4	123	25	176	166	167	177	0.0
CBAR	124	10	63	66-.130554.9914412			0.0
CBAR	125	10	66	69-.382749.9238524			0.0
CBAR	126	10	69	72-.608805.7933197			0.0
CBAR	127	10	72	75-.793320.6088052			0.0

```
CBAR       128     10     75     78-.923852.3827488     0.0
CBAR       129     10     78     88-.991441.1305538     0.0
CBAR       130     10     88    113-.991441-.130554     0.0
CBAR       131     10    113    110-.923852-.382749     0.0
CBAR       132     10    110    107-.793320-.608805     0.0
CBAR       133     10    107    104-.608805-.793320     0.0
CBAR       134     10    104    101-.382749-.923852     0.0
CBAR       135     10    101     98-.130554-.991441     0.0
CGAP       136      8     63     65                    0
CGAP       137      8     66     68                    0
CGAP       138      8     69     71                    0
CGAP       139      8     72     74                    0
CGAP       140      8     75     77                    0
CGAP       141      8     78     80                    0
CGAP       142      8     88     90                    0
CGAP       143      8    113    115                    0
CGAP       144      8    110    112                    0
CGAP       145      8    107    109                    0
CGAP       146      8    104    106                    0
CGAP       147      8    101    103                    0
CGAP       148      8     98    100                    0
$*
$*  MATERIAL CARDS
$*  I-DEAS Material: 11   name: MAT1  11
MAT1        11110000.042307.69.3000000     0.1     0.0             0.0
MAT1        12  2000.0  840.34.1900000.0694444     0.0             0.0
$*
$*  PROPERTY CARDS
$*
PBAR        10      111.0000000.0833330.0000000.0000000.0000000.000000  +
   +     0.50    0.0000 -0.50    0.0000  0.0000  0.0000  0.0000  0.0000  +
   +   0.00E+000.00E+000.00E+00
PSHELL      21      121.000000      -1
PSHELL      22      121.000000      -1
PSHELL      23      121.000000      -1
PSHELL      24      121.000000      -1
PSHELL      25      121.000000      -1
FORCE        1     168          13.5       0      -1       0
FORCE        1     169         33.75       0      -1       0
FORCE        1     170          40.5       0      -1       0
FORCE        1     171         47.25       0      -1       0
FORCE        1     172            54       0      -1       0
FORCE        1     173            81       0      -1       0
FORCE        1     174           108       0      -1       0
FORCE        1     175           108       0      -1       0
FORCE        1     176           108       0      -1       0
FORCE        1     177            54       0      -1       0
PGAP         8     0.0     0.0     0.0     0.0        .2500000
$*
$*  RESTRAINT CARDS
$*
SPC          1      11       1     0.0
SPC          1      62       1     0.0
SPC          1      65       1     0.0
SPC          1      87       1     0.0
```

```
SPC          1     97      1    0.0
SPC          1    100      1    0.0
SPC          1    138      1    0.0
SPC          1    177      1    0.0
SPC          1     63     16    0.0
SPC          1     98     16    0.0
SPC1         1      1     20THRU       21
SPC1         1      1     30THRU       31
SPC1         1      1     40THRU       41
SPC1         1      1     50THRU       51
SPC1         1      1    122THRU      123
SPC1         1      1    133THRU      134
SPC1         1      1    147THRU      148
SPC1         1      1    157THRU      158
SPC1         1      1    167THRU      168
SPC1         1     12      1THRU       10
GRAV         0      0  1.0000 0.00000-1.00000 0.00000
$
 9XPROPS     10 1.00000
 9CONSTS  14.700   1    0.10000     50

9LAYER       1     24
9LAYER       2     25

9INC         1      2      1    1.0
```

Candedunc2.dat

This is the same mesh as the first test case but using the Duncan soil model instead of a linear elastic one.

```
ID Pipe5 Reformatted File
$*  GRID CARDS
$*
GRID         1      0     0.0-48.0000     0.0       0
GRID         2      0 3.00000-48.0000     0.0       0
GRID         3      0 7.50000-48.0000     0.0       0
GRID         4      0 12.0000-48.0000     0.0       0
GRID         5      0 18.0000-48.0000     0.0       0
GRID         6      0 24.0000-48.0000     0.0       0
GRID         7      0 36.0000-48.0000     0.0       0
GRID         8      0 48.0000-48.0000     0.0       0
GRID         9      0 60.0000-48.0000     0.0       0
GRID        10      0 72.0000-48.0000     0.0       0
GRID        11      0     0.0-36.0000     0.0       0
GRID        12      0 3.00000-36.0000     0.0       0
GRID        13      0 7.50000-36.0000     0.0       0
GRID        14      0 12.0000-36.0000     0.0       0
GRID        15      0 18.0000-36.0000     0.0       0
GRID        16      0 24.0000-36.0000     0.0       0
GRID        17      0 36.0000-36.0000     0.0       0
GRID        18      0 48.0000-36.0000     0.0       0
GRID        19      0 60.0000-36.0000     0.0       0
GRID        20      0 72.0000-36.0000     0.0       0
GRID        21      0     0.0-24.0000     0.0       0
GRID        22      0 3.00000-24.0000     0.0       0
```

```
GRID      23     0 7.50000-24.0000     0.0       0
GRID      24     0 12.0000-24.0000     0.0       0
GRID      25     0 18.0000-24.0000     0.0       0
GRID      26     0 24.0000-24.0000     0.0       0
GRID      27     0 36.0000-24.0000     0.0       0
GRID      28     0 48.0000-24.0000     0.0       0
GRID      29     0 60.0000-24.0000     0.0       0
GRID      30     0 72.0000-24.0000     0.0       0
GRID      31     0     0.0-20.0000     0.0       0
GRID      32     0 3.00000-20.0000     0.0       0
GRID      33     0 7.50000-20.0000     0.0       0
GRID      34     0 12.0000-20.0000     0.0       0
GRID      35     0 18.0000-20.0000     0.0       0
GRID      36     0 24.0000-20.0000     0.0       0
GRID      37     0 36.0000-20.0000     0.0       0
GRID      38     0 48.0000-20.0000     0.0       0
GRID      39     0 60.0000-20.0000     0.0       0
GRID      40     0 72.0000-20.0000     0.0       0
GRID      41     0     0.0-16.0000     0.0       0
GRID      42     0 3.00000-16.0000     0.0       0
GRID      43     0 7.50000-16.0000     0.0       0
GRID      44     0 12.0000-16.0000     0.0       0
GRID      45     0 18.0000-16.0000     0.0       0
GRID      46     0 24.0000-16.0000     0.0       0
GRID      47     0 36.0000-16.0000     0.0       0
GRID      48     0 48.0000-16.0000     0.0       0
GRID      49     0 60.0000-16.0000     0.0       0
GRID      50     0 72.0000-16.0000     0.0       0
GRID      51     0     0.0-14.0000     0.0       0
GRID      52     0 3.62300-13.5230     0.0       0
GRID      53     0 7.00000-12.1240     0.0       0
GRID      54     0 9.89900-9.89900     0.0       0
GRID      55     0 12.0000-12.0000     0.0       0
GRID      56     0 12.1240-7.00000     0.0       0
GRID      57     0 18.0000-12.0000     0.0       0
GRID      58     0 24.0000-12.0000     0.0       0
GRID      59     0 36.0000-12.0000     0.0       0
GRID      60     0 48.0000-12.0000     0.0       0
GRID      61     0 60.0000-12.0000     0.0       0
GRID      62     0 72.0000-12.0000     0.0       0
GRID      63     0     0.0-12.0000     0.0       0
GRID      64     0 3.10600-11.5910     0.0       0
GRID      65     0 6.00001-10.3920     0.0       0
GRID      66     0 8.48500-8.48500     0.0       0
GRID      67     0 10.3920-6.00001     0.0       0
GRID      68     0 11.5910-3.10600     0.0       0
GRID      69     0 13.5230-3.62300     0.0       0
GRID      70     0 18.0000-6.00000     0.0       0
GRID      71     0 24.0000-6.00000     0.0       0
GRID      72     0 36.0000-6.00000     0.0       0
GRID      73     0 48.0000-6.00000     0.0       0
GRID      74     0 60.0000-6.00000     0.0       0
GRID      75     0 72.0000-6.00000     0.0       0
GRID      76     0 12.0000     0.0     0.0       0
GRID      77     0 14.0000     0.0     0.0       0
```

GRID	78	0	18.0000	0.0	0.0	0
GRID	79	0	24.0000	0.0	0.0	0
GRID	80	0	36.0000	0.0	0.0	0
GRID	81	0	48.0000	0.0	0.0	0
GRID	82	0	60.0000	0.0	0.0	0
GRID	83	0	72.0000	0.0	0.0	0
GRID	84	0	0.0	12.0000	0.0	0
GRID	85	0	3.10600	11.5910	0.0	0
GRID	86	0	6.00001	10.3920	0.0	0
GRID	87	0	8.48500	8.48500	0.0	0
GRID	88	0	10.3920	6.00001	0.0	0
GRID	89	0	11.5910	3.10600	0.0	0
GRID	90	0	13.5230	3.62300	0.0	0
GRID	91	0	18.0000	4.80000	0.0	0
GRID	92	0	24.0000	4.80000	0.0	0
GRID	93	0	36.0000	4.80000	0.0	0
GRID	94	0	48.0000	4.80000	0.0	0
GRID	95	0	60.0000	4.80000	0.0	0
GRID	96	0	72.0000	4.80000	0.0	0
GRID	97	0	0.0	14.0000	0.0	0
GRID	98	0	3.62300	13.5230	0.0	0
GRID	99	0	7.00000	12.1240	0.0	0
GRID	100	0	9.89900	9.89900	0.0	0
GRID	101	0	12.1240	7.00000	0.0	0
GRID	102	0	18.0000	11.4000	0.0	0
GRID	103	0	24.0000	11.4000	0.0	0
GRID	104	0	36.0000	11.4000	0.0	0
GRID	105	0	48.0000	11.4000	0.0	0
GRID	106	0	60.0000	11.4000	0.0	0
GRID	107	0	72.0000	11.4000	0.0	0
GRID	108	0	0.0	16.0000	0.0	0
GRID	109	0	3.00000	16.0000	0.0	0
GRID	110	0	7.50000	15.0000	0.0	0
GRID	111	0	12.0000	14.0000	0.0	0
GRID	112	0	0.0	18.0000	0.0	0
GRID	113	0	3.00000	18.0000	0.0	0
GRID	114	0	7.50000	18.0000	0.0	0
GRID	115	0	12.0000	18.0000	0.0	0
GRID	116	0	18.0000	18.0000	0.0	0
GRID	117	0	24.0000	18.0000	0.0	0
GRID	118	0	36.0000	18.0000	0.0	0
GRID	119	0	48.0000	18.0000	0.0	0
GRID	120	0	60.0000	18.0000	0.0	0
GRID	121	0	72.0000	18.0000	0.0	0
GRID	122	0	0.0	22.0000	0.0	0
GRID	123	0	3.00000	22.0000	0.0	0
GRID	124	0	7.50000	22.0000	0.0	0
GRID	125	0	12.0000	22.0000	0.0	0
GRID	126	0	18.0000	22.0000	0.0	0
GRID	127	0	24.0000	22.0000	0.0	0
GRID	128	0	36.0000	22.0000	0.0	0
GRID	129	0	48.0000	22.0000	0.0	0
GRID	130	0	60.0000	22.0000	0.0	0
GRID	131	0	72.0000	22.0000	0.0	0
GRID	132	0	0.0	27.0000	0.0	0

```
GRID         133        0 3.00000 27.0000     0.0        0
GRID         134        0 7.50000 27.0000     0.0        0
GRID         135        0 12.0000 27.0000     0.0        0
GRID         136        0 18.0000 27.0000     0.0        0
GRID         137        0 24.0000 27.0000     0.0        0
GRID         138        0 36.0000 27.0000     0.0        0
GRID         139        0 48.0000 27.0000     0.0        0
GRID         140        0 60.0000 27.0000     0.0        0
GRID         141        0 72.0000 27.0000     0.0        0
GRID         142        0     0.0 34.0000     0.0        0
GRID         143        0 3.00000 34.0000     0.0        0
GRID         144        0 7.50000 34.0000     0.0        0
GRID         145        0 12.0000 34.0000     0.0        0
GRID         146        0 18.0000 34.0000     0.0        0
GRID         147        0 24.0000 34.0000     0.0        0
GRID         148        0 36.0000 34.0000     0.0        0
GRID         149        0 48.0000 34.0000     0.0        0
GRID         150        0 60.0000 34.0000     0.0        0
GRID         151        0 72.0000 34.0000     0.0        0
$*
$*  ELEMENT CARDS
$*
CQUAD4         1      21      11       1       2      12     0.0
CQUAD4         2      21      12       2       3      13     0.0
CQUAD4         3      21      13       3       4      14     0.0
CQUAD4         4      21      14       4       5      15     0.0
CQUAD4         5      21      15       5       6      16     0.0
CQUAD4         6      21      16       6       7      17     0.0
CQUAD4         7      21      17       7       8      18     0.0
CQUAD4         8      21      18       8       9      19     0.0
CQUAD4         9      21      19       9      10      20     0.0
CQUAD4        10      21      21      11      12      22     0.0
CQUAD4        11      21      22      12      13      23     0.0
CQUAD4        12      21      23      13      14      24     0.0
CQUAD4        13      21      24      14      15      25     0.0
CQUAD4        14      21      25      15      16      26     0.0
CQUAD4        15      21      26      16      17      27     0.0
CQUAD4        16      21      27      17      18      28     0.0
CQUAD4        17      21      28      18      19      29     0.0
CQUAD4        18      21      29      19      20      30     0.0
CQUAD4        19      21      31      21      22      32     0.0
CQUAD4        20      21      32      22      23      33     0.0
CQUAD4        21      21      33      23      24      34     0.0
CQUAD4        22      21      34      24      25      35     0.0
CQUAD4        23      21      35      25      26      36     0.0
CQUAD4        24      21      36      26      27      37     0.0
CQUAD4        25      21      37      27      28      38     0.0
CQUAD4        26      21      38      28      29      39     0.0
CQUAD4        27      21      39      29      30      40     0.0
CQUAD4        28      22      41      31      32      42     0.0
CQUAD4        29      22      42      32      33      43     0.0
CQUAD4        30      22      43      33      34      44     0.0
CQUAD4        31      22      44      34      35      45     0.0
CQUAD4        32      22      45      35      36      46     0.0
CQUAD4        33      22      46      36      37      47     0.0
```

CQUAD4	34	22	47	37	38	48	0.0
CQUAD4	35	22	48	38	39	49	0.0
CQUAD4	36	22	49	39	40	50	0.0
CQUAD4	37	22	51	41	42	52	0.0
CQUAD4	38	22	63	51	52	64	0.0
CQUAD4	39	22	64	52	53	65	0.0
CQUAD4	40	22	52	42	43	53	0.0
CQUAD4	41	22	53	43	44	55	0.0
CQUAD4	42	22	55	44	45	57	0.0
CQUAD4	43	22	57	45	46	58	0.0
CQUAD4	44	22	58	46	47	59	0.0
CQUAD4	45	22	59	47	48	60	0.0
CQUAD4	46	22	60	48	49	61	0.0
CQUAD4	47	22	61	49	50	62	0.0
CQUAD4	48	23	65	53	54	66	0.0
CQUAD4	49	23	67	66	54	56	0.0
CTRIA3	50	23	55	54	53	0.0	
CQUAD4	51	23	57	56	54	55	0.0
CQUAD4	52	23	68	67	56	69	0.0
CQUAD4	53	23	69	56	57	70	0.0
CQUAD4	54	23	70	57	58	71	0.0
CQUAD4	55	23	71	58	59	72	0.0
CQUAD4	56	23	72	59	60	73	0.0
CQUAD4	57	23	73	60	61	74	0.0
CQUAD4	58	23	74	61	62	75	0.0
CQUAD4	59	23	76	68	69	77	0.0
CQUAD4	60	23	77	69	70	78	0.0
CQUAD4	61	23	78	70	71	79	0.0
CQUAD4	62	23	79	71	72	80	0.0
CQUAD4	63	23	80	72	73	81	0.0
CQUAD4	64	23	81	73	74	82	0.0
CQUAD4	65	23	82	74	75	83	0.0
CQUAD4	66	24	89	76	77	90	0.0
CQUAD4	67	24	90	77	78	91	0.0
CQUAD4	68	24	91	78	79	92	0.0
CQUAD4	69	24	92	79	80	93	0.0
CQUAD4	70	24	93	80	81	94	0.0
CQUAD4	71	24	94	81	82	95	0.0
CQUAD4	72	24	95	82	83	96	0.0
CQUAD4	73	24	88	89	90	101	0.0
CQUAD4	74	24	100	87	88	101	0.0
CQUAD4	75	24	99	86	87	100	0.0
CQUAD4	76	24	98	85	86	99	0.0
CQUAD4	77	24	97	84	85	98	0.0
CQUAD4	78	24	108	97	98	109	0.0
CQUAD4	79	24	109	98	99	110	0.0
CQUAD4	80	24	110	99	100	111	0.0
CQUAD4	81	24	101	102	111	100	0.0
CQUAD4	82	24	101	90	91	102	0.0
CQUAD4	83	24	102	91	92	103	0.0
CQUAD4	84	24	103	92	93	104	0.0
CQUAD4	85	24	104	93	94	105	0.0
CQUAD4	86	24	105	94	95	106	0.0
CQUAD4	87	24	106	95	96	107	0.0
CQUAD4	88	24	112	108	109	113	0.0

```
CQUAD4      89     24    113    109    110    114    0.0
CQUAD4      90     24    111    115    114    110    0.0
CQUAD4      91     24    115    111    102    116    0.0
CQUAD4      92     24    116    102    103    117    0.0
CQUAD4      93     24    117    103    104    118    0.0
CQUAD4      94     24    118    104    105    119    0.0
CQUAD4      95     24    119    105    106    120    0.0
CQUAD4      96     24    120    106    107    121    0.0
CQUAD4      97     25    122    112    113    123    0.0
CQUAD4      98     25    123    113    114    124    0.0
CQUAD4      99     25    124    114    115    125    0.0
CQUAD4     100     25    125    115    116    126    0.0
CQUAD4     101     25    126    116    117    127    0.0
CQUAD4     102     25    127    117    118    128    0.0
CQUAD4     103     25    128    118    119    129    0.0
CQUAD4     104     25    129    119    120    130    0.0
CQUAD4     105     25    130    120    121    131    0.0
CQUAD4     106     25    132    122    123    133    0.0
CQUAD4     107     25    133    123    124    134    0.0
CQUAD4     108     25    134    124    125    135    0.0
CQUAD4     109     25    135    125    126    136    0.0
CQUAD4     110     25    136    126    127    137    0.0
CQUAD4     111     25    137    127    128    138    0.0
CQUAD4     112     25    138    128    129    139    0.0
CQUAD4     113     25    139    129    130    140    0.0
CQUAD4     114     25    140    130    131    141    0.0
CQUAD4     115     25    142    132    133    143    0.0
CQUAD4     116     25    143    133    134    144    0.0
CQUAD4     117     25    144    134    135    145    0.0
CQUAD4     118     25    145    135    136    146    0.0
CQUAD4     119     25    146    136    137    147    0.0
CQUAD4     120     25    147    137    138    148    0.0
CQUAD4     121     25    148    138    139    149    0.0
CQUAD4     122     25    149    139    140    150    0.0
CQUAD4     123     25    150    140    141    151    0.0
CBAR       124     10     63     64-.130554.9914412    0.0
CBAR       125     10     64     65-.382749.9238524    0.0
CBAR       126     10     65     66-.608805.7933197    0.0
CBAR       127     10     66     67-.793320.6088052    0.0
CBAR       128     10     67     68-.923852.3827488    0.0
CBAR       129     10     68     76-.991441.1305538    0.0
CBAR       130     10     76     89-.991441-.130554    0.0
CBAR       131     10     89     88-.923852-.382749    0.0
CBAR       132     10     88     87-.793320-.608805    0.0
CBAR       133     10     87     86-.608805-.793320    0.0
CBAR       134     10     86     85-.382749-.923852    0.0
CBAR       135     10     85     84-.130554-.991441    0.0
$*
$*  MATERIAL CARDS
$*
$*  I-DEAS Material: 11   name: MAT1  11
MAT1          11110000.042307.69.3000000     0.1     0.0             0.0
MAT1          12  2000.0  840.34.1900000.0694444     0.0             0.0
$*
$*
```

```
$*  RESTRAINT CARDS
$*
SPC        1     11      1    0.0
SPC        1     62      1    0.0
SPC        1     75      1    0.0
SPC        1     83      1    0.0
SPC        1    112      1    0.0
SPC        1    151      1    0.0
SPC        1     63     16    0.0
SPC        1     84     16    0.0
SPC1       1      1     20THRU        21
SPC1       1      1     30THRU        31
SPC1       1      1     40THRU        41
SPC1       1      1     50THRU        51
SPC1       1      1     96THRU        97
SPC1       1      1    107THRU       108
SPC1       1      1    121THRU       122
SPC1       1      1    131THRU       132
SPC1       1      1    141THRU       142
SPC1       1     12      1THRU        10
GRAV       0      0  1.0000 0.00000-1.00000 0.00000
FORCE      1    142           13.5      0      -1      0
FORCE      1    143          33.75      0      -1      0
FORCE      1    144           40.5      0      -1      0
FORCE      1    145          47.25      0      -1      0
FORCE      1    146             54      0      -1      0
FORCE      1    147             81      0      -1      0
FORCE      1    148            108      0      -1      0
FORCE      1    149            108      0      -1      0
FORCE      1    150            108      0      -1      0
FORCE      1    151             54      0      -1      0

$*  PROPERTY CARDS
PSHELL    21      11.000000     -1
PSHELL    22      21.000000     -1
PSHELL    23      31.000000     -1
PSHELL    24      41.000000     -1
PSHELL    25      51.000000     -1
$SM100
 9DUNCAN      10.000000  36.000   8.000   0.000  600.000.2500000.700000      +
   +    450.000.0000000.259616  000.000.000000
$SM90
 9DUNCAN      20.000000  32.000   4.000   0.000  300.000.2500000.700000      +
   +    250.000.0000000.307258  000.000.000000
$SM90
 9DUNCAN      30.000000  32.000   4.000   0.000  300.000.2500000.700000      +
   +    250.000.0000000.307258  000.000.000000
$SM85
 9DUNCAN      40.000000  30.000   2.000   0.000  150.000.2500000.700000      +
   +    150.000.0000000.333333  000.000.000000
$SM85
 9DUNCAN      50.000000  30.000   2.000   0.000  150.000.2500000.700000      +
   +    150.000.0000000.333333  000.000.000000
PBAR      10      111.0000000.0833330.0000000.0000000.0000000.000000  +
   +    0.50    0.0000 -0.50    0.0000  0.0000  0.0000  0.0000  0.0000  +
```

```
  +   0.00E+000.00E+000.00E+00

 9XPROPS      10 1.00000
 9CONSTS  14.700    1    0.10000      50
9LAYER        1      24
9LAYER        2      25

9INC          1       2       1     1.0
9INC          2       2       1     5.0
```

Candeeinterdunc.dat

This is the same as candee2.dat but with the Duncan soil model.

```
ID Pipe5 Reformatted File
$*  GRID CARDS
$*
GRID          1       0     0.0-48.0000     0.0       0
GRID          2       0 3.00000-48.0000     0.0       0
GRID          3       0 7.50000-48.0000     0.0       0
GRID          4       0 12.0000-48.0000     0.0       0
GRID          5       0 18.0000-48.0000     0.0       0
GRID          6       0 24.0000-48.0000     0.0       0
GRID          7       0 36.0000-48.0000     0.0       0
GRID          8       0 48.0000-48.0000     0.0       0
GRID          9       0 60.0000-48.0000     0.0       0
GRID         10       0 72.0000-48.0000     0.0       0
GRID         11       0     0.0-36.0000     0.0       0
GRID         12       0 3.00000-36.0000     0.0       0
GRID         13       0 7.50000-36.0000     0.0       0
GRID         14       0 12.0000-36.0000     0.0       0
GRID         15       0 18.0000-36.0000     0.0       0
GRID         16       0 24.0000-36.0000     0.0       0
GRID         17       0 36.0000-36.0000     0.0       0
GRID         18       0 48.0000-36.0000     0.0       0
GRID         19       0 60.0000-36.0000     0.0       0
GRID         20       0 72.0000-36.0000     0.0       0
GRID         21       0     0.0-24.0000     0.0       0
GRID         22       0 3.00000-24.0000     0.0       0
GRID         23       0 7.50000-24.0000     0.0       0
GRID         24       0 12.0000-24.0000     0.0       0
GRID         25       0 18.0000-24.0000     0.0       0
GRID         26       0 24.0000-24.0000     0.0       0
GRID         27       0 36.0000-24.0000     0.0       0
GRID         28       0 48.0000-24.0000     0.0       0
GRID         29       0 60.0000-24.0000     0.0       0
GRID         30       0 72.0000-24.0000     0.0       0
GRID         31       0     0.0-20.0000     0.0       0
GRID         32       0 3.00000-20.0000     0.0       0
GRID         33       0 7.50000-20.0000     0.0       0
GRID         34       0 12.0000-20.0000     0.0       0
GRID         35       0 18.0000-20.0000     0.0       0
GRID         36       0 24.0000-20.0000     0.0       0
GRID         37       0 36.0000-20.0000     0.0       0
GRID         38       0 48.0000-20.0000     0.0       0
GRID         39       0 60.0000-20.0000     0.0       0
```

```
GRID      40     0 72.0000-20.0000     0.0       0
GRID      41     0     0.0-16.0000     0.0       0
GRID      42     0 3.00000-16.0000     0.0       0
GRID      43     0 7.50000-16.0000     0.0       0
GRID      44     0 12.0000-16.0000     0.0       0
GRID      45     0 18.0000-16.0000     0.0       0
GRID      46     0 24.0000-16.0000     0.0       0
GRID      47     0 36.0000-16.0000     0.0       0
GRID      48     0 48.0000-16.0000     0.0       0
GRID      49     0 60.0000-16.0000     0.0       0
GRID      50     0 72.0000-16.0000     0.0       0
GRID      51     0     0.0-14.0000     0.0       0
GRID      52     0 3.62300-13.5230     0.0       0
GRID      53     0 7.00000-12.1240     0.0       0
GRID      54     0 9.89900-9.89900     0.0       0
GRID      55     0 12.0000-12.0000     0.0       0
GRID      56     0 12.1240-7.00000     0.0       0
GRID      57     0 18.0000-12.0000     0.0       0
GRID      58     0 24.0000-12.0000     0.0       0
GRID      59     0 36.0000-12.0000     0.0       0
GRID      60     0 48.0000-12.0000     0.0       0
GRID      61     0 60.0000-12.0000     0.0       0
GRID      62     0 72.0000-12.0000     0.0       0
GRID      63     0     0.0-12.0000     0.0       0
GRID      65     0     0.0-12.1000     0.0       0
GRID      66     0 3.10600-11.5910     0.0       0
GRID      68     0 3.13188-11.6876     0.0       0
GRID      69     0 6.00001-10.3920     0.0       0
GRID      71     0 6.05000-10.4786     0.0       0
GRID      72     0 8.48500-8.48500     0.0       0
GRID      74     0 8.55571-8.55571     0.0       0
GRID      75     0 10.3920-6.00001     0.0       0
GRID      77     0 10.4786-6.05000     0.0       0
GRID      78     0 11.5910-3.10600     0.0       0
GRID      80     0 11.6876-3.13188     0.0       0
GRID      81     0 13.5230-3.62300     0.0       0
GRID      82     0 18.0000-6.00000     0.0       0
GRID      83     0 24.0000-6.00000     0.0       0
GRID      84     0 36.0000-6.00000     0.0       0
GRID      85     0 48.0000-6.00000     0.0       0
GRID      86     0 60.0000-6.00000     0.0       0
GRID      87     0 72.0000-6.00000     0.0       0
GRID      88     0 12.0000     0.0     0.0       0
GRID      90     0 12.1000     0.0     0.0       0
GRID      91     0 14.0000     0.0     0.0       0
GRID      92     0 18.0000     0.0     0.0       0
GRID      93     0 24.0000     0.0     0.0       0
GRID      94     0 36.0000     0.0     0.0       0
GRID      95     0 48.0000     0.0     0.0       0
GRID      96     0 60.0000     0.0     0.0       0
GRID      97     0 72.0000     0.0     0.0       0
GRID      98     0     0.0 12.0000     0.0       0
GRID     100     0     0.0 12.1000     0.0       0
GRID     101     0 3.10600 11.5910     0.0       0
GRID     103     0 3.13188 11.6876     0.0       0
```

GRID	104	0	6.00001	10.3920	0.0	0
GRID	106	0	6.05000	10.4786	0.0	0
GRID	107	0	8.48500	8.48500	0.0	0
GRID	109	0	8.55571	8.55571	0.0	0
GRID	110	0	10.3920	6.00001	0.0	0
GRID	112	0	10.4786	6.05000	0.0	0
GRID	113	0	11.5910	3.10600	0.0	0
GRID	115	0	11.6876	3.13188	0.0	0
GRID	116	0	13.5230	3.62300	0.0	0
GRID	117	0	18.0000	4.80000	0.0	0
GRID	118	0	24.0000	4.80000	0.0	0
GRID	119	0	36.0000	4.80000	0.0	0
GRID	120	0	48.0000	4.80000	0.0	0
GRID	121	0	60.0000	4.80000	0.0	0
GRID	122	0	72.0000	4.80000	0.0	0
GRID	123	0	0.0	14.0000	0.0	0
GRID	124	0	3.62300	13.5230	0.0	0
GRID	125	0	7.00000	12.1240	0.0	0
GRID	126	0	9.89900	9.89900	0.0	0
GRID	127	0	12.1240	7.00000	0.0	0
GRID	128	0	18.0000	11.4000	0.0	0
GRID	129	0	24.0000	11.4000	0.0	0
GRID	130	0	36.0000	11.4000	0.0	0
GRID	131	0	48.0000	11.4000	0.0	0
GRID	132	0	60.0000	11.4000	0.0	0
GRID	133	0	72.0000	11.4000	0.0	0
GRID	134	0	0.0	16.0000	0.0	0
GRID	135	0	3.00000	16.0000	0.0	0
GRID	136	0	7.50000	15.0000	0.0	0
GRID	137	0	12.0000	14.0000	0.0	0
GRID	138	0	0.0	18.0000	0.0	0
GRID	139	0	3.00000	18.0000	0.0	0
GRID	140	0	7.50000	18.0000	0.0	0
GRID	141	0	12.0000	18.0000	0.0	0
GRID	142	0	18.0000	18.0000	0.0	0
GRID	143	0	24.0000	18.0000	0.0	0
GRID	144	0	36.0000	18.0000	0.0	0
GRID	145	0	48.0000	18.0000	0.0	0
GRID	146	0	60.0000	18.0000	0.0	0
GRID	147	0	72.0000	18.0000	0.0	0
GRID	148	0	0.0	22.0000	0.0	0
GRID	149	0	3.00000	22.0000	0.0	0
GRID	150	0	7.50000	22.0000	0.0	0
GRID	151	0	12.0000	22.0000	0.0	0
GRID	152	0	18.0000	22.0000	0.0	0
GRID	153	0	24.0000	22.0000	0.0	0
GRID	154	0	36.0000	22.0000	0.0	0
GRID	155	0	48.0000	22.0000	0.0	0
GRID	156	0	60.0000	22.0000	0.0	0
GRID	157	0	72.0000	22.0000	0.0	0
GRID	158	0	0.0	27.0000	0.0	0
GRID	159	0	3.00000	27.0000	0.0	0
GRID	160	0	7.50000	27.0000	0.0	0
GRID	161	0	12.0000	27.0000	0.0	0
GRID	162	0	18.0000	27.0000	0.0	0

```
GRID     163     0 24.0000 27.0000     0.0     0
GRID     164     0 36.0000 27.0000     0.0     0
GRID     165     0 48.0000 27.0000     0.0     0
GRID     166     0 60.0000 27.0000     0.0     0
GRID     167     0 72.0000 27.0000     0.0     0
GRID     168     0     0.0 34.0000     0.0     0
GRID     169     0 3.00000 34.0000     0.0     0
GRID     170     0 7.50000 34.0000     0.0     0
GRID     171     0 12.0000 34.0000     0.0     0
GRID     172     0 18.0000 34.0000     0.0     0
GRID     173     0 24.0000 34.0000     0.0     0
GRID     174     0 36.0000 34.0000     0.0     0
GRID     175     0 48.0000 34.0000     0.0     0
GRID     176     0 60.0000 34.0000     0.0     0
GRID     177     0 72.0000 34.0000     0.0     0
$*
$*  ELEMENT CARDS
$*
CQUAD4       1      21      11       1       2      12     0.0
CQUAD4       2      21      12       2       3      13     0.0
CQUAD4       3      21      13       3       4      14     0.0
CQUAD4       4      21      14       4       5      15     0.0
CQUAD4       5      21      15       5       6      16     0.0
CQUAD4       6      21      16       6       7      17     0.0
CQUAD4       7      21      17       7       8      18     0.0
CQUAD4       8      21      18       8       9      19     0.0
CQUAD4       9      21      19       9      10      20     0.0
CQUAD4      10      21      21      11      12      22     0.0
CQUAD4      11      21      22      12      13      23     0.0
CQUAD4      12      21      23      13      14      24     0.0
CQUAD4      13      21      24      14      15      25     0.0
CQUAD4      14      21      25      15      16      26     0.0
CQUAD4      15      21      26      16      17      27     0.0
CQUAD4      16      21      27      17      18      28     0.0
CQUAD4      17      21      28      18      19      29     0.0
CQUAD4      18      21      29      19      20      30     0.0
CQUAD4      19      21      31      21      22      32     0.0
CQUAD4      20      21      32      22      23      33     0.0
CQUAD4      21      21      33      23      24      34     0.0
CQUAD4      22      21      34      24      25      35     0.0
CQUAD4      23      21      35      25      26      36     0.0
CQUAD4      24      21      36      26      27      37     0.0
CQUAD4      25      21      37      27      28      38     0.0
CQUAD4      26      21      38      28      29      39     0.0
CQUAD4      27      21      39      29      30      40     0.0
CQUAD4      28      22      41      31      32      42     0.0
CQUAD4      29      22      42      32      33      43     0.0
CQUAD4      30      22      43      33      34      44     0.0
CQUAD4      31      22      44      34      35      45     0.0
CQUAD4      32      22      45      35      36      46     0.0
CQUAD4      33      22      46      36      37      47     0.0
CQUAD4      34      22      47      37      38      48     0.0
CQUAD4      35      22      48      38      39      49     0.0
CQUAD4      36      22      49      39      40      50     0.0
CQUAD4      37      22      51      41      42      52     0.0
```

CQUAD4	38	22	65	51	52	68	0.0
CQUAD4	39	22	68	52	53	71	0.0
CQUAD4	40	22	52	42	43	53	0.0
CQUAD4	41	22	53	43	44	55	0.0
CQUAD4	42	22	55	44	45	57	0.0
CQUAD4	43	22	57	45	46	58	0.0
CQUAD4	44	22	58	46	47	59	0.0
CQUAD4	45	22	59	47	48	60	0.0
CQUAD4	46	22	60	48	49	61	0.0
CQUAD4	47	22	61	49	50	62	0.0
CQUAD4	48	23	71	53	54	74	0.0
CQUAD4	49	23	77	74	54	56	0.0
CTRIA3	50	23	55	54	53	0.0	
CQUAD4	51	23	57	56	54	55	0.0
CQUAD4	52	23	80	77	56	81	0.0
CQUAD4	53	23	81	56	57	82	0.0
CQUAD4	54	23	82	57	58	83	0.0
CQUAD4	55	23	83	58	59	84	0.0
CQUAD4	56	23	84	59	60	85	0.0
CQUAD4	57	23	85	60	61	86	0.0
CQUAD4	58	23	86	61	62	87	0.0
CQUAD4	59	23	90	80	81	91	0.0
CQUAD4	60	23	91	81	82	92	0.0
CQUAD4	61	23	92	82	83	93	0.0
CQUAD4	62	23	93	83	84	94	0.0
CQUAD4	63	23	94	84	85	95	0.0
CQUAD4	64	23	95	85	86	96	0.0
CQUAD4	65	23	96	86	87	97	0.0
CQUAD4	66	24	115	90	91	116	0.0
CQUAD4	67	24	116	91	92	117	0.0
CQUAD4	68	24	117	92	93	118	0.0
CQUAD4	69	24	118	93	94	119	0.0
CQUAD4	70	24	119	94	95	120	0.0
CQUAD4	71	24	120	95	96	121	0.0
CQUAD4	72	24	121	96	97	122	0.0
CQUAD4	73	24	112	115	116	127	0.0
CQUAD4	74	24	126	109	112	127	0.0
CQUAD4	75	24	125	106	109	126	0.0
CQUAD4	76	24	124	103	106	125-1.000-3	
CQUAD4	77	24	123	100	103	124	0.0
CQUAD4	78	24	134	123	124	135	0.0
CQUAD4	79	24	135	124	125	136	0.0
CQUAD4	80	24	136	125	126	137	0.0
CQUAD4	81	24	127	128	137	126	0.0
CQUAD4	82	24	127	116	117	128	0.0
CQUAD4	83	24	128	117	118	129	0.0
CQUAD4	84	24	129	118	119	130	0.0
CQUAD4	85	24	130	119	120	131	0.0
CQUAD4	86	24	131	120	121	132	0.0
CQUAD4	87	24	132	121	122	133	0.0
CQUAD4	88	24	138	134	135	139	0.0
CQUAD4	89	24	139	135	136	140	0.0
CQUAD4	90	24	137	141	140	136	0.0
CQUAD4	91	24	141	137	128	142	0.0
CQUAD4	92	24	142	128	129	143	0.0

CQUAD4	93	24	143	129	130	144	0.0
CQUAD4	94	24	144	130	131	145	0.0
CQUAD4	95	24	145	131	132	146	0.0
CQUAD4	96	24	146	132	133	147	0.0
CQUAD4	97	25	148	138	139	149	0.0
CQUAD4	98	25	149	139	140	150	0.0
CQUAD4	99	25	150	140	141	151	0.0
CQUAD4	100	25	151	141	142	152	0.0
CQUAD4	101	25	152	142	143	153	0.0
CQUAD4	102	25	153	143	144	154	0.0
CQUAD4	103	25	154	144	145	155	0.0
CQUAD4	104	25	155	145	146	156	0.0
CQUAD4	105	25	156	146	147	157	0.0
CQUAD4	106	25	158	148	149	159	0.0
CQUAD4	107	25	159	149	150	160	0.0
CQUAD4	108	25	160	150	151	161	0.0
CQUAD4	109	25	161	151	152	162	0.0
CQUAD4	110	25	162	152	153	163	0.0
CQUAD4	111	25	163	153	154	164	0.0
CQUAD4	112	25	164	154	155	165	0.0
CQUAD4	113	25	165	155	156	166	0.0
CQUAD4	114	25	166	156	157	167	0.0
CQUAD4	115	25	168	158	159	169	0.0
CQUAD4	116	25	169	159	160	170	0.0
CQUAD4	117	25	170	160	161	171	0.0
CQUAD4	118	25	171	161	162	172	0.0
CQUAD4	119	25	172	162	163	173	0.0
CQUAD4	120	25	173	163	164	174	0.0
CQUAD4	121	25	174	164	165	175	0.0
CQUAD4	122	25	175	165	166	176	0.0
CQUAD4	123	25	176	166	167	177	0.0
CBAR	124	10	63	66-.130554.9914412			0.0
CBAR	125	10	66	69-.382749.9238524			0.0
CBAR	126	10	69	72-.608805.7933197			0.0
CBAR	127	10	72	75-.793320.6088052			0.0
CBAR	128	10	75	78-.923852.3827488			0.0
CBAR	129	10	78	88-.991441.1305538			0.0
CBAR	130	10	88	113-.991441-.130554			0.0
CBAR	131	10	113	110-.923852-.382749			0.0
CBAR	132	10	110	107-.793320-.608805			0.0
CBAR	133	10	107	104-.608805-.793320			0.0
CBAR	134	10	104	101-.382749-.923852			0.0
CBAR	135	10	101	98-.130554-.991441			0.0
CGAP	136	8	63	65			0
CGAP	137	8	66	68			0
CGAP	138	8	69	71			0
CGAP	139	8	72	74			0
CGAP	140	8	75	77			0
CGAP	141	8	78	80			0
CGAP	142	8	88	90			0
CGAP	143	8	113	115			0
CGAP	144	8	110	112			0
CGAP	145	8	107	109			0
CGAP	146	8	104	106			0
CGAP	147	8	101	103			0

```
CGAP        148       8      98     100                          0
$*
$*  MATERIAL CARDS
$*  I-DEAS Material: 11   name: MAT1  11
MAT1         11110000.042307.69.3000000     0.1     0.0            0.0

$*
$*  PROPERTY CARDS
$*
PBAR         10      111.0000000.0833330.0000000.0000000.0000000.000000  +
   +    0.50    0.0000 -0.50    0.0000  0.0000  0.0000  0.0000  0.0000  +
   +   0.00E+000.00E+000.00E+00
PGAP          8     0.0     0.0     0.0     0.0       .2500000
PSHELL       21       11.000000      -1
PSHELL       22       21.000000      -1
PSHELL       23       31.000000      -1
PSHELL       24       41.000000      -1
PSHELL       25       51.000000      -1
$SM100
 9DUNCAN      10.000000  36.000   8.000   0.000  600.000.2500000.700000       +
   +    450.000.0000000.259616  000.000.000000
$SM90
 9DUNCAN      20.000000  32.000   4.000   0.000  300.000.2500000.700000       +
   +    250.000.0000000.307258  000.000.000000
$SM90
 9DUNCAN      30.000000  32.000   4.000   0.000  300.000.2500000.700000       +
   +    250.000.0000000.307258  000.000.000000
$SM85
 9DUNCAN      40.000000  30.000   2.000   0.000  150.000.2500000.700000       +
   +    150.000.0000000.333333  000.000.000000
$SM85
 9DUNCAN      50.000000  30.000   2.000   0.000  150.000.2500000.700000       +
   +    150.000.0000000.333333  000.000.000000
$*
$*  RESTRAINT CARDS
$*
SPC           1      11       1     0.0
SPC           1      62       1     0.0
SPC           1      65       1     0.0
SPC           1      87       1     0.0
SPC           1      97       1     0.0
SPC           1     100       1     0.0
SPC           1     138       1     0.0
SPC           1     177       1     0.0
SPC           1      63      16     0.0
SPC           1      98      16     0.0
SPC1          1       1      20THRU         21
SPC1          1       1      30THRU         31
SPC1          1       1      40THRU         41
SPC1          1       1      50THRU         51
SPC1          1       1     122THRU        123
SPC1          1       1     133THRU        134
SPC1          1       1     147THRU        148
SPC1          1       1     157THRU        158
SPC1          1       1     167THRU        168
```

```
SPC1          1      12       1THRU         10
GRAV          0       0  1.0000 0.00000-1.00000 0.00000
FORCE         1     168          13.5      0     -1       0
FORCE         1     169         33.75      0     -1       0
FORCE         1     170          40.5      0     -1       0
FORCE         1     171         47.25      0     -1       0
FORCE         1     172            54      0     -1       0
FORCE         1     173            81      0     -1       0
FORCE         1     174           108      0     -1       0
FORCE         1     175           108      0     -1       0
FORCE         1     176           108      0     -1       0
FORCE         1     177            54      0     -1       0
$
 9XPROPS      10 1.00000
 9CONSTS  14.700    1    0.10000     50

9LAYER        1      24
9LAYER        2      25

9INC          1       2       1     5.0
```

Corotate_Beam.dat

This was used to test the Corotational formulation. This was run in plane stress with large displacements turned on then with large displacements turned off. To get the comparable results in NASTRAN when comparing to the case with the small displacement assumption the solver must be changed to 101 and the LGDISP PARAM must be deleted.

```
$*$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
$*
$*              I-DEAS 12M1 NASTRAN TRANSLATOR
$*                FOR NX NASTRAN VERSION 4.0
$*
$*          MODEL FILE: C:\usr\corotate_beam.mf1
$*          INPUT FILE: corotate_beam.dat
$*            EXPORTED: AT 07:55:11 ON 18-Jul-06
$*                PART: Part1
$*                 FEM: Fem4
$*
$*               UNITS: MM-mm (milli-newton)
$*                  ... LENGTH : MM
$*                  ... TIME   : sec
$*                  ... MASS   : kilogram (kg)
$*                  ... FORCE  : milli-newton
$*                  ... TEMPERATURE : deg Celsius
$*
$*     NASTRAN BASIC COORDINATE SYSTEM: PART
$*
$*     SUBSET EXPORT: OFF
$*
$*     REAL DATA FILTER: ON (   0.1000E-14 )
$*
$*     MATERIAL ORIENTATION VECTOR EXPORT: ON
$*
```

```
$*    ROUND-TRIPPING: OFF
$*
$*    PERMANENT SINGLE POINT CONSTRAINT EXPORT: OFF
$*
$*$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
ASSIGN OUTPUT2='advnlin.op2',UNIT=21
$*
$*$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
$*
$*  EXECUTIVE CONTROL
$*
$*$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
$*
ID IDEAS,NX
SOL 601,106
CEND
$*
$*$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
$*
$*  CASE CONTROL
$*
$*$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
$*
TITLE    = NX  NASTRAN FILE TRANSLATOR  -- UNITS = MM
ECHO     = SORT
$*
$* GLOBAL CASE
$*
SPC = 1
LOAD = 1
DISPLACEMENT(PRINT) = ALL
STRESS(PRINT) = ALL
SPCFORCES(PRINT) = ALL
$*
$*$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
$*
$*  BULK DATA
$*
$*$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
$*
BEGIN BULK
$*
$*  PARAM CARDS
$*
PARAM   LGDISP        1
PARAM   LGSTRN        0
PARAM   POST         -2
$*
$*
$*  COORDINATE SYSTEM CARDS
$*
CORD2R        4       0     0.0     0.0     0.0     0.0     0.01.000000+
+       1.000000     0.0     0.0
$*
$*  GRID CARDS
```

```
$*
GRID    1   0-7.988-4 20.0000   0.0   0
GRID    2   0 9.99920 20.0000   0.0   0
GRID    3   0 19.9992 20.0000   0.0   0
GRID    4   0 29.9992 20.0000   0.0   0
GRID    5   0 39.9992 20.0000   0.0   0
GRID    6   0 49.9992 20.0000   0.0   0
GRID    7   0 59.9992 20.0000   0.0   0
GRID    8   0 69.9992 20.0000   0.0   0
GRID    9   0 79.9992 20.0000   0.0   0
GRID    10   0 89.9992 20.0000   0.0   0
GRID    11   0 99.9746 20.4754   0.0   0
GRID    12   0 109.860 21.8972   0.0   0
GRID    13   0 119.565 24.2525   0.0   0
GRID    14   0 129.002 27.5200   0.0   0
GRID    15   0 138.085 31.6700   0.0   0
GRID    16   0 146.731 36.6643   0.0   0
GRID    17   0 154.864 42.4584   0.0   0
GRID    18   0 162.408 48.9992   0.0   0
GRID    19   0 168.291 55.4263   0.0   0
GRID    20   0 172.873 61.0962   0.0   0
GRID    21   0 178.122 68.6937   0.0   0
GRID    22   0 182.958 77.1761   0.0   0
GRID    23   0 187.052 86.1841   0.0   0
GRID    24   0 190.300 95.5671   0.0   0
GRID    25   0 192.654 105.220   0.0   0
GRID    26   0 194.116 115.036   0.0   0
GRID    27   0 194.763 124.876   0.0   0
GRID    28   0 194.936 134.417   0.0   0
GRID    29   0 194.982 143.752   0.0   0
GRID    30   0 194.995 152.570   0.0   0
GRID    31   0 195.000 167.500   0.0   0
GRID    32   0 195.000 177.000   0.0   0
GRID    33   0 195.000 186.500   0.0   0
GRID    34   0 195.000 196.000   0.0   0
GRID    35   0 195.000 205.500   0.0   0
GRID    36   0 195.000 215.000   0.0   0
GRID    101   0 195.000-215.000   0.0   0
GRID    102   0 195.000-205.500   0.0   0
GRID    103   0 195.000-196.000   0.0   0
GRID    104   0 195.000-186.500   0.0   0
GRID    105   0 195.000-177.000   0.0   0
GRID    106   0 195.000-167.500   0.0   0
GRID    107   0 187.052-86.1841   0.0   0
GRID    108   0 192.654-105.220   0.0   0
GRID    109   0 194.763-124.876   0.0   0
GRID    110   0 194.116-115.036   0.0   0
GRID    111   0 194.936-134.417   0.0   0
GRID    112   0 194.982-143.752   0.0   0
GRID    113   0 194.995-152.570   0.0   0
GRID    114   0 190.300-95.5671   0.0   0
GRID    115   0 178.122-68.6937   0.0   0
GRID    116   0 172.873-61.0962   0.0   0
GRID    117   0 168.291-55.4263   0.0   0
GRID    118   0 182.958-77.1761   0.0   0
```

```
GRID     119     0-7.988-4-20.0000     0.0     0
GRID     120     0 9.99920-20.0000     0.0     0
GRID     121     0 19.9992-20.0000     0.0     0
GRID     122     0 29.9992-20.0000     0.0     0
GRID     123     0 39.9992-20.0000     0.0     0
GRID     124     0 49.9992-20.0000     0.0     0
GRID     125     0 59.9992-20.0000     0.0     0
GRID     126     0 69.9992-20.0000     0.0     0
GRID     127     0 79.9992-20.0000     0.0     0
GRID     128     0 89.9992-20.0000     0.0     0
GRID     129     0 99.9746-20.4754     0.0     0
GRID     130     0 109.860-21.8972     0.0     0
GRID     131     0 119.565-24.2525     0.0     0
GRID     132     0 129.002-27.5200     0.0     0
GRID     133     0 138.085-31.6700     0.0     0
GRID     134     0 146.731-36.6643     0.0     0
GRID     135     0 154.864-42.4584     0.0     0
GRID     136     0 162.408-48.9992     0.0     0
$*
$*  ELEMENT CARDS
$*
CBAR       1     2     1     2   0.01.000000     0.0
CBAR       2     2     2     3   0.01.000000     0.0
CBAR       3     2     3     4   0.01.000000     0.0
CBAR       4     2     4     5   0.01.000000     0.0
CBAR       5     2     5     6   0.01.000000     0.0
CBAR       6     2     6     7   0.01.000000     0.0
CBAR       7     2     7     8   0.01.000000     0.0
CBAR       8     2     8     9   0.01.000000     0.0
CBAR       9     2     9    10   0.01.000000     0.0
CBAR      10     2    10    11-.047604.9988663     0.0
CBAR      11     2    11    12-.142363.9898145     0.0
CBAR      12     2    13    12.2358494-.971790     0.0
CBAR      13     2    14    13.3271886-.944959     0.0
CBAR      14     2    15    14.4155831-.909555     0.0
CBAR      15     2    16    15.5001642-.865931     0.0
CBAR      16     2    17    16.5802544-.814435     0.0
CBAR      17     2    18    17.6550688-.755569     0.0
CBAR      18     2    18    19-.737636.6751988     0.0
CBAR      19     2    19    20-.777775.6285433     0.0
CBAR      20     2    20    21-.822740.5684185     0.0
CBAR      21     2    21    22-.868732.4952826     0.0
CBAR      22     2    22    23-.910388.4137568     0.0
CBAR      23     2    23    24-.944985.3271146     0.0
CBAR      24     2    24    25-.971529.2369192     0.0
CBAR      25     2    25    26-.989090.1473153     0.0
CBAR      26     2    26    27-.997845.0656112     0.0
CBAR      27     2    27    28-.999836.0181295     0.0
CBAR      28     2    28    29-.9999884.9276-3     0.0
CBAR      29     2    29    30-.9999991.4736-3     0.0
CBAR      30     2    30    31-1.000003.3436-4     0.0
CBAR      31     2    31    32-1.00000     0.0     0.0
CBAR      32     2    32    33-1.00000     0.0     0.0
CBAR      33     2    33    34-1.00000     0.0     0.0
CBAR      34     2    34    35-1.00000     0.0     0.0
```

```
CBAR      35   2   35   36-1.00000   0.0   0.0
CBAR     101   2  120  119   0.0-1.00000   0.0
CBAR     102   2  121  120   0.0-1.00000   0.0
CBAR     103   2  122  121   0.0-1.00000   0.0
CBAR     104   2  123  122   0.0-1.00000   0.0
CBAR     105   2  124  123   0.0-1.00000   0.0
CBAR     106   2  125  124   0.0-1.00000   0.0
CBAR     107   2  126  125   0.0-1.00000   0.0
CBAR     108   2  127  126   0.0-1.00000   0.0
CBAR     109   2  128  127   0.0-1.00000   0.0
CBAR     110   2  129  128-.047604-.998866   0.0
CBAR     111   2  130  129-.142363-.989815   0.0
CBAR     112   2  130  131.2358494.9717897   0.0
CBAR     113   2  131  132.3271886.9449591   0.0
CBAR     114   2  132  133.4155831.9095553   0.0
CBAR     115   2  133  134.5001642.8659306   0.0
CBAR     116   2  134  135.5802544.8144353   0.0
CBAR     117   2  135  136.6550688.7555692   0.0
CBAR     118   2  117  136-.737636-.675199   0.0
CBAR     119   2  116  117-.777775-.628543   0.0
CBAR     120   2  115  116-.822740-.568419   0.0
CBAR     121   2  118  115-.868732-.495283   0.0
CBAR     122   2  107  118-.910388-.413757   0.0
CBAR     123   2  114  107-.944985-.327115   0.0
CBAR     124   2  108  114-.971529-.236919   0.0
CBAR     125   2  110  108-.989090-.147315   0.0
CBAR     126   2  109  110-.997845-.065611   0.0
CBAR     127   2  111  109-.999836-.018130   0.0
CBAR     128   2  112  111-.999988-4.928-3   0.0
CBAR     129   2  113  112-.999999-1.474-3   0.0
CBAR     130   2  106  113-1.00000-3.344-4   0.0
CBAR     131   2  105  106-1.00000   0.0   0.0
CBAR     132   2  104  105-1.00000   0.0   0.0
CBAR     133   2  103  104-1.00000   0.0   0.0
CBAR     134   2  102  103-1.00000   0.0   0.0
CBAR     135   2  101  102-1.00000   0.0   0.0
$*
$*  MATERIAL CARDS
$*
$*
$*  I-DEAS Material: 1  name: GENERIC_ISOTROPIC_STEEL
MAT1       12.0680+88.0155+7.29000007.8200-61.1700-521.85000   0.0+
+    150000.0150000.068000.00
$*
$*  PROPERTY CARDS
$*
$*
$*  I-DEAS property: 2  name: BEAM2
$*  Fore Section   : 1  name: RECTANGLE 1.0 X 10.0
PBAR       2    110.0000083.33334.83333343.123314   0.0     +
+    5.000000.50000005.000000-.500000-5.00000-.500000-5.00000.5000000+
+    .8333333.8333333
$*
$*  RESTRAINT CARDS
$*
```

```
SPC          1      1  123456     0.0
SPC          1    119  123456     0.0
SPC1         1      3      2THRU        36
SPC1         1      3    101THRU       118
SPC1         1      3    120THRU       136
$*
$*  LOAD CARDS
$*
FORCE        1     36      01.000000    0.0-200000.    0.0
FORCE        1    101      01.000000    0.0200000.0    0.0
$*
ENDDATA
```

Corotate_CST.dat

This was used to test the Corotational formulation. This was run in plane stress with large displacements turned on then with large displacements turned off. To get the comparable results in NASTRAN when comparing to the case with the small displacement assumption the solver must be changed to 101 and the LGDISP PARAM must be deleted.

```
$*$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
$*
$*              I-DEAS 12M1 NASTRAN TRANSLATOR
$*                FOR NX NASTRAN VERSION 4.0
$*
$*         MODEL FILE: C:\usr\QuadBeam.mf1
$*         INPUT FILE: Corotate_CST.dat
$*           EXPORTED: AT 11:16:11 ON 14-Jul-06
$*              PART: Part2
$*               FEM: Fem3
$*
$*             UNITS: MM-mm (milli-newton)
$*                 ... LENGTH : MM
$*                 ... TIME   : sec
$*                 ... MASS   : kilogram (kg)
$*                 ... FORCE  : milli-newton
$*                 ... TEMPERATURE : deg Celsius
$*
$*    NASTRAN BASIC COORDINATE SYSTEM: PART
$*
$*    SUBSET EXPORT: OFF
$*
$*    REAL DATA FILTER: ON (   0.1000E-14 )
$*
$*    MATERIAL ORIENTATION VECTOR EXPORT: ON
$*
$*    ROUND-TRIPPING: OFF
$*
$*    PERMANENT SINGLE POINT CONSTRAINT EXPORT: OFF
$*
$*$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
ASSIGN OUTPUT2='advnlin.op2',UNIT=21
$*
$*$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
```

```
$*
$*  EXECUTIVE CONTROL
$*
$*$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
$*
ID IDEAS,NX
SOL 601,106
CEND
$*
$*$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
$*
$*  CASE CONTROL
$*
$*$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
$*
TITLE   = NX  NASTRAN FILE TRANSLATOR  -- UNITS = MM
ECHO    = SORT
$*
$* GLOBAL CASE
$*
SPC = 1
LOAD = 1
DISPLACEMENT(PRINT) = ALL
STRESS(PRINT) = ALL
SPCFORCES(PRINT) = ALL
$*
$*$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
$*
$*  BULK DATA
$*
$*$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
$*
BEGIN BULK
$*
$*  PARAM CARDS
$*
PARAM   LGDISP        1
PARAM   LGSTRN        0
PARAM   POST         -2
$*
$*
$*  COORDINATE SYSTEM CARDS
$*
CORD2R         2       0     0.0     0.0     0.0     0.0     0.01.000000+
+       1.000000     0.0     0.0
$*
$*  GRID CARDS
$*
GRID           1       0 127.229 151.516     0.0       0
GRID           2       0 127.229 241.516     0.0       0
GRID           3       0 137.229 241.516     0.0       0
GRID           4       0 137.229 151.516     0.0       0
GRID           5       0 27.2292 41.5159     0.0       0
GRID           6       0-62.7708 41.5159     0.0       0
GRID           7       0-62.7708 51.5159     0.0       0
```

GRID	8	0	27.2292	51.5159	0.0	0
GRID	9	0	127.229	161.516	0.0	0
GRID	10	0	127.229	171.516	0.0	0
GRID	11	0	127.229	181.516	0.0	0
GRID	12	0	127.229	191.516	0.0	0
GRID	13	0	127.229	201.516	0.0	0
GRID	14	0	127.229	211.516	0.0	0
GRID	15	0	127.229	221.516	0.0	0
GRID	16	0	127.229	231.516	0.0	0
GRID	17	0	137.229	231.516	0.0	0
GRID	18	0	137.229	221.516	0.0	0
GRID	19	0	137.229	211.516	0.0	0
GRID	20	0	137.229	201.516	0.0	0
GRID	21	0	137.229	191.516	0.0	0
GRID	22	0	137.229	181.516	0.0	0
GRID	23	0	137.229	171.516	0.0	0
GRID	24	0	137.229	161.516	0.0	0
GRID	25	0	136.760	141.367	0.0	0
GRID	26	0	135.356	131.304	0.0	0
GRID	27	0	133.030	121.413	0.0	0
GRID	28	0	129.801	111.779	0.0	0
GRID	29	0	125.697	102.485	0.0	0
GRID	30	0	120.754	93.6093	0.0	0
GRID	31	0	115.012	85.2269	0.0	0
GRID	32	0	108.520	77.4096	0.0	0
GRID	33	0	101.336	70.2249	0.0	0
GRID	34	0	93.5191	63.7341	0.0	0
GRID	35	0	85.1369	57.9921	0.0	0
GRID	36	0	76.2605	53.0480	0.0	0
GRID	37	0	66.9659	48.9440	0.0	0
GRID	38	0	57.3323	45.7151	0.0	0
GRID	39	0	47.4418	43.3889	0.0	0
GRID	40	0	37.3788	41.9852	0.0	0
GRID	41	0	17.2292	41.5159	0.0	0
GRID	42	0	7.22917	41.5159	0.0	0
GRID	43	0	-2.77083	41.5159	0.0	0
GRID	44	0	-12.7708	41.5159	0.0	0
GRID	45	0	-22.7708	41.5159	0.0	0
GRID	46	0	-32.7708	41.5159	0.0	0
GRID	47	0	-42.7708	41.5159	0.0	0
GRID	48	0	-52.7708	41.5159	0.0	0
GRID	49	0	-52.7708	51.5159	0.0	0
GRID	50	0	-42.7708	51.5159	0.0	0
GRID	51	0	-32.7708	51.5159	0.0	0
GRID	52	0	-22.7708	51.5159	0.0	0
GRID	53	0	-12.7708	51.5159	0.0	0
GRID	54	0	-2.77083	51.5159	0.0	0
GRID	55	0	7.22917	51.5159	0.0	0
GRID	56	0	17.2292	51.5159	0.0	0
GRID	57	0	37.0305	51.9974	0.0	0
GRID	58	0	46.7378	53.4373	0.0	0
GRID	59	0	56.2575	55.8218	0.0	0
GRID	60	0	65.4974	59.1279	0.0	0
GRID	61	0	74.3684	63.3236	0.0	0
GRID	62	0	82.7853	68.3683	0.0	0

```
GRID      63      0 90.6680 74.2145    0.0      0
GRID      64      0 97.9398 80.8052    0.0      0
GRID      65      0 104.530 88.0765    0.0      0
GRID      66      0 110.376 95.9587    0.0      0
GRID      67      0 115.421 104.376    0.0      0
GRID      68      0 119.617 113.247    0.0      0
GRID      69      0 122.923 122.487    0.0      0
GRID      70      0 125.308 132.007    0.0      0
GRID      71      0 126.748 141.714    0.0      0
$*
$*  ELEMENT CARDS
$*
CTRIA3     1     1     4     9     1    0.0    0.0
CTRIA3     2     1     1    25     4    0.0    0.0
CTRIA3     3     1    71    25     1    0.0    0.0
CTRIA3     4     1     2    17     3    0.0    0.0
CTRIA3     5     1    16    17     2    0.0    0.0
CTRIA3     6     1    24     9     4    0.0    0.0
CTRIA3     7     1     8    40     5    0.0    0.0
CTRIA3     8     1     5    56     8    0.0    0.0
CTRIA3     9     1    41    56     5    0.0    0.0
CTRIA3    10     1    49     6     7    0.0    0.0
CTRIA3    11     1    49    48     6    0.0    0.0
CTRIA3    12     1    57    40     8    0.0    0.0
CTRIA3    13     1    24    10     9    0.0    0.0
CTRIA3    14     1    23    11    10    0.0    0.0
CTRIA3    15     1    10    24    23    0.0    0.0
CTRIA3    16     1    22    12    11    0.0    0.0
CTRIA3    17     1    11    23    22    0.0    0.0
CTRIA3    18     1    21    13    12    0.0    0.0
CTRIA3    19     1    12    22    21    0.0    0.0
CTRIA3    20     1    20    14    13    0.0    0.0
CTRIA3    21     1    13    21    20    0.0    0.0
CTRIA3    22     1    18    15    14    0.0    0.0
CTRIA3    23     1    14    19    18    0.0    0.0
CTRIA3    24     1    14    20    19    0.0    0.0
CTRIA3    25     1    18    16    15    0.0    0.0
CTRIA3    26     1    16    18    17    0.0    0.0
CTRIA3    27     1    71    26    25    0.0    0.0
CTRIA3    28     1    70    27    26    0.0    0.0
CTRIA3    29     1    26    71    70    0.0    0.0
CTRIA3    30     1    69    28    27    0.0    0.0
CTRIA3    31     1    27    70    69    0.0    0.0
CTRIA3    32     1    68    29    28    0.0    0.0
CTRIA3    33     1    28    69    68    0.0    0.0
CTRIA3    34     1    67    30    29    0.0    0.0
CTRIA3    35     1    29    68    67    0.0    0.0
CTRIA3    36     1    31    66    30    0.0    0.0
CTRIA3    37     1    30    67    66    0.0    0.0
CTRIA3    38     1    32    65    31    0.0    0.0
CTRIA3    39     1    66    31    65    0.0    0.0
CTRIA3    40     1    33    64    32    0.0    0.0
CTRIA3    41     1    65    32    64    0.0    0.0
CTRIA3    42     1    34    63    33    0.0    0.0
CTRIA3    43     1    64    33    63    0.0    0.0
```

```
CTRIA3     44    1    35    62    34    0.0    0.0
CTRIA3     45    1    63    34    62    0.0    0.0
CTRIA3     46    1    36    61    35    0.0    0.0
CTRIA3     47    1    62    35    61    0.0    0.0
CTRIA3     48    1    37    60    36    0.0    0.0
CTRIA3     49    1    61    36    60    0.0    0.0
CTRIA3     50    1    38    59    37    0.0    0.0
CTRIA3     51    1    60    37    59    0.0    0.0
CTRIA3     52    1    39    58    38    0.0    0.0
CTRIA3     53    1    59    38    58    0.0    0.0
CTRIA3     54    1    40    57    39    0.0    0.0
CTRIA3     55    1    58    39    57    0.0    0.0
CTRIA3     56    1    42    56    41    0.0    0.0
CTRIA3     57    1    43    55    42    0.0    0.0
CTRIA3     58    1    56    42    55    0.0    0.0
CTRIA3     59    1    44    54    43    0.0    0.0
CTRIA3     60    1    55    43    54    0.0    0.0
CTRIA3     61    1    45    53    44    0.0    0.0
CTRIA3     62    1    54    44    53    0.0    0.0
CTRIA3     63    1    46    52    45    0.0    0.0
CTRIA3     64    1    53    45    52    0.0    0.0
CTRIA3     65    1    47    51    46    0.0    0.0
CTRIA3     66    1    52    46    51    0.0    0.0
CTRIA3     67    1    48    50    47    0.0    0.0
CTRIA3     68    1    51    47    50    0.0    0.0
CTRIA3     69    1    50    48    49    0.0    0.0
$*
$*  MATERIAL CARDS
$*
$*
$*  I-DEAS Material: 1  name: GENERIC_ISOTROPIC_STEEL
MAT1           12.0680+88.0155+7.29000007.8200-61.1700-521.85000     0.0+
+       150000.0150000.068000.00
$*
$*  PROPERTY CARDS
$*
$*
$*  I-DEAS property: 1  name: THIN SHELL1
PSHELL         1      11.000000       11.000000       1.8333330
$*
$*  RESTRAINT CARDS
$*
SPC1           1       3       1THRU           5
SPC1           1       3       8THRU          71
SPC1           1  123456       6THRU           7
$*
$*  LOAD CARDS
$*
FORCE          1       2       01.000000     0.0-100000.     0.0
FORCE          1       3       01.000000     0.0-100000.     0.0
GRAV          11       01.000000     0.0-1.00000     0.0
$*
ENDDATA
```

Corotate_QM6.dat

This was used to test the Corotational formulation. This was run in plane stress with large displacements turned on then with large displacements turned off. To get the comparable results in NASTRAN when comparing to the case with the small displacement assumption the solver must be changed to 101 and the LGDISP PARAM must be deleted.

```
$*$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
$*
$*              I-DEAS 12M1 NASTRAN TRANSLATOR
$*                FOR NX NASTRAN VERSION 4.0
$*
$*          MODEL FILE:
$*          INPUT FILE: none.dat
$*            EXPORTED: AT 11:00:30 ON 17-Aug-06
$*                PART: Part1
$*                 FEM: Fem1
$*
$*               UNITS: MM-mm (milli-newton)
$*                   ... LENGTH : MM
$*                   ... TIME   : sec
$*                   ... MASS   : kilogram (kg)
$*                   ... FORCE  : milli-newton
$*                   ... TEMPERATURE : deg Celsius
$*
$*     NASTRAN BASIC COORDINATE SYSTEM: PART
$*
$*     SUBSET EXPORT: OFF
$*
$*     REAL DATA FILTER: ON (   0.1000E-14 )
$*
$*     MATERIAL ORIENTATION VECTOR EXPORT: ON
$*
$*     ROUND-TRIPPING: OFF
$*
$*     PERMANENT SINGLE POINT CONSTRAINT EXPORT: OFF
$*
$*$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
ASSIGN OUTPUT2='advnlin.op2',UNIT=21
$*
$*$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
$*
$*  EXECUTIVE CONTROL
$*
$*$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
$*
ID IDEAS,NX
SOL 601,106
CEND
$*
$*$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
$*
$*  CASE CONTROL
$*
```

```
$*$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
$*
TITLE    = NX  NASTRAN FILE TRANSLATOR  -- UNITS = MM
ECHO     = SORT
$*
$* GLOBAL CASE
$*
SPC = 1
LOAD = 10
DISPLACEMENT(PRINT) = ALL
STRESS(PRINT) = ALL
SPCFORCES(PRINT) = ALL
$*
$*$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
$*
$*  BULK DATA
$*
$*$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
$*
BEGIN BULK
$*
$*  PARAM CARDS
$*
PARAM   LGDISP        1
PARAM   LGSTRN        0
PARAM   POST         -2
$*
LOAD          101.0000001.000000       11.000000      11
$*
$*  COORDINATE SYSTEM CARDS
$*
CORD2R        4       0     0.0     0.0     0.0     0.0     0.01.000000+
+       1.000000     0.0     0.0
$*
$*  GRID CARDS
$*
GRID          1       0 127.229 151.516     0.0       0
GRID          2       0 127.229 241.516     0.0       0
GRID          3       0 137.229 241.516     0.0       0
GRID          4       0 137.229 151.516     0.0       0
GRID          5       0 27.2292 41.5159     0.0       0
GRID          6       0-62.7708 41.5159     0.0       0
GRID          7       0-62.7708 51.5159     0.0       0
GRID          8       0 27.2292 51.5159     0.0       0
GRID          9       0 127.229 160.516     0.0       0
GRID         10       0 127.229 169.516     0.0       0
GRID         11       0 127.229 178.516     0.0       0
GRID         12       0 127.229 187.516     0.0       0
GRID         13       0 127.229 196.516     0.0       0
GRID         14       0 127.229 205.516     0.0       0
GRID         15       0 127.229 214.516     0.0       0
GRID         16       0 127.229 223.516     0.0       0
GRID         17       0 127.229 232.516     0.0       0
GRID         18       0 137.229 231.516     0.0       0
GRID         19       0 137.229 221.516     0.0       0
```

GRID	20	0	137.229	211.516	0.0	0
GRID	21	0	137.229	201.516	0.0	0
GRID	22	0	137.229	191.516	0.0	0
GRID	23	0	137.229	181.516	0.0	0
GRID	24	0	137.229	171.516	0.0	0
GRID	25	0	137.229	161.516	0.0	0
GRID	26	0	136.760	141.367	0.0	0
GRID	27	0	135.356	131.304	0.0	0
GRID	28	0	133.030	121.413	0.0	0
GRID	29	0	129.801	111.779	0.0	0
GRID	30	0	125.697	102.485	0.0	0
GRID	31	0	120.754	93.6093	0.0	0
GRID	32	0	115.012	85.2269	0.0	0
GRID	33	0	108.520	77.4096	0.0	0
GRID	34	0	101.336	70.2249	0.0	0
GRID	35	0	93.5191	63.7341	0.0	0
GRID	36	0	85.1369	57.9921	0.0	0
GRID	37	0	76.2605	53.0480	0.0	0
GRID	38	0	66.9659	48.9440	0.0	0
GRID	39	0	57.3323	45.7151	0.0	0
GRID	40	0	47.4418	43.3889	0.0	0
GRID	41	0	37.3788	41.9852	0.0	0
GRID	42	0	17.2292	41.5159	0.0	0
GRID	43	0	7.22917	41.5159	0.0	0
GRID	44	0	-2.77083	41.5159	0.0	0
GRID	45	0	-12.7708	41.5159	0.0	0
GRID	46	0	-22.7708	41.5159	0.0	0
GRID	47	0	-32.7708	41.5159	0.0	0
GRID	48	0	-42.7708	41.5159	0.0	0
GRID	49	0	-52.7708	41.5159	0.0	0
GRID	50	0	-52.7708	51.5159	0.0	0
GRID	51	0	-42.7708	51.5159	0.0	0
GRID	52	0	-32.7708	51.5159	0.0	0
GRID	53	0	-22.7708	51.5159	0.0	0
GRID	54	0	-12.7708	51.5159	0.0	0
GRID	55	0	-2.77083	51.5159	0.0	0
GRID	56	0	7.22917	51.5159	0.0	0
GRID	57	0	17.2292	51.5159	0.0	0
GRID	58	0	37.0305	51.9974	0.0	0
GRID	59	0	46.7378	53.4373	0.0	0
GRID	60	0	56.2575	55.8218	0.0	0
GRID	61	0	65.4974	59.1279	0.0	0
GRID	62	0	74.3684	63.3236	0.0	0
GRID	63	0	82.7853	68.3683	0.0	0
GRID	64	0	90.6680	74.2145	0.0	0
GRID	65	0	97.9398	80.8052	0.0	0
GRID	66	0	104.530	88.0765	0.0	0
GRID	67	0	110.376	95.9587	0.0	0
GRID	68	0	115.421	104.376	0.0	0
GRID	69	0	119.617	113.247	0.0	0
GRID	70	0	122.923	122.487	0.0	0
GRID	71	0	125.308	132.007	0.0	0
GRID	72	0	126.748	141.714	0.0	0
GRID	73	0	124.282	112.697	0.0	0
GRID	74	0	129.884	131.736	0.0	0

```
GRID      75     0 131.993 151.392   0.0     0
GRID      76     0 131.346 141.552   0.0     0
GRID      77     0 132.166 160.933   0.0     0
GRID      78     0 132.212 170.268   0.0     0
GRID      79     0 132.225 179.086   0.0     0
GRID      80     0 132.228 186.039   0.0     0
GRID      81     0 127.530 122.083   0.0     0
GRID      82     0 115.352 95.2096   0.0     0
GRID      83     0 110.103 87.6121   0.0     0
GRID      84     0 105.521 81.9423   0.0     0
GRID      85     0 120.188 103.692   0.0     0
$*
$*  ELEMENT CARDS
$*
CQUAD4     1     1    75    77     9     1   0.0   0.0
CQUAD4     2     1    76    75     1    72   0.0   0.0
CQUAD4     3     1    18     3     2    17   0.0   0.0
CQUAD4     4     1     4    25    77    75   0.0   0.0
CQUAD4     5     1    26     4    75    76   0.0   0.0
CQUAD4     6     1    58    41     5     8   0.0   0.0
CQUAD4     7     1     8     5    42    57   0.0   0.0
CQUAD4     8     1    50    49     6     7   0.0   0.0
CQUAD4     9     1    77    78    10     9   0.0   0.0
CQUAD4    10     1    78    79    11    10   0.0   0.0
CQUAD4    11     1    79    80    12    11   0.0   0.0
CQUAD4    12     1    80    22    13    12   0.0   0.0
CQUAD4    13     1    22    21    14    13   0.0   0.0
CQUAD4    14     1    21    20    15    14   0.0   0.0
CQUAD4    15     1    20    19    16    15   0.0   0.0
CQUAD4    16     1    19    18    17    16   0.0   0.0
CQUAD4    17     1    23    22    80    79   0.0   0.0
CQUAD4    18     1    24    23    79    78   0.0   0.0
CQUAD4    19     1    25    24    78    77   0.0   0.0
CQUAD4    20     1    27    26    76    74   0.0   0.0
CQUAD4    21     1    28    27    74    81   0.0   0.0
CQUAD4    22     1    29    28    81    73   0.0   0.0
CQUAD4    23     1    30    29    73    85   0.0   0.0
CQUAD4    24     1    31    30    85    82   0.0   0.0
CQUAD4    25     1    32    31    82    83   0.0   0.0
CQUAD4    26     1    33    32    83    84   0.0   0.0
CQUAD4    27     1    33    84    65    34   0.0   0.0
CQUAD4    28     1    34    65    64    35   0.0   0.0
CQUAD4    29     1    35    64    63    36   0.0   0.0
CQUAD4    30     1    36    63    62    37   0.0   0.0
CQUAD4    31     1    62    37    38    61   0.0   0.0
CQUAD4    32     1    61    38    39    60   0.0   0.0
CQUAD4    33     1    60    39    40    59   0.0   0.0
CQUAD4    34     1    59    40    41    58   0.0   0.0
CQUAD4    35     1    57    42    43    56   0.0   0.0
CQUAD4    36     1    56    43    44    55   0.0   0.0
CQUAD4    37     1    55    44    45    54   0.0   0.0
CQUAD4    38     1    54    45    46    53   0.0   0.0
CQUAD4    39     1    53    46    47    52   0.0   0.0
CQUAD4    40     1    52    47    48    51   0.0   0.0
CQUAD4    41     1    51    48    49    50   0.0   0.0
```

```
CQUAD4      42     1     84     83     66     65    0.0    0.0
CQUAD4      43     1     83     82     67     66    0.0    0.0
CQUAD4      44     1     82     85     68     67    0.0    0.0
CQUAD4      45     1     85     73     69     68    0.0    0.0
CQUAD4      46     1     73     81     70     69    0.0    0.0
CQUAD4      47     1     81     74     71     70    0.0    0.0
CQUAD4      48     1     74     76     72     71    0.0    0.0
$*
$*  MATERIAL CARDS
$*
$*
$*  I-DEAS Material: 2  name: 1 - GENERIC_ISOTROPIC_STEEL
MAT1          22.0680+88.0155+7.29000007.8200-61.1700-521.85000     0.0+
+      150000.0150000.068000.00
$*
$*  PROPERTY CARDS
$*
$*
$*  I-DEAS property: 1  name: THIN SHELL1
PSHELL        1      21.000000      21.000000      2.8333330
$*
$*  RESTRAINT CARDS
$*
SPC1          1      3      1THRU          5
SPC1          1      3      8THRU         85
SPC1          1  123456      6THRU          7
$*
$*  LOAD CARDS
$*
FORCE         1      2      01.000000     0.0-100000.    0.0
FORCE         1      3      01.000000     0.0-100000.    0.0
GRAV         11      01.000000     0.0-1.00000     0.0
$*
ENDDATA
```

Patch_test1.dat

This is a simple patch test to test the Duncan soil model

```
ID IDEAS,NX
SOL 101
CEND
TITLE   = NX  NASTRAN FILE TRANSLATOR  -- UNITS = MM
ECHO    = SORT
SPC = 1
LOAD = 1
DISPLACEMENT(PLOT) = ALL
STRESS(PLOT,CENTER,VONMISES) = ALL
SPCFORCES(PRINT) = ALL
BEGIN BULK
PARAM   AUTOSPC YES
PARAM   GRDPNT        0
PARAM   K6ROT   100.0000
PARAM   POST         -2
PARAM   POSTEXT YES
$*
```

```
GRID         1      0     0.0   0.000     0.0       0
GRID         2      0     1.0   0.000     0.0       0
GRID         3      0     1.0   1.000     0.0       0
GRID         4      0     0.0   1.000     0.0       0
$*
CQUAD4       1      6      1      2      3      4    0.0
$*
PSHELL       6      21.000000     -1
$*
$MAT1        2  3.00+7          .3000     0.0     0.0           0.0
$ SM85 properties
$  1  ><  2  ><  3  ><  4  ><  5  ><  6  ><  7  ><  8  ><  9  ><  10  >
$ 9DUNCAN      2 0.0      30.000   2.000   0.000    150.  0.2500  0.7000    +
$   +     150.0    0.00  0.4800  300.00  0.6000
$SM85
 9DUNCAN      20.000000  30.000   2.000   0.000  150.000.2500000.700000      +
   +     150.000.0000000.333333  000.000.000000
$*
$*
SPC          1      1     123     0.0
SPC          1      2      23     0.0
SPC          1      3       3     0.0
SPC          1      4      13     0.0
$*
FORCE        1      2      01.000000   -10.0     0.0     0.0
FORCE        1      3      01.000000   -10.0   -10.0     0.0
FORCE        1      4      01.000000     0.0   -10.0     0.0
ENDDATA
```

Noinitialstress.dat

This was the model used to compare PIPE5v2 to PIPE5v3

```
ID Pipe5 Reformatted File
GRID         1      0   0.000 -72.000   0.000      012
GRID         2      0   4.500 -72.000   0.000      012
GRID         3      0  11.250 -72.000   0.000      012
GRID         4      0  18.000 -72.000   0.000      012
GRID         5      0  27.000 -72.000   0.000      012
GRID         6      0  36.000 -72.000   0.000      012
GRID         7      0  54.000 -72.000   0.000      012
GRID         8      0  72.000 -72.000   0.000      012
GRID         9      0  90.000 -72.000   0.000      012
GRID        10      0 108.000 -72.000   0.000      012
GRID        11      0   0.000 -54.000   0.000      010
GRID        12      0   4.500 -54.000   0.000      000
GRID        13      0  11.250 -54.000   0.000      000
GRID        14      0  18.000 -54.000   0.000      000
GRID        15      0  27.000 -54.000   0.000      000
GRID        16      0  36.000 -54.000   0.000      000
GRID        17      0  54.000 -54.000   0.000      000
GRID        18      0  72.000 -54.000   0.000      000
GRID        19      0  90.000 -54.000   0.000      000
GRID        20      0 108.000 -54.000   0.000      010
GRID        21      0   0.000 -36.000   0.000      010
GRID        22      0   4.500 -36.000   0.000      000
```

GRID	23	0	11.250	-36.000	0.000	000
GRID	24	0	18.000	-36.000	0.000	000
GRID	25	0	27.000	-36.000	0.000	000
GRID	26	0	36.000	-36.000	0.000	000
GRID	27	0	54.000	-36.000	0.000	000
GRID	28	0	72.000	-36.000	0.000	000
GRID	29	0	90.000	-36.000	0.000	000
GRID	30	0	108.000	-36.000	0.000	010
GRID	31	0	0.000	-30.000	0.000	010
GRID	32	0	4.500	-30.000	0.000	000
GRID	33	0	11.250	-30.000	0.000	000
GRID	34	0	18.000	-30.000	0.000	000
GRID	35	0	27.000	-30.000	0.000	000
GRID	36	0	36.000	-30.000	0.000	000
GRID	37	0	54.000	-30.000	0.000	000
GRID	38	0	72.000	-30.000	0.000	000
GRID	39	0	90.000	-30.000	0.000	000
GRID	40	0	108.000	-30.000	0.000	010
GRID	41	0	0.000	-24.000	0.000	010
GRID	42	0	4.500	-24.000	0.000	000
GRID	43	0	11.250	-24.000	0.000	000
GRID	44	0	18.000	-24.000	0.000	000
GRID	45	0	27.000	-24.000	0.000	000
GRID	46	0	36.000	-24.000	0.000	000
GRID	47	0	54.000	-24.000	0.000	000
GRID	48	0	72.000	-24.000	0.000	000
GRID	49	0	90.000	-24.000	0.000	000
GRID	50	0	108.000	-24.000	0.000	010
GRID	51	0	0.000	-21.000	0.000	010
GRID	52	0	5.434	-20.285	0.000	000
GRID	53	0	10.500	-18.186	0.000	000
GRID	54	0	14.849	-14.849	0.000	000
GRID	55	0	18.000	-18.000	0.000	000
GRID	56	0	18.186	-10.500	0.000	000
GRID	57	0	27.000	-18.000	0.000	000
GRID	58	0	36.000	-18.000	0.000	000
GRID	59	0	54.000	-18.000	0.000	000
GRID	60	0	72.000	-18.000	0.000	000
GRID	61	0	90.000	-18.000	0.000	000
GRID	62	0	108.000	-18.000	0.000	010
GRID	63	0	0.000	-18.000	0.000	010
GRID	64	0	4.659	-17.386	0.000	000
GRID	65	0	9.000	-15.588	0.000	000
GRID	66	0	12.727	-12.727	0.000	000
GRID	67	0	15.588	-9.000	0.000	000
GRID	68	0	17.386	-4.659	0.000	000
GRID	69	0	20.285	-5.434	0.000	000
GRID	70	0	27.000	-9.000	0.000	000
GRID	71	0	36.000	-9.000	0.000	000
GRID	72	0	54.000	-9.000	0.000	000
GRID	73	0	72.000	-9.000	0.000	000
GRID	74	0	90.000	-9.000	0.000	000
GRID	75	0	108.000	-9.000	0.000	010
GRID	76	0	18.000	0.000	0.000	000
GRID	77	0	21.000	0.000	0.000	000

GRID	78	0	27.000	0.000	0.000	000
GRID	79	0	36.000	0.000	0.000	000
GRID	80	0	54.000	0.000	0.000	000
GRID	81	0	72.000	0.000	0.000	000
GRID	82	0	90.000	0.000	0.000	000
GRID	83	0	108.000	0.000	0.000	010
GRID	84	0	0.000	18.000	0.000	010
GRID	85	0	4.659	17.386	0.000	000
GRID	86	0	9.000	15.588	0.000	000
GRID	87	0	12.727	12.727	0.000	000
GRID	88	0	15.588	9.000	0.000	000
GRID	89	0	17.386	4.659	0.000	000
GRID	90	0	20.285	5.434	0.000	000
GRID	91	0	27.000	7.200	0.000	000
GRID	92	0	36.000	7.200	0.000	000
GRID	93	0	54.000	7.200	0.000	000
GRID	94	0	72.000	7.200	0.000	000
GRID	95	0	90.000	7.200	0.000	000
GRID	96	0	108.000	7.200	0.000	010
GRID	97	0	0.000	21.000	0.000	010
GRID	98	0	5.434	20.285	0.000	000
GRID	99	0	10.500	18.186	0.000	000
GRID	100	0	14.849	14.849	0.000	000
GRID	101	0	18.186	10.500	0.000	000
GRID	102	0	27.000	17.100	0.000	000
GRID	103	0	36.000	17.100	0.000	000
GRID	104	0	54.000	17.100	0.000	000
GRID	105	0	72.000	17.100	0.000	000
GRID	106	0	90.000	17.100	0.000	000
GRID	107	0	108.000	17.100	0.000	010
GRID	108	0	0.000	24.000	0.000	010
GRID	109	0	4.500	24.000	0.000	000
GRID	110	0	11.250	22.500	0.000	000
GRID	111	0	18.000	21.000	0.000	000
GRID	112	0	0.000	30.000	0.000	010
GRID	113	0	4.500	30.000	0.000	000
GRID	114	0	11.250	30.000	0.000	000
GRID	115	0	18.000	30.000	0.000	000
GRID	116	0	27.000	30.000	0.000	000
GRID	117	0	36.000	30.000	0.000	000
GRID	118	0	54.000	30.000	0.000	000
GRID	119	0	72.000	30.000	0.000	000
GRID	120	0	90.000	30.000	0.000	000
GRID	121	0	108.000	30.000	0.000	010
GRID	122	0	0.000	42.000	0.000	010
GRID	123	0	4.500	42.000	0.000	000
GRID	124	0	11.250	42.000	0.000	000
GRID	125	0	18.000	42.000	0.000	000
GRID	126	0	27.000	42.000	0.000	000
GRID	127	0	36.000	42.000	0.000	000
GRID	128	0	54.000	42.000	0.000	000
GRID	129	0	72.000	42.000	0.000	000
GRID	130	0	90.000	42.000	0.000	000
GRID	131	0	108.000	42.000	0.000	010
GRID	132	0	0.000	54.000	0.000	010

```
GRID        133      0   4.500  54.000   0.000       000
GRID        134      0  11.250  54.000   0.000       000
GRID        135      0  18.000  54.000   0.000       000
GRID        136      0  27.000  54.000   0.000       000
GRID        137      0  36.000  54.000   0.000       000
GRID        138      0  54.000  54.000   0.000       000
GRID        139      0  72.000  54.000   0.000       000
GRID        140      0  90.000  54.000   0.000       000
GRID        141      0 108.000  54.000   0.000       010
GRID        142      0   0.000  66.000   0.000       010
GRID        143      0   4.500  66.000   0.000       000
GRID        144      0  11.250  66.000   0.000       000
GRID        145      0  18.000  66.000   0.000       000
GRID        146      0  27.000  66.000   0.000       000
GRID        147      0  36.000  66.000   0.000       000
GRID        148      0  54.000  66.000   0.000       000
GRID        149      0  72.000  66.000   0.000       000
GRID        150      0  90.000  66.000   0.000       000
GRID        151      0 108.000  66.000   0.000       010
    SPC      0     84      6  0.0000
    SPC      0     63      6  0.0000
CQUAD4       1     20     11      1      2     12
CQUAD4       2     20     12      2      3     13
CQUAD4       3     20     13      3      4     14
CQUAD4       4     20     14      4      5     15
CQUAD4       5     20     15      5      6     16
CQUAD4       6     20     16      6      7     17
CQUAD4       7     20     17      7      8     18
CQUAD4       8     20     18      8      9     19
CQUAD4       9     20     19      9     10     20
CQUAD4      10     20     21     11     12     22
CQUAD4      11     20     22     12     13     23
CQUAD4      12     20     23     13     14     24
CQUAD4      13     20     24     14     15     25
CQUAD4      14     20     25     15     16     26
CQUAD4      15     20     26     16     17     27
CQUAD4      16     20     27     17     18     28
CQUAD4      17     20     28     18     19     29
CQUAD4      18     20     29     19     20     30
CQUAD4      19     20     31     21     22     32
CQUAD4      20     20     32     22     23     33
CQUAD4      21     20     33     23     24     34
CQUAD4      22     20     34     24     25     35
CQUAD4      23     20     35     25     26     36
CQUAD4      24     20     36     26     27     37
CQUAD4      25     20     37     27     28     38
CQUAD4      26     20     38     28     29     39
CQUAD4      27     20     39     29     30     40
CQUAD4      28     20     41     31     32     42
CQUAD4      29     20     42     32     33     43
CQUAD4      30     20     43     33     34     44
CQUAD4      31     20     44     34     35     45
CQUAD4      32     20     45     35     36     46
CQUAD4      33     20     46     36     37     47
CQUAD4      34     20     47     37     38     48
```

CQUAD4	35	20	48	38	39	49
CQUAD4	36	20	49	39	40	50
CQUAD4	37	20	51	41	42	52
CQUAD4	38	20	63	51	52	64
CQUAD4	39	20	64	52	53	65
CQUAD4	40	20	52	42	43	53
CQUAD4	41	20	53	43	44	55
CQUAD4	42	20	55	44	45	57
CQUAD4	43	20	57	45	46	58
CQUAD4	44	20	58	46	47	59
CQUAD4	45	20	59	47	48	60
CQUAD4	46	20	60	48	49	61
CQUAD4	47	20	61	49	50	62
CQUAD4	48	20	65	53	54	66
CQUAD4	49	20	67	66	54	56
CTRIA3	50	20	54	53	55	
CTRIA3	51	20	56	54	55	
CTRIA3	52	20	56	55	57	
CQUAD4	53	20	68	67	56	69
CQUAD4	54	20	69	56	57	70
CQUAD4	55	20	70	57	58	71
CQUAD4	56	20	71	58	59	72
CQUAD4	57	20	72	59	60	73
CQUAD4	58	20	73	60	61	74
CQUAD4	59	20	74	61	62	75
CQUAD4	60	20	76	68	69	77
CQUAD4	61	20	77	69	70	78
CQUAD4	62	20	78	70	71	79
CQUAD4	63	20	79	71	72	80
CQUAD4	64	20	80	72	73	81
CQUAD4	65	20	81	73	74	82
CQUAD4	66	20	82	74	75	83
CQUAD4	67	21	89	76	77	90
CQUAD4	68	21	90	77	78	91
CQUAD4	69	21	91	78	79	92
CQUAD4	70	21	92	79	80	93
CQUAD4	71	21	93	80	81	94
CQUAD4	72	21	94	81	82	95
CQUAD4	73	21	95	82	83	96
CQUAD4	74	21	101	88	89	90
CQUAD4	75	21	100	87	88	101
CQUAD4	76	21	99	86	87	100
CQUAD4	77	21	98	85	86	99
CQUAD4	78	21	97	84	85	98
CQUAD4	79	21	108	97	98	109
CQUAD4	80	21	109	98	99	110
CQUAD4	81	21	110	99	100	111
CTRIA3	82	21	111	100	101	
CTRIA3	83	21	101	102	111	
CQUAD4	84	21	101	90	91	102
CQUAD4	85	21	102	91	92	103
CQUAD4	86	21	103	92	93	104
CQUAD4	87	21	104	93	94	105
CQUAD4	88	21	105	94	95	106
CQUAD4	89	21	106	95	96	107

CQUAD4	90	22	112	108	109	113
CQUAD4	91	22	113	109	110	114
CTRIA3	92	22	114	110	111	
CTRIA3	93	22	111	115	114	
CQUAD4	94	22	115	111	102	116
CQUAD4	95	22	116	102	103	117
CQUAD4	96	22	117	103	104	118
CQUAD4	97	22	118	104	105	119
CQUAD4	98	22	119	105	106	120
CQUAD4	99	22	120	106	107	121
CQUAD4	100	23	122	112	113	123
CQUAD4	101	23	123	113	114	124
CQUAD4	102	23	124	114	115	125
CQUAD4	103	23	125	115	116	126
CQUAD4	104	23	126	116	117	127
CQUAD4	105	23	127	117	118	128
CQUAD4	106	23	128	118	119	129
CQUAD4	107	23	129	119	120	130
CQUAD4	108	23	130	120	121	131
CQUAD4	109	24	132	122	123	133
CQUAD4	110	24	133	123	124	134
CQUAD4	111	24	134	124	125	135
CQUAD4	112	24	135	125	126	136
CQUAD4	113	24	136	126	127	137
CQUAD4	114	24	137	127	128	138
CQUAD4	115	24	138	128	129	139
CQUAD4	116	24	139	129	130	140
CQUAD4	117	24	140	130	131	141
CQUAD4	118	25	142	132	133	143
CQUAD4	119	25	143	133	134	144
CQUAD4	120	25	144	134	135	145
CQUAD4	121	25	145	135	136	146
CQUAD4	122	25	146	136	137	147
CQUAD4	123	25	147	137	138	148
CQUAD4	124	25	148	138	139	149
CQUAD4	125	25	149	139	140	150
CQUAD4	126	25	150	140	141	151
CBAR	127	10	84	85		
CBAR	128	10	85	86		
CBAR	129	10	86	87		
CBAR	130	10	87	88		
CBAR	131	10	88	89		
CBAR	132	10	89	76		
CBAR	133	10	76	68		
CBAR	134	10	68	67		
CBAR	135	10	67	66		
CBAR	136	10	66	65		
CBAR	137	10	65	64		
CBAR	138	10	64	63		
PSHELL	20	1	1.0	-1		
PSHELL	21	2	1.0	-1		
PSHELL	22	3	1.0	-1		
PSHELL	23	4	1.0	-1		
PSHELL	24	5	1.0	-1		
PSHELL	25	6	1.0	-1		

```
 9DUNCAN      10.065000  30.000   2.000   0.000  150.000.6000000.700000       +
   +    150.000.0000000.480000  300.000.600000
 9DUNCAN      20.065000  30.000   2.000   0.000  150.000.6000000.700000       +
   +    150.000.0000000.480000  300.000.600000
 9DUNCAN      30.065000  30.000   2.000   0.000  150.000.6000000.700000       +
   +    150.000.0000000.480000  300.000.600000
 9DUNCAN      40.065000  30.000   2.000   0.000  150.000.6000000.700000       +
   +    150.000.0000000.480000  300.000.600000
 9DUNCAN      50.065000  30.000   2.000   0.000  150.000.6000000.700000       +
   +    150.000.0000000.480000  300.000.600000
 9DUNCAN      60.062000  30.000   2.000   5.900  415.000.3600000.820000       +
   +     47.000.3900000.430000  622.500.360000
   MAT1      111.10E+053.93E+04  0.4000  0.0000  0.0000  0.0000  0.0000       +
     +     0.     0.     0.      0
PBAR         10      110.4400000.6610000.0000000.0000000.0000000.000000  +
   +    2.0680  0.0000 -1.1720  0.0000  0.0000  0.0000  0.0000  0.0000  +
   +  1.00E+000.00E+000.00E+00
   GRAV      0       0  1.0000 0.00000-1.00000 0.00000
 9XPROPS      10 1.00000
 9CONSTS  14.700       1 0.10000       5
9PRESS        1     142     143   1.000   6.700   6.700
9PRESS        1     143     144   1.000   6.700   6.700
9PRESS        1     144     145   1.000   6.700   6.700
9PRESS        1     145     146   1.000   6.700   6.700
9PRESS        1     146     147   1.000   6.700   6.700
9PRESS        1     147     148   1.000   6.700   6.700
9PRESS        1     148     149   1.000   6.700   6.700
9PRESS        1     149     150   1.000   6.700   6.700
9PRESS        1     150     151   1.000   6.700   6.700
9PRESS        2     142     143   1.000   6.700   6.700
9PRESS        2     143     144   1.000   6.700   6.700
9PRESS        2     144     145   1.000   6.700   6.700
9PRESS        2     145     146   1.000   6.700   6.700
9PRESS        2     146     147   1.000   6.700   6.700
9PRESS        2     147     148   1.000   6.700   6.700
9PRESS        2     148     149   1.000   6.700   6.700
9PRESS        2     149     150   1.000   6.700   6.700
9PRESS        2     150     151   1.000   6.700   6.700
9PRESS        3     142     143   1.000  13.300  13.300
9PRESS        3     143     144   1.000  13.300  13.300
9PRESS        3     144     145   1.000  13.300  13.300
9PRESS        3     145     146   1.000  13.300  13.300
9PRESS        3     146     147   1.000  13.300  13.300
9PRESS        3     147     148   1.000  13.300  13.300
9PRESS        3     148     149   1.000  13.300  13.300
9PRESS        3     149     150   1.000  13.300  13.300
9PRESS        3     150     151   1.000  13.300  13.300
9PRESS        4     142     143   1.000  30.000  30.000
9PRESS        4     143     144   1.000  30.000  30.000
9PRESS        4     144     145   1.000  30.000  30.000
9PRESS        4     145     146   1.000  30.000  30.000
9PRESS        4     146     147   1.000  30.000  30.000
9PRESS        4     147     148   1.000  30.000  30.000
9PRESS        4     148     149   1.000  30.000  30.000
9PRESS        4     149     150   1.000  30.000  30.000
```

```
9PRESS        4     150     151   1.000  30.000  30.000
  9LAYER      0      20
  9LAYER      1      21
  9LAYER      2      22
  9LAYER      3      23
  9LAYER      4      24
  9LAYER      5      25
  9INC       1      1
  9INC       2      2
  9INC       3      3
  9INC       4      4
  9INC       5      5
  9INC       6      5      1    1.0
  9INC       7      5      2    1.0
  9INC       8      5      3    1.0
  9INC       9      5      4    1.0
```

Soilcellcomp.dat

This is the model used to compare triple wall pipes in the soil cell to simulations.

```
GRID          1       0 16.1690-17.2560 1.00000       0
GRID          2       0     0.0-17.2560 1.00000       0
GRID          3       0     0.0-16.2560 1.00000       0
GRID          4       0 13.8187-8.56159 1.00000       0
GRID          5       0 16.1690-10.2515 1.00000       0
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CQUAD4	56	22	87	64	65	131	0.0	0.0
CQUAD4	57	22	131	65	66	147	0.0	0.0
CQUAD4	58	22	143	66	67	145	0.0	0.0
CQUAD4	59	22	147	66	143	142	0.0	0.0
CQUAD4	60	22	145	67	68	102	0.0	0.0
CQUAD4	61	22	102	68	69	98	0.0	0.0
CQUAD4	62	22	98	69	70	99	0.0	0.0
CQUAD4	63	22	99	71	72	100	0.0	0.0
CQUAD4	64	22	100	72	73	101	0.0	0.0
CQUAD4	65	22	95	73	74	94	0.0	0.0
CQUAD4	66	22	96	101	73	95	0.0	0.0
CQUAD4	67	22	94	74	75	93	0.0	0.0
CQUAD4	68	22	76	77	108	103	0.0	0.0
CQUAD4	69	22	224	223	77	76	0.0	0.0
CQUAD4	70	22	77	78	104	108	0.0	0.0
CQUAD4	71	22	223	225	78	77	0.0	0.0
CQUAD4	72	22	78	79	110	104	0.0	0.0
CQUAD4	73	22	225	220	79	78	0.0	0.0
CQUAD4	74	22	79	80	116	110	0.0	0.0
CQUAD4	75	22	220	222	80	79	0.0	0.0
CQUAD4	76	22	80	81	118	122	0.0	0.0
CQUAD4	77	22	222	221	81	80	0.0	0.0
CQUAD4	78	22	116	80	122	121	0.0	0.0
CQUAD4	79	22	81	82	129	118	0.0	0.0
CQUAD4	80	22	221	214	82	81	0.0	0.0
CQUAD4	81	22	82	83	125	129	0.0	0.0
CQUAD4	82	22	214	219	83	82	0.0	0.0
CQUAD4	83	22	83	84	134	125	0.0	0.0
CQUAD4	84	22	219	218	84	83	0.0	0.0
CQUAD4	85	22	84	85	133	134	0.0	0.0
CQUAD4	86	22	218	215	85	84	0.0	0.0
CQUAD4	87	22	85	86	132	133	0.0	0.0
CQUAD4	88	22	215	217	86	85	0.0	0.0
CQUAD4	89	22	86	87	131	132	0.0	0.0
CQUAD4	90	22	217	216	87	86	0.0	0.0
CQUAD4	91	22	88	89	94	93	0.0	0.0
CQUAD4	92	22	115	124	89	88	0.0	0.0
CQUAD4	93	22	89	90	95	94	0.0	0.0
CQUAD4	94	22	135	136	90	89	0.0	0.0
CQUAD4	95	22	128	135	89	124	0.0	0.0
CQUAD4	96	22	90	91	96	95	0.0	0.0
CQUAD4	97	22	136	144	91	90	0.0	0.0
CQUAD4	98	22	91	92	97	96	0.0	0.0
CQUAD4	99	22	144	146	92	91	0.0	0.0
CQUAD4	100	22	92	102	98	97	0.0	0.0

CQUAD4	101	22	146	145	102	92	0.0	0.0
CQUAD4	102	22	96	97	100	101	0.0	0.0
CQUAD4	103	22	97	98	99	100	0.0	0.0
CQUAD4	104	22	103	108	109	107	0.0	0.0
CQUAD4	105	22	108	104	105	109	0.0	0.0
CQUAD4	106	22	104	110	111	105	0.0	0.0
CQUAD4	107	22	107	109	105	106	0.0	0.0
CQUAD4	108	22	105	111	112	106	0.0	0.0
CQUAD4	109	22	110	116	117	111	0.0	0.0
CQUAD4	110	22	111	117	113	112	0.0	0.0
CQUAD4	111	22	117	123	114	113	0.0	0.0
CQUAD4	112	22	123	120	115	114	0.0	0.0
CQUAD4	113	22	120	233	124	115	0.0	0.0
CQUAD4	114	22	116	121	123	117	0.0	0.0
CQUAD4	115	22	122	118	119	121	0.0	0.0
CQUAD4	116	22	118	129	130	119	0.0	0.0
CQUAD4	117	22	121	119	120	123	0.0	0.0
CQUAD4	118	22	119	130	233	120	0.0	0.0
CQUAD4	119	22	233	127	128	124	0.0	0.0
CQUAD4	120	22	129	125	126	130	0.0	0.0
CQUAD4	121	22	125	134	137	126	0.0	0.0
CQUAD4	122	22	130	126	127	233	0.0	0.0
CQUAD4	123	22	126	137	138	127	0.0	0.0
CQUAD4	124	22	127	138	135	128	0.0	0.0
CQUAD4	125	22	132	131	147	148	0.0	0.0
CQUAD4	126	22	133	132	148	140	0.0	0.0
CQUAD4	127	22	134	133	140	137	0.0	0.0
CQUAD4	128	22	138	139	136	135	0.0	0.0
CQUAD4	129	22	139	141	144	136	0.0	0.0
CQUAD4	130	22	137	140	139	138	0.0	0.0
CQUAD4	131	22	140	148	141	139	0.0	0.0
CQUAD4	132	22	141	142	146	144	0.0	0.0
CQUAD4	133	22	148	147	142	141	0.0	0.0
CQUAD4	134	22	142	143	145	146	0.0	0.0
CQUAD4	135	22	150	190	162	149	0.0	0.0
CQUAD4	136	22	150	149	227	226	0.0	0.0
CQUAD4	137	22	151	194	190	150	0.0	0.0
CQUAD4	138	22	228	151	150	226	0.0	0.0
CQUAD4	139	22	191	192	151	152	0.0	0.0
CQUAD4	140	22	152	151	228	229	0.0	0.0
CQUAD4	141	22	192	193	194	151	0.0	0.0
CQUAD4	142	22	172	191	152	153	0.0	0.0
CQUAD4	143	22	153	152	229	230	0.0	0.0
CQUAD4	144	22	175	172	153	154	0.0	0.0
CQUAD4	145	22	154	153	230	231	0.0	0.0
CQUAD4	146	22	173	175	154	155	0.0	0.0
CQUAD4	147	22	155	154	231	232	0.0	0.0
CQUAD4	148	22	156	178	173	155	0.0	0.0
CQUAD4	149	22	156	155	232	207	0.0	0.0
CQUAD4	150	22	157	177	178	156	0.0	0.0
CQUAD4	151	22	157	156	207	206	0.0	0.0
CQUAD4	152	22	158	180	177	157	0.0	0.0
CQUAD4	153	22	158	157	206	205	0.0	0.0
CQUAD4	154	22	204	159	158	205	0.0	0.0
CQUAD4	155	22	160	159	204	203	0.0	0.0

CQUAD4	156	22	161	160	203	202	0.0	0.0
CQUAD4	157	22	162	163	168	169	0.0	0.0
CQUAD4	158	22	190	189	163	162	0.0	0.0
CQUAD4	159	22	163	164	166	168	0.0	0.0
CQUAD4	160	22	189	188	164	163	0.0	0.0
CQUAD4	161	22	164	165	167	166	0.0	0.0
CQUAD4	162	22	188	201	165	164	0.0	0.0
CQUAD4	163	22	174	170	171	176	0.0	0.0
CQUAD4	164	22	170	184	198	171	0.0	0.0
CQUAD4	165	22	176	171	172	175	0.0	0.0
CQUAD4	166	22	171	198	191	172	0.0	0.0
CQUAD4	167	22	234	176	175	173	0.0	0.0
CQUAD4	168	22	178	179	234	173	0.0	0.0
CQUAD4	169	22	179	174	176	234	0.0	0.0
CQUAD4	170	22	183	182	181	200	0.0	0.0
CQUAD4	171	22	186	185	181	182	0.0	0.0
CQUAD4	172	22	187	186	182	183	0.0	0.0
CQUAD4	173	22	199	187	183	196	0.0	0.0
CQUAD4	174	22	196	183	200	201	0.0	0.0
CQUAD4	175	22	198	184	199	197	0.0	0.0
CQUAD4	176	22	193	195	188	189	0.0	0.0
CQUAD4	177	22	195	196	201	188	0.0	0.0
CQUAD4	178	22	193	189	190	194	0.0	0.0
CQUAD4	179	22	198	197	192	191	0.0	0.0
CQUAD4	180	22	197	195	193	192	0.0	0.0
CQUAD4	181	22	197	199	196	195	0.0	0.0
CQUAD4	182	22	202	203	223	224	0.0	0.0
CQUAD4	183	22	203	204	225	223	0.0	0.0
CQUAD4	184	22	204	205	220	225	0.0	0.0
CQUAD4	185	22	205	206	222	220	0.0	0.0
CQUAD4	186	22	206	207	221	222	0.0	0.0
CQUAD4	187	22	207	208	214	221	0.0	0.0
CQUAD4	188	22	207	232	231	208	0.0	0.0
CQUAD4	189	22	208	209	219	214	0.0	0.0
CQUAD4	190	22	231	230	209	208	0.0	0.0
CQUAD4	191	22	209	210	218	219	0.0	0.0
CQUAD4	192	22	230	229	210	209	0.0	0.0
CQUAD4	193	22	210	211	215	218	0.0	0.0
CQUAD4	194	22	229	228	211	210	0.0	0.0
CQUAD4	195	22	211	212	217	215	0.0	0.0
CQUAD4	196	22	228	226	212	211	0.0	0.0
CQUAD4	197	22	212	213	216	217	0.0	0.0
CQUAD4	198	22	226	227	213	212	0.0	0.0
CQUAD4	199	23	291	33	29	244	0.0	0.0
CQUAD4	200	23	246	292	245	236	0.0	0.0
CQUAD4	201	23	237	253	297	252	0.0	0.0
CQUAD4	202	23	254	30	39	298	0.0	0.0
CQUAD4	203	23	292	291	244	245	0.0	0.0
CQUAD4	204	23	247	288	292	246	0.0	0.0
CQUAD4	205	23	248	289	288	247	0.0	0.0
CQUAD4	206	23	249	285	289	248	0.0	0.0
CQUAD4	207	23	250	296	285	249	0.0	0.0
CQUAD4	208	23	251	293	296	250	0.0	0.0
CQUAD4	209	23	252	297	293	251	0.0	0.0
CQUAD4	210	23	253	254	298	297	0.0	0.0

CQUAD4	211	23	287	34	33	291	0.0	0.0
CQUAD4	212	23	290	35	34	287	0.0	0.0
CQUAD4	213	23	286	36	35	290	0.0	0.0
CQUAD4	214	23	295	37	36	286	0.0	0.0
CQUAD4	215	23	294	38	37	295	0.0	0.0
CQUAD4	216	23	298	39	38	294	0.0	0.0
CQUAD4	217	23	285	286	290	289	0.0	0.0
CQUAD4	218	23	296	295	286	285	0.0	0.0
CQUAD4	219	23	289	290	287	288	0.0	0.0
CQUAD4	220	23	288	287	291	292	0.0	0.0
CQUAD4	221	23	293	294	295	296	0.0	0.0
CQUAD4	222	23	297	298	294	293	0.0	0.0
CQUAD4	223	24	262	45	31	240	0.0	0.0
CQUAD4	224	24	241	307	305	268	0.0	0.0
CQUAD4	225	24	241	269	302	307	0.0	0.0
CQUAD4	226	24	269	2	309	302	0.0	0.0
CQUAD4	227	24	309	2	11	308	0.0	0.0
CQUAD4	228	24	315	6	1	316	0.0	0.0
CQUAD4	229	24	316	1	53	317	0.0	0.0
CQUAD4	230	24	263	46	45	262	0.0	0.0
CQUAD4	231	24	264	47	46	263	0.0	0.0
CQUAD4	232	24	265	48	47	264	0.0	0.0
CQUAD4	233	24	266	322	48	265	0.0	0.0
CQUAD4	234	24	267	314	325	266	0.0	0.0
CQUAD4	235	24	266	325	326	322	0.0	0.0
CQUAD4	236	24	268	301	318	267	0.0	0.0
CQUAD4	237	24	318	319	314	267	0.0	0.0
CQUAD4	238	24	268	305	306	301	0.0	0.0
CQUAD4	239	24	299	7	6	315	0.0	0.0
CQUAD4	240	24	310	8	7	299	0.0	0.0
CQUAD4	241	24	311	9	8	310	0.0	0.0
CQUAD4	242	24	312	10	9	311	0.0	0.0
CQUAD4	243	24	308	11	10	312	0.0	0.0
CQUAD4	244	24	326	49	48	322	0.0	0.0
CQUAD4	245	24	323	50	49	326	0.0	0.0
CQUAD4	246	24	324	51	50	323	0.0	0.0
CQUAD4	247	24	313	52	51	324	0.0	0.0
CQUAD4	248	24	317	53	52	313	0.0	0.0
CQUAD4	249	24	304	310	299	300	0.0	0.0
CQUAD4	250	24	300	299	315	320	0.0	0.0
CQUAD4	251	24	306	304	300	301	0.0	0.0
CQUAD4	252	24	301	300	320	318	0.0	0.0
CQUAD4	253	24	307	302	303	305	0.0	0.0
CQUAD4	254	24	302	309	311	303	0.0	0.0
CQUAD4	255	24	305	303	304	306	0.0	0.0
CQUAD4	256	24	303	311	310	304	0.0	0.0
CQUAD4	257	24	309	308	312	311	0.0	0.0
CQUAD4	258	24	319	317	313	314	0.0	0.0
CQUAD4	259	24	314	313	324	325	0.0	0.0
CQUAD4	260	24	320	315	316	321	0.0	0.0
CQUAD4	261	24	321	316	317	319	0.0	0.0
CQUAD4	262	24	318	320	321	319	0.0	0.0
CQUAD4	263	24	325	324	323	326	0.0	0.0
CBAR	264	25	327	329-.063464.9979842			0.0	
CBAR	265	25	329	330-.189371.9819057			0.0	

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CBAR     266   25   330   331-.312225.9500082   0.0
CBAR     267   25   331   332-.430050.9028052   0.0
CBAR     268   25   332   333-.540948.8410560   0.0
CBAR     269   25   333   334-.643130.7657572   0.0
CBAR     270   25   334   335-.734951.6781207   0.0
CBAR     271   25   335   328-.814930.5795597   0.0
CBAR     272   25   328   337-.887562.4606892   0.0
CBAR     273   25   337   338-.947026.3211571   0.0
CBAR     274   25   338   339-.984704.1742373   0.0
CBAR     275   25   339   340-.999728.0233100   0.0
CBAR     276   25   340   341-.991755-.128152   0.0
CBAR     277   25   341   342-.960965-.276669   0.0
CBAR     278   25   342   343-.908069-.418819   0.0
CBAR     279   25   343   344-.834285-.551333   0.0
CBAR     280   25   344   345-.741304-.671169   0.0
CBAR     281   25   345   346-.631269-.775564   0.0
CBAR     282   25   346   347-.506714-.862114   0.0
CBAR     283   25   347   348-.370502-.928832   0.0
CBAR     284   25   348   349-.225766-.974182   0.0
CBAR     285   25   349   336-.075836-.997120   0.0
CGAP     286   8    3    327                  0
CGAP     287   8    4    328                  0
CGAP     288   8    12   329                  0
CGAP     289   8    13   330                  0
CGAP     290   8    14   331                  0
CGAP     291   8    15   332                  0
CGAP     292   8    16   333                  0
CGAP     293   8    17   334                  0
CGAP     294   8    18   335                  0
CGAP     295   8    57   336                  0
CGAP     296   8    58   337                  0
CGAP     297   8    59   338                  0
CGAP     298   8    60   339                  0
CGAP     299   8    61   340                  0
CGAP     300   8    62   341                  0
CGAP     301   8    63   342                  0
CGAP     302   8    64   343                  0
CGAP     303   8    65   344                  0
CGAP     304   8    66   345                  0
CGAP     305   8    67   346                  0
CGAP     306   8    68   347                  0
CGAP     307   8    69   348                  0
CGAP     308   8    70   349                  0
$*
$*  MATERIAL CARDS
$*
MAT1      11110000.042307.69.3000000   0.1   0.0        0.0
$*
$SM100
 9DUNCAN    40.078125  36.000   8.000   0.000  600.000.2500000.700000     +
   +   450.000.0000000.259616  000.000.000000
$SM90
 9DUNCAN    30.072338  32.000   4.000   0.000  300.000.2500000.700000     +
   +   250.000.0000000.307258  000.000.000000
$SM75  values interpolated from higher compactions
```

```
 9DUNCAN      20.063657  26.000   0.000   0.000   50.000.2500000.700000      +
   +     50.000.0000000.333333  000.000.000000
$SM haunches
MAT1          1   400        .0700000     0.1     0.0           0.0
$commented out soil properties are included below
$to use them erase the comment symbol and match the material number to the pshell
$ 9DUNCAN      10.039444  28.000   0.000   0.000   15.000.2500000.700000      +
$   +     15.000.0000000.1       000.000.000000
$SM85
$ 9DUNCAN      20.069444  30.000   2.000   0.000  150.000.2500000.700000      +
$   +    150.000.0000000.333333  000.000.000000
$SM95
$ 9DUNCAN      10.075231  34.000   6.000   0.000  450.000.2500000.700000      +
$   +    350.000.0000000.283437  000.000.000000
$*  PROPERTY CARDS
$*
$*
 9XPROPS     25 1.00000
 9CONSTS  14.700    1    0.10000      50
PGAP          8     0.0     0.0     0.0     0.0       .2500000
$*
$*
$*
PBAR         25      111.971   0.294351.0833333.1408312     0.0       +
+      .5000000.5000000.5000000-.500000-.500000-.500000-.500000.5000000+
+      2.2     0.000000
$*
$*  RESTRAINT CARDS
$*
SPC          1       2       1     0.0
SPC          1     269       1     0.0
SPC          1       3       1     0.0
SPC          1      57       1     0.0
SPC          1     327      16     0.0
SPC          1     336      16     0.0
SPC1         1       1      29THRU        31
SPC1         1       1      40THRU        44
SPC1         1       1      71THRU        75
SPC1         1       1     236THRU       237
SPC1         1       1     244THRU       245
SPC1         1       1     253THRU       254
SPC1         1      12     240THRU       241
SPC1         1      12     262THRU       268
$*
$*  LOAD CARDS
$*
$*
$* Nodal loads converted from I-DEAS edge loads
$*
FORCE        1     236      01.000000     0.0-112.500-1.10-15
FORCE        1     237      01.000000     0.0-112.500-1.10-15
FORCE        1     246      01.000000-1.75-13-225.000-3.29-15
FORCE        1     247      01.000000     0.0-225.000-4.39-15
FORCE        1     248      01.000000     0.0-225.000-4.39-15
FORCE        1     249      01.000000-1.75-13-225.000-4.39-15
```

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FORCE       1    250      01.000000    0.0-225.000-4.39-15
FORCE       1    251      01.000000    0.0-225.000-4.39-15
FORCE       1    252      01.000000    0.0-225.000-3.29-15
$*
PSHELL     21      11.000000     -1
PSHELL     22      21.000000     -1
PSHELL     23      31.000000     -1
PSHELL     24      41.000000     -1
9LAYER      1     24


9INC        1     1
9INC        2     1     1    .5
9INC        3     1     1     1
9INC        4     1     1   1.5
9INC        5     1     1     2
9INC        6     1     1     3
```

Soilcellcompn.dat

This was used to compare the typical corrugated pipes to real soil cell tests.

```
$*
$*  GRID CARDS
$*
GRID        1     0 16.1690-17.2560 1.00000      0
GRID        2     0     0.0-17.2560 1.00000      0
GRID        3     0-2.907-7-15.8570 1.00000      0
GRID        4     0 13.4795-8.35145 1.00000      0
GRID        5     0 16.1690-10.2515 1.00000      0
GRID        6     0 13.8592-17.2560 1.00000      0
GRID        7     0 11.5493-17.2560 1.00000      0
GRID        8     0 9.23944-17.2560 1.00000      0
GRID        9     0 6.92958-17.2560 1.00000      0
GRID       10     0 4.61972-17.2560 1.00000      0
GRID       11     0 2.30986-17.2560 1.00000      0
GRID       12     0 2.00864-15.7293 1.00000      0
GRID       13     0 3.98495-15.3481 1.00000      0
GRID       14     0 5.89700-14.7197 1.00000      0
GRID       15     0 7.71411-13.8541 1.00000      0
GRID       16     0 9.40693-12.7653 1.00000      0
GRID       17     0 10.9482-11.4709 1.00000      0
GRID       18     0 12.3131-9.99166 1.00000      0
GRID       19     0 16.1690-14.9212 1.00000      0
GRID       20     0 16.1690-12.5863 1.00000      0
GRID       21     0 14.1757-15.1857 1.00000      0
GRID       22     0 12.2219-12.9891 1.00000      0
GRID       23     0 12.9655-13.8515 1.00000      0
GRID       24     0 14.2837-13.3318 1.00000      0
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CQUAD4	63	22	99	71	72	100	0.0	0.0
CQUAD4	64	22	100	72	73	101	0.0	0.0
CQUAD4	65	22	95	73	74	94	0.0	0.0
CQUAD4	66	22	96	101	73	95	0.0	0.0
CQUAD4	67	22	94	74	75	93	0.0	0.0
CQUAD4	68	22	76	77	108	103	0.0	0.0
CQUAD4	69	22	224	223	77	76	0.0	0.0
CQUAD4	70	22	77	78	104	108	0.0	0.0
CQUAD4	71	22	223	225	78	77	0.0	0.0
CQUAD4	72	22	78	79	110	104	0.0	0.0
CQUAD4	73	22	225	220	79	78	0.0	0.0
CQUAD4	74	22	79	80	116	110	0.0	0.0
CQUAD4	75	22	220	222	80	79	0.0	0.0
CQUAD4	76	22	80	81	118	122	0.0	0.0
CQUAD4	77	22	222	221	81	80	0.0	0.0
CQUAD4	78	22	116	80	122	121	0.0	0.0
CQUAD4	79	22	81	82	129	118	0.0	0.0
CQUAD4	80	22	221	214	82	81	0.0	0.0
CQUAD4	81	22	82	83	125	129	0.0	0.0
CQUAD4	82	22	214	219	83	82	0.0	0.0
CQUAD4	83	22	83	84	134	125	0.0	0.0
CQUAD4	84	22	219	218	84	83	0.0	0.0
CQUAD4	85	22	84	85	133	134	0.0	0.0
CQUAD4	86	22	218	215	85	84	0.0	0.0
CQUAD4	87	22	85	86	132	133	0.0	0.0
CQUAD4	88	22	215	217	86	85	0.0	0.0
CQUAD4	89	22	86	87	131	132	0.0	0.0
CQUAD4	90	22	217	216	87	86	0.0	0.0
CQUAD4	91	22	88	89	94	93	0.0	0.0
CQUAD4	92	22	115	124	89	88	0.0	0.0
CQUAD4	93	22	89	90	95	94	0.0	0.0
CQUAD4	94	22	135	136	90	89	0.0	0.0
CQUAD4	95	22	128	135	89	124	0.0	0.0
CQUAD4	96	22	90	91	96	95	0.0	0.0

CQUAD4	97	22	136	144	91	90	0.0	0.0
CQUAD4	98	22	91	92	97	96	0.0	0.0
CQUAD4	99	22	144	146	92	91	0.0	0.0
CQUAD4	100	22	92	102	98	97	0.0	0.0
CQUAD4	101	22	146	145	102	92	0.0	0.0
CQUAD4	102	22	96	97	100	101	0.0	0.0
CQUAD4	103	22	97	98	99	100	0.0	0.0
CQUAD4	104	22	103	108	109	107	0.0	0.0
CQUAD4	105	22	108	104	105	109	0.0	0.0
CQUAD4	106	22	104	110	111	105	0.0	0.0
CQUAD4	107	22	107	109	105	106	0.0	0.0
CQUAD4	108	22	105	111	112	106	0.0	0.0
CQUAD4	109	22	110	116	117	111	0.0	0.0
CQUAD4	110	22	111	117	113	112	0.0	0.0
CQUAD4	111	22	117	123	114	113	0.0	0.0
CQUAD4	112	22	123	120	115	114	0.0	0.0
CQUAD4	113	22	120	233	124	115	0.0	0.0
CQUAD4	114	22	116	121	123	117	0.0	0.0
CQUAD4	115	22	122	118	119	121	0.0	0.0
CQUAD4	116	22	118	129	130	119	0.0	0.0
CQUAD4	117	22	121	119	120	123	0.0	0.0
CQUAD4	118	22	119	130	233	120	0.0	0.0
CQUAD4	119	22	233	127	128	124	0.0	0.0
CQUAD4	120	22	129	125	126	130	0.0	0.0
CQUAD4	121	22	125	134	137	126	0.0	0.0
CQUAD4	122	22	130	126	127	233	0.0	0.0
CQUAD4	123	22	126	137	138	127	0.0	0.0
CQUAD4	124	22	127	138	135	128	0.0	0.0
CQUAD4	125	22	132	131	147	148	0.0	0.0
CQUAD4	126	22	133	132	148	140	0.0	0.0
CQUAD4	127	22	134	133	140	137	0.0	0.0
CQUAD4	128	22	138	139	136	135	0.0	0.0
CQUAD4	129	22	139	141	144	136	0.0	0.0
CQUAD4	130	22	137	140	139	138	0.0	0.0
CQUAD4	131	22	140	148	141	139	0.0	0.0
CQUAD4	132	22	141	142	146	144	0.0	0.0
CQUAD4	133	22	148	147	142	141	0.0	0.0
CQUAD4	134	22	142	143	145	146	0.0	0.0
CQUAD4	135	22	150	190	162	149	0.0	0.0
CQUAD4	136	22	150	149	227	226	0.0	0.0
CQUAD4	137	22	151	194	190	150	0.0	0.0
CQUAD4	138	22	228	151	150	226	0.0	0.0
CQUAD4	139	22	191	192	151	152	0.0	0.0
CQUAD4	140	22	152	151	228	229	0.0	0.0
CQUAD4	141	22	192	193	194	151	0.0	0.0
CQUAD4	142	22	172	191	152	153	0.0	0.0
CQUAD4	143	22	153	152	229	230	0.0	0.0
CQUAD4	144	22	175	172	153	154	0.0	0.0
CQUAD4	145	22	154	153	230	231	0.0	0.0
CQUAD4	146	22	173	175	154	155	0.0	0.0
CQUAD4	147	22	155	154	231	232	0.0	0.0
CQUAD4	148	22	156	178	173	155	0.0	0.0
CQUAD4	149	22	156	155	232	207	0.0	0.0
CQUAD4	150	22	157	177	178	156	0.0	0.0
CQUAD4	151	22	157	156	207	206	0.0	0.0

CQUAD4	152	22	158	180	177	157	0.0	0.0
CQUAD4	153	22	158	157	206	205	0.0	0.0
CQUAD4	154	22	204	159	158	205	0.0	0.0
CQUAD4	155	22	160	159	204	203	0.0	0.0
CQUAD4	156	22	161	160	203	202	0.0	0.0
CQUAD4	157	22	162	163	168	169	0.0	0.0
CQUAD4	158	22	190	189	163	162	0.0	0.0
CQUAD4	159	22	163	164	166	168	0.0	0.0
CQUAD4	160	22	189	188	164	163	0.0	0.0
CQUAD4	161	22	164	165	167	166	0.0	0.0
CQUAD4	162	22	188	201	165	164	0.0	0.0
CQUAD4	163	22	174	170	171	176	0.0	0.0
CQUAD4	164	22	170	184	198	171	0.0	0.0
CQUAD4	165	22	176	171	172	175	0.0	0.0
CQUAD4	166	22	171	198	191	172	0.0	0.0
CQUAD4	167	22	234	176	175	173	0.0	0.0
CQUAD4	168	22	178	179	234	173	0.0	0.0
CQUAD4	169	22	179	174	176	234	0.0	0.0
CQUAD4	170	22	183	182	181	200	0.0	0.0
CQUAD4	171	22	186	185	181	182	0.0	0.0
CQUAD4	172	22	187	186	182	183	0.0	0.0
CQUAD4	173	22	199	187	183	196	0.0	0.0
CQUAD4	174	22	196	183	200	201	0.0	0.0
CQUAD4	175	22	198	184	199	197	0.0	0.0
CQUAD4	176	22	193	195	188	189	0.0	0.0
CQUAD4	177	22	195	196	201	188	0.0	0.0
CQUAD4	178	22	193	189	190	194	0.0	0.0
CQUAD4	179	22	198	197	192	191	0.0	0.0
CQUAD4	180	22	197	195	193	192	0.0	0.0
CQUAD4	181	22	197	199	196	195	0.0	0.0
CQUAD4	182	22	202	203	223	224	0.0	0.0
CQUAD4	183	22	203	204	225	223	0.0	0.0
CQUAD4	184	22	204	205	220	225	0.0	0.0
CQUAD4	185	22	205	206	222	220	0.0	0.0
CQUAD4	186	22	206	207	221	222	0.0	0.0
CQUAD4	187	22	207	208	214	221	0.0	0.0
CQUAD4	188	22	207	232	231	208	0.0	0.0
CQUAD4	189	22	208	209	219	214	0.0	0.0
CQUAD4	190	22	231	230	209	208	0.0	0.0
CQUAD4	191	22	209	210	218	219	0.0	0.0
CQUAD4	192	22	230	229	210	209	0.0	0.0
CQUAD4	193	22	210	211	215	218	0.0	0.0
CQUAD4	194	22	229	228	211	210	0.0	0.0
CQUAD4	195	22	211	212	217	215	0.0	0.0
CQUAD4	196	22	228	226	212	211	0.0	0.0
CQUAD4	197	22	212	213	216	217	0.0	0.0
CQUAD4	198	22	226	227	213	212	0.0	0.0
CQUAD4	199	23	291	33	29	244	0.0	0.0
CQUAD4	200	23	246	292	245	236	0.0	0.0
CQUAD4	201	23	237	253	297	252	0.0	0.0
CQUAD4	202	23	254	30	39	298	0.0	0.0
CQUAD4	203	23	292	291	244	245	0.0	0.0
CQUAD4	204	23	247	288	292	246	0.0	0.0
CQUAD4	205	23	248	289	288	247	0.0	0.0
CQUAD4	206	23	249	285	289	248	0.0	0.0

CQUAD4	207	23	250	296	285	249	0.0	0.0
CQUAD4	208	23	251	293	296	250	0.0	0.0
CQUAD4	209	23	252	297	293	251	0.0	0.0
CQUAD4	210	23	253	254	298	297	0.0	0.0
CQUAD4	211	23	287	34	33	291	0.0	0.0
CQUAD4	212	23	290	35	34	287	0.0	0.0
CQUAD4	213	23	286	36	35	290	0.0	0.0
CQUAD4	214	23	295	37	36	286	0.0	0.0
CQUAD4	215	23	294	38	37	295	0.0	0.0
CQUAD4	216	23	298	39	38	294	0.0	0.0
CQUAD4	217	23	285	286	290	289	0.0	0.0
CQUAD4	218	23	296	295	286	285	0.0	0.0
CQUAD4	219	23	289	290	287	288	0.0	0.0
CQUAD4	220	23	288	287	291	292	0.0	0.0
CQUAD4	221	23	293	294	295	296	0.0	0.0
CQUAD4	222	23	297	298	294	293	0.0	0.0
CQUAD4	223	24	262	45	31	240	0.0	0.0
CQUAD4	224	24	241	307	305	268	0.0	0.0
CQUAD4	225	24	241	269	302	307	0.0	0.0
CQUAD4	226	24	269	2	309	302	0.0	0.0
CQUAD4	227	24	309	2	11	308	0.0	0.0
CQUAD4	228	24	315	6	1	316	0.0	0.0
CQUAD4	229	24	316	1	53	317	0.0	0.0
CQUAD4	230	24	263	46	45	262	0.0	0.0
CQUAD4	231	24	264	47	46	263	0.0	0.0
CQUAD4	232	24	265	48	47	264	0.0	0.0
CQUAD4	233	24	266	322	48	265	0.0	0.0
CQUAD4	234	24	267	314	325	266	0.0	0.0
CQUAD4	235	24	266	325	326	322	0.0	0.0
CQUAD4	236	24	268	301	318	267	0.0	0.0
CQUAD4	237	24	318	319	314	267	0.0	0.0
CQUAD4	238	24	268	305	306	301	0.0	0.0
CQUAD4	239	24	299	7	6	315	0.0	0.0
CQUAD4	240	24	310	8	7	299	0.0	0.0
CQUAD4	241	24	311	9	8	310	0.0	0.0
CQUAD4	242	24	312	10	9	311	0.0	0.0
CQUAD4	243	24	308	11	10	312	0.0	0.0
CQUAD4	244	24	326	49	48	322	0.0	0.0
CQUAD4	245	24	323	50	49	326	0.0	0.0
CQUAD4	246	24	324	51	50	323	0.0	0.0
CQUAD4	247	24	313	52	51	324	0.0	0.0
CQUAD4	248	24	317	53	52	313	0.0	0.0
CQUAD4	249	24	304	310	299	300	0.0	0.0
CQUAD4	250	24	300	299	315	320	0.0	0.0
CQUAD4	251	24	306	304	300	301	0.0	0.0
CQUAD4	252	24	301	300	320	318	0.0	0.0
CQUAD4	253	24	307	302	303	305	0.0	0.0
CQUAD4	254	24	302	309	311	303	0.0	0.0
CQUAD4	255	24	305	303	304	306	0.0	0.0
CQUAD4	256	24	303	311	310	304	0.0	0.0
CQUAD4	257	24	309	308	312	311	0.0	0.0
CQUAD4	258	24	319	317	313	314	0.0	0.0
CQUAD4	259	24	314	313	324	325	0.0	0.0
CQUAD4	260	24	320	315	316	321	0.0	0.0
CQUAD4	261	24	321	316	317	319	0.0	0.0

```
CQUAD4     262     24    318    320    321    319    0.0    0.0
CQUAD4     263     24    325    324    323    326    0.0    0.0
CBAR       264     25    327    329-.063464.9979842    0.0
CBAR       265     25    329    330-.189371.9819057    0.0
CBAR       266     25    330    331-.312225.9500082    0.0
CBAR       267     25    331    332-.430050.9028052    0.0
CBAR       268     25    332    333-.540948.8410560    0.0
CBAR       269     25    333    334-.643130.7657572    0.0
CBAR       270     25    334    335-.734951.6781207    0.0
CBAR       271     25    335    328-.814930.5795597    0.0
CBAR       272     25    328    337-.887562.4606892    0.0
CBAR       273     25    337    338-.947026.3211571    0.0
CBAR       274     25    338    339-.984704.1742373    0.0
CBAR       275     25    339    340-.999728.0233100    0.0
CBAR       276     25    340    341-.991755-.128152    0.0
CBAR       277     25    341    342-.960965-.276669    0.0
CBAR       278     25    342    343-.908069-.418819    0.0
CBAR       279     25    343    344-.834285-.551333    0.0
CBAR       280     25    344    345-.741304-.671169    0.0
CBAR       281     25    345    346-.631269-.775564    0.0
CBAR       282     25    346    347-.506714-.862114    0.0
CBAR       283     25    347    348-.370502-.928832    0.0
CBAR       284     25    348    349-.225766-.974182    0.0
CBAR       285     25    349    336-.075836-.997120    0.0
CGAP       286      8      3    327                    0
CGAP       287      8      4    328                    0
CGAP       288      8     12    329                    0
CGAP       289      8     13    330                    0
CGAP       290      8     14    331                    0
CGAP       291      8     15    332                    0
CGAP       292      8     16    333                    0
CGAP       293      8     17    334                    0
CGAP       294      8     18    335                    0
CGAP       295      8     57    336                    0
CGAP       296      8     58    337                    0
CGAP       297      8     59    338                    0
CGAP       298      8     60    339                    0
CGAP       299      8     61    340                    0
CGAP       300      8     62    341                    0
CGAP       301      8     63    342                    0
CGAP       302      8     64    343                    0
CGAP       303      8     65    344                    0
CGAP       304      8     66    345                    0
CGAP       305      8     67    346                    0
CGAP       306      8     68    347                    0
CGAP       307      8     69    348                    0
CGAP       308      8     70    349                    0
$*
$*  MATERIAL CARDS
$*
MAT1       11110000.042307.69.3000000    0.1    0.0          0.0
$*
$SM100
 9DUNCAN     40.078125  36.000   8.000   0.000  600.000.2500000.700000      +
   +    450.000.0000000.259616  000.000.000000
```

```
$SM90
 9DUNCAN      30.072338  32.000   4.000   0.000  300.000.2500000.700000      +
   +    250.000.0000000.307258  000.000.000000
$SM75  values interpolated from higher compactions
 9DUNCAN      20.063657  26.000   0.000   0.000   50.000.2500000.700000      +
   +     50.000.0000000.333333  000.000.000000
$SM haunches
MAT1         1   400        .0700000    0.1     0.0           0.0
$commented out soil properties are included below
$to use them erase the comment symbol and match the material number to the pshell
$ 9DUNCAN      10.039444  28.000   0.000   0.000   15.000.2500000.700000      +
$   +     15.000.0000000.1       000.000.000000
$SM85
$ 9DUNCAN      20.069444  30.000   2.000   0.000  150.000.2500000.700000      +
$   +    150.000.0000000.333333  000.000.000000
$SM95
$ 9DUNCAN      10.075231  34.000   6.000   0.000  450.000.2500000.700000      +
$   +    350.000.0000000.283437  000.000.000000
$*
$*  PROPERTY CARDS
$*
$*
 9XPROPS     25 1.00000
 9CONSTS  14.700    1    0.10000     50
PGAP         8     0.0     0.0     0.0     0.0       .250000
$*
$*
$*
PBAR        25      111.531    0.196994.0833333.1408312     0.0       +
+      .5000000.5000000.5000000-.500000-.500000-.500000-.500000.5000000+
+      2.2     0.000000
$*
$*  RESTRAINT CARDS
$*
SPC          1       2       1     0.0
SPC          1     269       1     0.0
SPC          1       3       1     0.0
SPC          1      57       1     0.0
SPC          1     327      16     0.0
SPC          1     336      16     0.0
SPC1         1       1      29THRU        31
SPC1         1       1      40THRU        44
SPC1         1       1      71THRU        75
SPC1         1       1     236THRU       237
SPC1         1       1     244THRU       245
SPC1         1       1     253THRU       254
SPC1         1      12     240THRU       241
SPC1         1      12     262THRU       268
$*
$*  LOAD CARDS
$*
$*
$* Nodal loads converted from I-DEAS edge loads
$*
FORCE        1     236      01.000000     0.0-112.500-1.10-15
```

```
FORCE        1    237      01.000000    0.0-112.500-1.10-15
FORCE        1    246      01.000000-1.75-13-225.000-3.29-15
FORCE        1    247      01.000000    0.0-225.000-4.39-15
FORCE        1    248      01.000000    0.0-225.000-4.39-15
FORCE        1    249      01.000000-1.75-13-225.000-4.39-15
FORCE        1    250      01.000000    0.0-225.000-4.39-15
FORCE        1    251      01.000000    0.0-225.000-4.39-15
FORCE        1    252      01.000000    0.0-225.000-3.29-15
$*
PSHELL      21      11.000000     -1
PSHELL      22      21.000000     -1
PSHELL      23      31.000000     -1
PSHELL      24      41.000000     -1
9LAYER       1     24


9INC         1      1
9INC         2      1      1     .5
9INC         3      1      1      1
9INC         4      1      1    1.5
9INC         5      1      1      2
9INC         6      1      1      3
```

Xelem_etest.dat

This is the model used to test interface elements. As it is set up this is for a mue=.25. To run another mue value change the last number in the pgap card.

```
$*$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
$*
$*              I-DEAS 12M1 NASTRAN TRANSLATOR
$*                FOR NX NASTRAN VERSION 4.0
$*
$*         MODEL FILE: C:\usr\Friction_no_Xelem.mf1
$*         INPUT FILE: Friction_no_Xelem.dat
$*           EXPORTED: AT 11:23:13 ON 21-Jul-06
$*               PART: Part1
$*                FEM: Fem2
$*
$*              UNITS: MM-mm (milli-newton)
$*                  ... LENGTH : MM
$*                  ... TIME   : sec
$*                  ... MASS   : kilogram (kg)
$*                  ... FORCE  : milli-newton
$*                  ... TEMPERATURE : deg Celsius
$*
$*    NASTRAN BASIC COORDINATE SYSTEM: PART
$*
$*    SUBSET EXPORT: OFF
$*
$*    REAL DATA FILTER: ON (   0.1000E-14 )
$*
$*    MATERIAL ORIENTATION VECTOR EXPORT: ON
$*
$*    ROUND-TRIPPING: OFF
```

```
$*
$*    PERMANENT SINGLE POINT CONSTRAINT EXPORT: OFF
$*
$*$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
$*
$*$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
$*
$*  EXECUTIVE CONTROL
$*
$*$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
$*
ID IDEAS,NX
SOL 101
CEND
$*
$*$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
$*
$*  CASE CONTROL
$*
$*$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
$*
TITLE    = NX  NASTRAN FILE TRANSLATOR  -- UNITS = MM
ECHO     = SORT
$*
$* GLOBAL CASE
$*
SPC = 1
LOAD = 1
DISPLACEMENT(PLOT) = ALL
STRESS(PLOT,CENTER,VONMISES) = ALL
SPCFORCES(PRINT) = ALL
$*
$*$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
$*
$*  BULK DATA
$*
$*$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
$*
BEGIN BULK
$*
$*  PARAM CARDS
$*
PARAM   AUTOSPC YES
PARAM   GRDPNT        0
PARAM   K6ROT   100.0000
PARAM   POST          -2
PARAM   POSTEXT YES
$*
$*
$*  GRID CARDS
$*
GRID           1       0     0.0-132.000     0.0       0
GRID           2       0 8.25000-132.000     0.0       0
GRID           3       0 20.6250-132.000     0.0       0
GRID           4       0 33.0000-132.000     0.0       0
```

GRID	5	0	49.5000-132.000	0.0	0
GRID	6	0	66.0000-132.000	0.0	0
GRID	7	0	99.0000-132.000	0.0	0
GRID	8	0	132.000-132.000	0.0	0
GRID	9	0	165.000-132.000	0.0	0
GRID	10	0	198.000-132.000	0.0	0
GRID	11	0	0.0-99.0000	0.0	0
GRID	12	0	8.25000-99.0000	0.0	0
GRID	13	0	20.6250-99.0000	0.0	0
GRID	14	0	33.0000-99.0000	0.0	0
GRID	15	0	49.5000-99.0000	0.0	0
GRID	16	0	66.0000-99.0000	0.0	0
GRID	17	0	99.0000-99.0000	0.0	0
GRID	18	0	132.000-99.0000	0.0	0
GRID	19	0	165.000-99.0000	0.0	0
GRID	20	0	198.000-99.0000	0.0	0
GRID	21	0	0.0-66.0000	0.0	0
GRID	22	0	8.25000-66.0000	0.0	0
GRID	23	0	20.6250-66.0000	0.0	0
GRID	24	0	33.0000-66.0000	0.0	0
GRID	25	0	49.5000-66.0000	0.0	0
GRID	26	0	66.0000-66.0000	0.0	0
GRID	27	0	99.0000-66.0000	0.0	0
GRID	28	0	132.000-66.0000	0.0	0
GRID	29	0	165.000-66.0000	0.0	0
GRID	30	0	198.000-66.0000	0.0	0
GRID	31	0	0.0-55.0000	0.0	0
GRID	32	0	8.25000-55.0000	0.0	0
GRID	33	0	20.6250-55.0000	0.0	0
GRID	34	0	33.0000-55.0000	0.0	0
GRID	35	0	49.5000-55.0000	0.0	0
GRID	36	0	66.0000-55.0000	0.0	0
GRID	37	0	99.0000-55.0000	0.0	0
GRID	38	0	132.000-55.0000	0.0	0
GRID	39	0	165.000-55.0000	0.0	0
GRID	40	0	198.000-55.0000	0.0	0
GRID	41	0	0.0-44.0000	0.0	0
GRID	42	0	8.25000-44.0000	0.0	0
GRID	43	0	20.6250-44.0000	0.0	0
GRID	44	0	33.0000-44.0000	0.0	0
GRID	45	0	49.5000-44.0000	0.0	0
GRID	46	0	66.0000-44.0000	0.0	0
GRID	47	0	99.0000-44.0000	0.0	0
GRID	48	0	132.000-44.0000	0.0	0
GRID	49	0	165.000-44.0000	0.0	0
GRID	50	0	198.000-44.0000	0.0	0
GRID	51	0	0.0-38.5000	0.0	0
GRID	52	0	9.96300-37.1880	0.0	0
GRID	53	0	19.2500-33.3410	0.0	0
GRID	54	0	27.2220-27.2220	0.0	0
GRID	55	0	33.0000-33.0000	0.0	0
GRID	56	0	33.3410-19.2500	0.0	0
GRID	57	0	49.5000-33.0000	0.0	0
GRID	58	0	66.0000-33.0000	0.0	0
GRID	59	0	99.0000-33.0000	0.0	0

```
GRID      60     0 132.000-33.0000     0.0       0
GRID      61     0 165.000-33.0000     0.0       0
GRID      62     0 198.000-33.0000     0.0       0
GRID      63     0     0.0-33.1000     0.0       0
GRID      66     0 8.56687-31.9716     0.0       0
GRID      69     0 16.5500-28.6646     0.0       0
GRID      72     0 23.4047-23.4047     0.0       0
GRID      75     0 28.6646-16.5500     0.0       0
GRID      78     0 31.9716-8.56689     0.0       0
GRID      81     0 37.1880-9.96300     0.0       0
GRID      82     0 49.5000-16.5000     0.0       0
GRID      83     0 66.0000-16.5000     0.0       0
GRID      84     0 99.0000-16.5000     0.0       0
GRID      85     0 132.000-16.5000     0.0       0
GRID      86     0 165.000-16.5000     0.0       0
GRID      87     0 198.000-16.5000     0.0       0
GRID      88     0 33.1000     0.0     0.0       0
GRID      91     0 38.5000     0.0     0.0       0
GRID      92     0 49.5000     0.0     0.0       0
GRID      93     0 66.0000     0.0     0.0       0
GRID      94     0 99.0000     0.0     0.0       0
GRID      95     0 132.000     0.0     0.0       0
GRID      96     0 165.000     0.0     0.0       0
GRID      97     0 198.000     0.0     0.0       0
GRID      98     0     0.0 33.1000     0.0       0
GRID     101     0 8.56688 31.9716     0.0       0
GRID     104     0 16.5500 28.6646     0.0       0
GRID     107     0 23.4047 23.4047     0.0       0
GRID     110     0 28.6646 16.5500     0.0       0
GRID     113     0 31.9716 8.56688     0.0       0
GRID     116     0 37.1880 9.96300     0.0       0
GRID     117     0 49.5000 13.2000     0.0       0
GRID     118     0 66.0000 13.2000     0.0       0
GRID     119     0 99.0000 13.2000     0.0       0
GRID     120     0 132.000 13.2000     0.0       0
GRID     121     0 165.000 13.2000     0.0       0
GRID     122     0 198.000 13.2000     0.0       0
GRID     123     0     0.0 38.5000     0.0       0
GRID     124     0 9.96300 37.1880     0.0       0
GRID     125     0 19.2500 33.3410     0.0       0
GRID     126     0 27.2220 27.2220     0.0       0
GRID     127     0 33.3410 19.2500     0.0       0
GRID     128     0 49.5000 31.3500     0.0       0
GRID     129     0 66.0000 31.3500     0.0       0
GRID     130     0 99.0000 31.3500     0.0       0
GRID     131     0 132.000 31.3500     0.0       0
GRID     132     0 165.000 31.3500     0.0       0
GRID     133     0 198.000 31.3500     0.0       0
GRID     134     0     0.0 44.0000     0.0       0
GRID     135     0 8.25000 44.0000     0.0       0
GRID     136     0 20.6250 41.2500     0.0       0
GRID     137     0 33.0000 38.5000     0.0       0
GRID     138     0     0.0 49.5000     0.0       0
GRID     139     0 8.25000 49.5000     0.0       0
GRID     140     0 20.6250 49.5000     0.0       0
```

```
GRID     141     0 33.0000 49.5000     0.0      0
GRID     142     0 49.5000 49.5000     0.0      0
GRID     143     0 66.0000 49.5000     0.0      0
GRID     144     0 99.0000 49.5000     0.0      0
GRID     145     0 132.000 49.5000     0.0      0
GRID     146     0 165.000 49.5000     0.0      0
GRID     147     0 198.000 49.5000     0.0      0
GRID     148     0     0.0 60.5000     0.0      0
GRID     149     0 8.25000 60.5000     0.0      0
GRID     150     0 20.6250 60.5000     0.0      0
GRID     151     0 33.0000 60.5000     0.0      0
GRID     152     0 49.5000 60.5000     0.0      0
GRID     153     0 66.0000 60.5000     0.0      0
GRID     154     0 99.0000 60.5000     0.0      0
GRID     155     0 132.000 60.5000     0.0      0
GRID     156     0 165.000 60.5000     0.0      0
GRID     157     0 198.000 60.5000     0.0      0
GRID     158     0     0.0 74.2500     0.0      0
GRID     159     0 8.25000 74.2500     0.0      0
GRID     160     0 20.6250 74.2500     0.0      0
GRID     161     0 33.0000 74.2500     0.0      0
GRID     162     0 49.5000 74.2500     0.0      0
GRID     163     0 66.0000 74.2500     0.0      0
GRID     164     0 99.0000 74.2500     0.0      0
GRID     165     0 132.000 74.2500     0.0      0
GRID     166     0 165.000 74.2500     0.0      0
GRID     167     0 198.000 74.2500     0.0      0
GRID     168     0     0.0 93.5000     0.0      0
GRID     169     0 8.25000 93.5000     0.0      0
GRID     170     0 20.6250 93.5000     0.0      0
GRID     171     0 33.0000 93.5000     0.0      0
GRID     172     0 49.5000 93.5000     0.0      0
GRID     173     0 66.0000 93.5000     0.0      0
GRID     174     0 99.0000 93.5000     0.0      0
GRID     175     0 132.000 93.5000     0.0      0
GRID     176     0 165.000 93.5000     0.0      0
GRID     177     0 198.000 93.5000     0.0      0
GRID     178     0-6.051-7-33.0000     0.0      0
GRID     179     0 8.54099-31.8750     0.0      0
GRID     180     0 16.5000-28.5780     0.0      0
GRID     181     0 23.3340-23.3340     0.0      0
GRID     182     0 28.5780-16.5000     0.0      0
GRID     183     0 31.8750-8.54101     0.0      0
GRID     184     0 33.0000     0.0     0.0      0
GRID     185     0-6.051-7 33.0000     0.0      0
GRID     186     0 8.54100 31.8750     0.0      0
GRID     187     0 16.5000 28.5780     0.0      0
GRID     188     0 23.3340 23.3340     0.0      0
GRID     189     0 28.5780 16.5000     0.0      0
GRID     190     0 31.8750 8.54100     0.0      0
$*
$*  ELEMENT CARDS
$*
CQUAD4         1       6      11       1       2      12     0.0
CQUAD4         2       6      12       2       3      13     0.0
```

CQUAD4	3	6	13	3	4	14	0.0
CQUAD4	4	6	14	4	5	15	0.0
CQUAD4	5	6	15	5	6	16	0.0
CQUAD4	6	6	16	6	7	17	0.0
CQUAD4	7	6	17	7	8	18	0.0
CQUAD4	8	6	18	8	9	19	0.0
CQUAD4	9	6	19	9	10	20	0.0
CQUAD4	10	6	21	11	12	22	0.0
CQUAD4	11	6	22	12	13	23	0.0
CQUAD4	12	6	23	13	14	24	0.0
CQUAD4	13	6	24	14	15	25	0.0
CQUAD4	14	6	25	15	16	26	0.0
CQUAD4	15	6	26	16	17	27	0.0
CQUAD4	16	6	27	17	18	28	0.0
CQUAD4	17	6	28	18	19	29	0.0
CQUAD4	18	6	29	19	20	30	0.0
CQUAD4	19	6	31	21	22	32	0.0
CQUAD4	20	6	32	22	23	33	0.0
CQUAD4	21	6	33	23	24	34	0.0
CQUAD4	22	6	34	24	25	35	0.0
CQUAD4	23	6	35	25	26	36	0.0
CQUAD4	24	6	36	26	27	37	0.0
CQUAD4	25	6	37	27	28	38	0.0
CQUAD4	26	6	38	28	29	39	0.0
CQUAD4	27	6	39	29	30	40	0.0
CQUAD4	28	6	41	31	32	42	0.0
CQUAD4	29	6	42	32	33	43	0.0
CQUAD4	30	6	43	33	34	44	0.0
CQUAD4	31	6	44	34	35	45	0.0
CQUAD4	32	6	45	35	36	46	0.0
CQUAD4	33	6	46	36	37	47	0.0
CQUAD4	34	6	47	37	38	48	0.0
CQUAD4	35	6	48	38	39	49	0.0
CQUAD4	36	6	49	39	40	50	0.0
CQUAD4	37	6	51	41	42	52	0.0
CQUAD4	38	6	63	51	52	66	0.0
CQUAD4	39	6	66	52	53	69	0.0
CQUAD4	40	6	52	42	43	53	0.0
CQUAD4	41	6	53	43	44	55	0.0
CQUAD4	42	6	55	44	45	57	0.0
CQUAD4	43	6	57	45	46	58	0.0
CQUAD4	44	6	58	46	47	59	0.0
CQUAD4	45	6	59	47	48	60	0.0
CQUAD4	46	6	60	48	49	61	0.0
CQUAD4	47	6	61	49	50	62	0.0
CQUAD4	48	6	69	53	54	72	0.0
CQUAD4	49	6	75	72	54	56	0.0
CQUAD4	53	6	78	75	56	81	0.0
CQUAD4	54	6	81	56	57	82	0.0
CQUAD4	55	6	82	57	58	83	0.0
CQUAD4	56	6	83	58	59	84	0.0
CQUAD4	57	6	84	59	60	85	0.0
CQUAD4	58	6	85	60	61	86	0.0
CQUAD4	59	6	86	61	62	87	0.0
CQUAD4	60	6	88	78	81	91	0.0

CQUAD4	61	6	91	81	82	92	0.0
CQUAD4	62	6	92	82	83	93	0.0
CQUAD4	63	6	93	83	84	94	0.0
CQUAD4	64	6	94	84	85	95	0.0
CQUAD4	65	6	95	85	86	96	0.0
CQUAD4	66	6	96	86	87	97	0.0
CQUAD4	67	6	113	88	91	116	0.0
CQUAD4	68	6	116	91	92	117	0.0
CQUAD4	69	6	117	92	93	118	0.0
CQUAD4	70	6	118	93	94	119	0.0
CQUAD4	71	6	119	94	95	120	0.0
CQUAD4	72	6	120	95	96	121	0.0
CQUAD4	73	6	121	96	97	122	0.0
CQUAD4	74	6	110	113	116	127	0.0
CQUAD4	75	6	126	107	110	127	0.0
CQUAD4	76	6	125	104	107	126	0.0
CQUAD4	77	6	124	101	104	125	0.0
CQUAD4	78	6	123	98	101	124	0.0
CQUAD4	79	6	134	123	124	135	0.0
CQUAD4	80	6	135	124	125	136	0.0
CQUAD4	81	6	136	125	126	137	0.0
CQUAD4	84	6	127	116	117	128	0.0
CQUAD4	85	6	128	117	118	129	0.0
CQUAD4	86	6	129	118	119	130	0.0
CQUAD4	87	6	130	119	120	131	0.0
CQUAD4	88	6	131	120	121	132	0.0
CQUAD4	89	6	132	121	122	133	0.0
CQUAD4	90	6	138	134	135	139	0.0
CQUAD4	91	6	139	135	136	140	0.0
CQUAD4	94	6	141	137	128	142	0.0
CQUAD4	95	6	142	128	129	143	0.0
CQUAD4	96	6	143	129	130	144	0.0
CQUAD4	97	6	144	130	131	145	0.0
CQUAD4	98	6	145	131	132	146	0.0
CQUAD4	99	6	146	132	133	147	0.0
CQUAD4	100	6	148	138	139	149	0.0
CQUAD4	101	6	149	139	140	150	0.0
CQUAD4	102	6	150	140	141	151	0.0
CQUAD4	103	6	151	141	142	152	0.0
CQUAD4	104	6	152	142	143	153	0.0
CQUAD4	105	6	153	143	144	154	0.0
CQUAD4	106	6	154	144	145	155	0.0
CQUAD4	107	6	155	145	146	156	0.0
CQUAD4	108	6	156	146	147	157	0.0
CQUAD4	109	6	158	148	149	159	0.0
CQUAD4	110	6	159	149	150	160	0.0
CQUAD4	111	6	160	150	151	161	0.0
CQUAD4	112	6	161	151	152	162	0.0
CQUAD4	113	6	162	152	153	163	0.0
CQUAD4	114	6	163	153	154	164	0.0
CQUAD4	115	6	164	154	155	165	0.0
CQUAD4	116	6	165	155	156	166	0.0
CQUAD4	117	6	166	156	157	167	0.0
CQUAD4	118	6	168	158	159	169	0.0
CQUAD4	119	6	169	159	160	170	0.0

```
CQUAD4     120     6    170    160    161    171    0.0
CQUAD4     121     6    171    161    162    172    0.0
CQUAD4     122     6    172    162    163    173    0.0
CQUAD4     123     6    173    163    164    174    0.0
CQUAD4     124     6    174    164    165    175    0.0
CQUAD4     125     6    175    165    166    176    0.0
CQUAD4     126     6    176    166    167    177    0.0
CBAR       127    10    178    179-.130591.9914364    0.0
CBAR       128    10    179    180-.382710.9238685    0.0
CBAR       129    10    180    181-.608768.7933480    0.0
CBAR       130    10    181    182-.793348.6087682    0.0
CBAR       131    10    182    183-.923868.3827108    0.0
CBAR       132    10    183    184-.991436.1305904    0.0
CBAR       133    10    184    190-.991436-.130591    0.0
CBAR       134    10    190    189-.923868-.382710    0.0
CBAR       135    10    189    188-.793348-.608768    0.0
CBAR       136    10    188    187-.608768-.793348    0.0
CBAR       137    10    187    186-.382710-.923868    0.0
CBAR       138    10    186    185-.130591-.991436    0.0
CQUAD4     139     6     57     56     54     55    0.0
CTRIA3     140     6     55     54     53    0.0
CQUAD4     141     6    127    128    137    126    0.0
CQUAD4     142     6    137    141    140    136    0.0
CGAP       143     7    178     63                   0
CGAP       144     7    179     66                   0
CGAP       145     7    180     69                   0
CGAP       146     7    181     72                   0
CGAP       147     7    182     75                   0
CGAP       148     7    183     78                   0
CGAP       149     7    184     88                   0
CGAP       150     7    190    113                   0
CGAP       151     7    189    110                   0
CGAP       152     7    188    107                   0
CGAP       153     7    187    104                   0
CGAP       154     7    186    101                   0
CGAP       155     7    185     98                   0
$*
$*  MATERIAL CARDS
$*
$*
$*  I-DEAS Material: 2  name: MAT1  1
MAT1           22668.7001003.271.3300000    0.0    0.0            0.0
$*
$*  I-DEAS Material: 11   name: MAT1  11
MAT1          113.0000+71.1538+7.3000000    0.0    0.0            0.0
$*
$*  PROPERTY CARDS
$*
$*
$*  I-DEAS property: 10   name: PBAR    10
$*  Fore Section   : 1  name: KEYIN SECTION1
PBAR          10      11.1059477.0106653.23831508.4603-4    0.0       +
+       .5004050    0.0-.393845    0.0                        +
+       .2568713.5827506
$*
```

```
$*  I-DEAS property: 6  name: PLANE STRAIN6
PSHELL        6      21.000000      -1
$*
$*  I-DEAS property: 7  name: NODE TO NODE GAP7
PGAP          7     0.0     0.02.0000001.000000        .2500000
$*
$*  RESTRAINT CARDS
$*
SPC          1      66       3     0.0
SPC          1      69       3     0.0
SPC          1      72       3     0.0
SPC          1      75       3     0.0
SPC          1      78       3     0.0
SPC          1      88       3     0.0
SPC          1     101       3     0.0
SPC          1     104       3     0.0
SPC          1     107       3     0.0
SPC          1     110       3     0.0
SPC          1     113       3     0.0
SPC          1      11      13     0.0
SPC          1      87      13     0.0
SPC          1     138      13     0.0
SPC          1     177      13     0.0
SPC          1     178     136     0.0
SPC          1     185     136     0.0
SPC1         1      13      20THRU        21
SPC1         1      13      30THRU        31
SPC1         1      13      40THRU        41
SPC1         1      13      50THRU        51
SPC1         1      13      62THRU        63
SPC1         1      13      97THRU        98
SPC1         1      13     122THRU       123
SPC1         1      13     133THRU       134
SPC1         1      13     147THRU       148
SPC1         1      13     157THRU       158
SPC1         1      13     167THRU       168
SPC1         1     123       1THRU        10
$*
$*  LOAD CARDS
$*
$* Nodal loads converted from I-DEAS edge loads
$*
FORCE        1     168       01.000000     0.0-4.12500     0.0
FORCE        1     169       01.000000     0.0-10.3125     0.0
FORCE        1     170       01.000000     0.0-12.3750     0.0
FORCE        1     171       01.000000     0.0-14.4375     0.0
FORCE        1     172       01.000000     0.0-16.5000     0.0
FORCE        1     173       01.000000     0.0-24.7500     0.0
FORCE        1     174       01.000000     0.0-33.0000     0.0
FORCE        1     175       01.000000     0.0-33.0000     0.0
FORCE        1     176       01.000000     0.0-33.0000     0.0
FORCE        1     177       01.000000     0.0-16.5000     0.0
$*
$*
ENDDATA
```

Appendix C. Soil properties

The Unified Soil Classification System (USCS) is used to classify soil types. The test cases in this thesis that used a soil model used a soil classified as silty sand. Silty sand is abbreviated as SM in the USCS system. It is classified as soil that contains silt and sand where more than 50% of the soil passes through a #4 sieve but more than 50% is retained in a #200 sieve. The properties of the soil depend on how well compacted it is. Table C-1 shows the properties used in the models in this thesis. Note that the values for 75% compaction soil were extrapolated from the other compactions because no data was available for that compaction. The data is from Duncan [2].

Table C-1. Duncan Soil Properties

Soil Type	AASHTO	Unit Weight	phi	delta phi	C	K	n	Rf	Kb	m
	RC	lb/ft3	degree	degree	lb/ft2					
SM	100	135	36	8	0	600	0.25	0.7	450	0
	95	130	34	6	0	450	0.25	0.7	350	0
	90	125	32	4	0	300	0.25	0.7	250	0
	85	120	30	2	0	150	0.25	0.7	150	0
	75	110	26	0	0	50	0.25	0.7	50	0