PVC Sewer System Seismic Analysis Made Practical

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Abstract

MSC is announcing a new business offering based upon a breakthrough technology. MSC has developed a means by which design engineers or occasional CAE software users can reliably perform complex engineering analysis with the same resultant quality as do the dedicated analysis experts. This breakthrough technology captures the expert's engineering knowledge and specific process solution methodologies to enable and guide the novice. Now CAE can readily enhance the design processes where it was previously unavailable. Most importantly, large productivity gains are realized in the design process. The first practical test case for this technology was to solve the problem that prevented Sekisui Chemical Company from deploying their analysis methods for creating earthquake resistant designs.

Sekisui Chemical Co. has developed new earthquake resistant PVC pipeline components. To support this new materials technology, complex nonlinear FEA models for evaluating system performance under earthquake loading were developed. The challenge now is to integrate for practical use, the performance analysis methods into the design process for system layout. Sekisui wishes to provide earthquake resistance checks for all new drainpipe system designs.

Modeling of one sewer system layout, including selected earthquake loads and nonlinear soil behavior has required an average of 40-days for expert analysts. A radical departure from the traditional FEA modeling tool set is required to enable non-FEA-expert design engineers to use the developed sewer system analysis methodology.

A sewer system modeling application was written in the form of extended HTML "drive pages" similar to web pages. Automation functions were produced by capturing MSC/PATRAN session files from the manual analysis process as performed by an expert. The special application written for Sekisui will reduce the effort of producing sewer system analysis models from 40-days, to a matter of hours. Furthermore, it will allow design engineers who are not FEA, earthquake engineering, or soil engineering experts to perform the job with expert quality results.

1.0 Introduction

MSC is announcing a new business offering based upon a breakthrough technology. MSC has developed a means by which design engineers or occasional CAE software users can reliably perform complex engineering analysis with the same resultant quality as do the dedicated analysis experts. This breakthrough technology captures the expert's engineering knowledge and specific process solution methodologies to enable and guide the novice. Now CAE can readily enhance the design processes where it was previously unavailable. Most importantly, large productivity gains are realized in the design process. The first practical test case for this technology was to solve the problem that prevented Sekisui Chemical Company from deploying their analysis methods for creating earthquake resistant designs.

Since the Great Hanshin Earthquake in 1995, Sekisui has been receiving many inquiries from Japanese government agencies regarding earthquake-proof products. Sekisui was in need of the capability to quickly develop these earthquake-proof products. One new product is a line of earthquake resistant PVC pipeline components for sewer system applications. This technology breakthrough holds the promise of greater public safety, especially in regions that are prone to serious earthquake damage. To evaluate the effectiveness of this development, Sekisui required a method for evaluating the performance of actual layout designs during earthquake loading scenarios.

Sekisui developed an analysis technique under the guidance of Prof. Takada (Kobe University), They concluded however, that it was impossible for the designers to perform an earthquake response analysis for underground drainpipe systems because of the complexity of the analysis, and the extensive training required to use the available software tools. Moreover, they found that it takes 40 days for an analysis expert to perform the analysis by using this technique.

Sekisui knew from experience that the analysis technique they developed was too complex for designers to use, although it was very useful. Moreover, they could not meet the customer's needs in a timely manner by spending 40 days on the analysis. They required a completely different approach to be able to use this technique.

The questions were:

1. How could a designer with no experience with CAE or CAD use this analysis technique easily?
2. How could the analysis time be shortened to one day, when it takes 40 days for an expert to do it?

2.0 Seismic Analysis Method developed by Sekisui

Two earthquake magnitude levels were fixed for the seismic criteria of the drain pipe system. Sekisui needed an analysis system to check the strength of a subject according to the two levels, and also to optimize the shape of the catch basin of the drainpipe. When performing earthquake response analysis, pipe connections are usually modeled by using spring elements, and pipes are modeled using beam elements. However, we modeled the pipe connections where local stress concentrates by using shell elements, which made it possible to represent geometry dependent stress correctly. Both shell and beam elements were used to create the analysis model (See Figure 2-1).

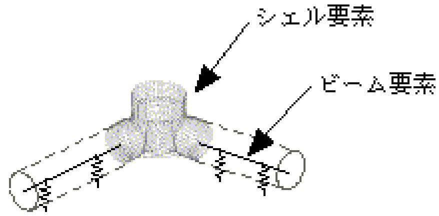

Figure 2-1. Example Shell & Beam Model

The below were considered as external forces caused by the earthquake:

- time history wave form
- ground deformation

Ground deformation is divided as follows:

- ground fissure
- ground subsidence
- side flow

Sekisui needed to know how much ground deformation would result from the two magnitude levels by considering the three types of external force. According to the reference document: "Seismic Guideline and Interpretation for Water Works Facilities", level 2 can be defined as follows:

·	ground fissure	100 millimeters
·	ground subsidence	500 millimeters (liquefied soil)
		300 millimeters (soft soil)
·	side flow	2.5%

The wave form measured at the time of the Great Hanshin Earthquake was used for the time history response analysis. The analysis technique simulates how the wave reaches the drainpipe system through the ground (See Figure 2-2), and how the drainpipe system vibrates simultaneously with the ground.

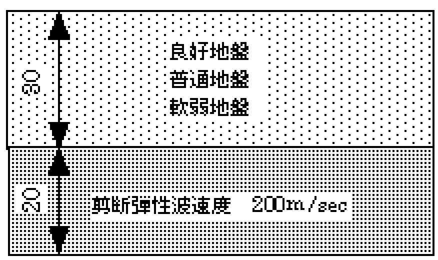

Figure 2-2. Ground Layers

2.1. Description of the Drainpipe System

Figure 2-3 shows the drainpipe system. The drainpipe system will be constructed several hundred millimeters deep around the house and the pipe diameter will be 100-200 millimeters

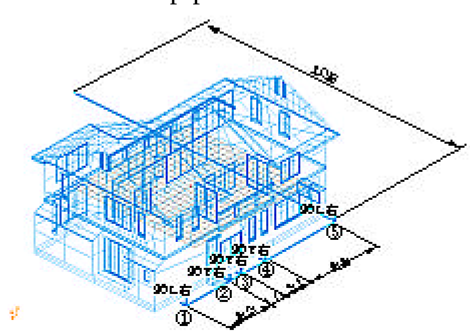

Figure 2-3. Drain Pipe System

2.2 Time History Response Analysis

The ground layers and the earthquake waveform Are defined first. Figure 2-4 shows 50 meters of the outer ground region. This was used for the analysis. This ground region has two layers. Based upon these layers, we inputted 800 Gals for the earthquake waveform as was measured at the time of the Great Hanshin Earthquake. Figure 2-5 shows the incidence waveform. We applied this waveform to the underground drainpipe system in order to perform the time history response analysis. The ground modeling and analysis was done using FRONT, an earthquake response analysis software. Figure 2-6 shows the analysis model of the drainpipe system. Shell elements were modeled for the catch basin. Beam elements were modeled for the pipes. Nonlinear spring elements represent the rigidity of the ground around the drainpipe system. The system was modeled with MSC/PATRAN. This model was combined with the analysis results from FRONT, and was analyzed using MSC/ABAQUS. Figure 2-7 shows the response waveform from the section close to the pipe connection.

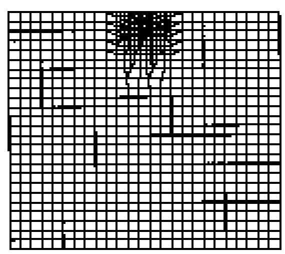

Figure 2-4. Ground Region

Figure 2-5. Incidence Waveform

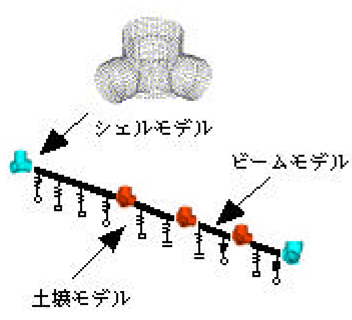

Figure 2-6. Analysis Model

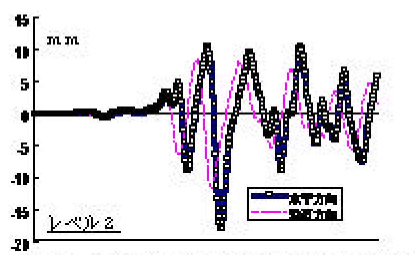

Figure 2-7. Ground Subsidence Analysis Model

2.3 Analysis of the Ground Deformation

The ground fissure and ground subsidence analyses are shown below. Figure 2-8 shows the analysis model of a ground subsidence based on the drainpipe system. This model was also created using MSC/PATRAN. Materials are modeled with nonlinear properties. The properties of the spring elements differ according to the soil type. The force between the ground and the soil will be constant over a certain value. As shown in Figure 2-9, the ground fissure was set to 100mm maximum, which was applied to the end point of the ground springs.

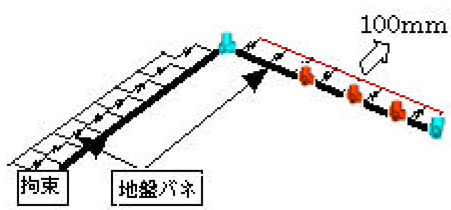

Figure 2-8. Ground Subsidence Analysis Model

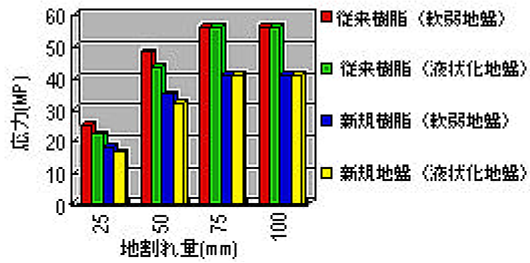

Figure 2-9. Ground Fissure Values

2.4. Assessment of Expertise Required to Perform the Analysis

In the absence of any new technology tools, the designer who performs the above analysis will be required to handle:

(a) FRONT — earthquake response analysis software
(b) MSC/PATRAN — 3D modeling software
(c) MSC/ABAQUS — Non-linear structural analysis software

with ease. This is a very high level to require, even for an analysis specialist.

Listed below is the actual computer use level and analysis ability of the Sekisui designers:

(a) they can handle a word processor,
(b) they are not experienced in CAE,
(c) they are not experienced in CAD,
(d) they know the product development process well.

3.0 Application of the New MSC Technology

The challenge Sekisui faced was to find a way to make seismic analysis of sewer systems a practical reality for layout designers. Sekisui became aware of a MSC project exploring a new technology to make FEA possible for non-experts to perform. Sekisui decided to team with MSC to mature this technology, and to create a sewer system modeling application that will meet the challenge.

3.1 Operational Description of the MSC New Technology System

The concept under exploration by MSC is more than a software product or system. It is a new business offering. This offering contains three essential elements. The first element is an expert analyst's professional practice, applying his knowledge to guide the novice user. The second element is a software toolkit that manifests the expert's applied knowledge into special applications that are both easy to create, and extremely easy and efficient for the end user to operate. The third element is training available to analysis experts for how to use the new application authoring environment. A set of principles will guide authors to write applications with clarity and minimum ambiguity.

The system allows experts to record their knowledge and methodology not only to offer advice to the inexperienced user, but also to guide and control the actual modeling process. Options open to the user are limited in context to the particular analysis step in progress. The application author decides what those options are. User responses and decisions are used in logic operations for the expert to exert control over the process. Automation in terms of expert created PCL functions are offered where possible to make applications efficient. This results in consistent quality FEA, and a radical ease-of-use for the novice or occasional user.

The software toolkit allows an easy and efficient creation of expert system applications. A new extended HTML technology platform enables a browser like one-form-only user interface. The HTML technology makes the scripting of analysis sequences and dialogs very much like the writing of web pages. No user interface or graphics programming is required.

HTML is the vehicle used to convey text and illustrations. Powerful hypertext links in HTML invoke PCL function operations to perform modeling actions. Also, extended HTML tags (XML) allow the calling of background PCL functions during any dialog display. For actions requiring user inputs, the tags reference an editable table describing what PCL function call to make. The table lists default values for the user inputs, plus the type of input widgets to display to the user. This means that the browser like single UI form will display on-the-fly, any input devices required for the analysis scenario. Navigation through functionality is automatic for the novice user.

Services available through MSC will help capture the knowledge and methodology of experts in industry to create the applications. MSC will also offer training to analysis and PCL exerts for how to write the applications. A special editor will aid the authoring by prompting available tags and writing them out automatically with the correct syntax. The editor has record-and-play macro capability to make the authoring of repetitive dialog blocks or logic paths easy. MSC training will establish a set of principles for quality application authoring. The authors must consider the important scenarios, writing according to the user's practice, mode of thinking, and data available.

Finally, industry will be able to establish a strong control for quality FEA. FEA can enjoy application in endeavors previously unavailable, due to lack of confidence in the outcome, or due to the large training and labor investment required. Dedicated analysts or hired consultants can extend their knowledge and influence over the enterprise. They will add more value to the corporation. Design cycle times and time-to-market will be reduced through automation and easy-to-use applications. Product quality will increase as a result of a consistent quality in design analysis.

3.2 Description of the Sewer System Analysis Scenario Required by Sekisui

The assumption made in stating the analysis scenario requirements is that the developed application will speak a language that designer users understand both in terminology and natural language (Japanese). The application must not require knowledge of, or request decisions about FEM details. The Sekisui Kyoto Research Center developed ABAQUS solution methods with nonlinear material properties, large displacement capability, and nonlinear springs to represent soil behavior. Designers at the Sekisui Tokyo works will use the modeling application. MSC is required to develop an application that follows the method developed in Kyoto, and generates models that do not fail to solve. The required scenario is summarized below.

1. System Layout Selection:

   The system model will include just the portion of a drain system that surrounds a building. The user selects between a left-handed or right-handed basic configuration. An additional arbitrary layout scheme shall be added, and will require more extensive user inputs.

2. Pipe Specification:

   The user may select from a menu, pipe diameter, pipe material, and a depth gradient value. A special menu selection shall also allow for arbitrary pipe material properties, input by manual means. The terminology and units must be those used by the designers.

3. Catch Basin Layout Specification:

   Input quantities and units must correspond to the items found on the layout drawings. Position is specified as distance from the preceding catch basin. Depth is input for the terminal catch basin and is computed for the rest by default from the layout gradient. An option for manual depth input is provided. Catch basin type is selected by catalog ID number. As the user is specifying the layout, a graphics screen symbol display will supply feed back. A separate review and edit step will make specification changes convenient.

4. Automatic FEM Modeling:

   Catch basins are modeled with shell elements. The user may select between a beam element model or plate element model for the connecting pipe. FEM models of the catch basin and pipe are automatically created and arranged according to the previously input layout specification The catch basin and pipe FEMs are automatically connected. Nonlinear soil modeling springs are automatically arranged along the pipe at set intervals. The type of soil modeling (e.g. Normal, Soft, Liquefied soil etc.) is selected in a dialog menu by the user.

5. Analysis Type and Earthquake Loading:

   Four types of analysis are performed; ground fissure, side flow and subsidence, which are static analyses, and a vertical quasi-transient response for which static loads at each time step are applied to the FEM.

   The load conditions for ground fissure, side flow and subsidence are enforced displacements based on the analysis method that Sekisui established. The load conditions for vertical quasi-transient response are enforced displacements as calculated by a special ground response simulator program. The enforced displacement loading, plus fixed boundary conditions are applied at the free ends of the nonlinear soil springs. To perform all four analysis types, the user shall simply select the analysis type to perform by name, and select existing ground response data files. The load/boundary condition data is automatically applied to the system model.

6. Method of Numerical Solution:

   The system model is submitted to ABAQUS for solution. The run deck creation and job submittal occurs automatically.

7. Results Processing:

Calculated results are summarized and output as a simple table with special indexes useful for quick evaluation of an analyzed sewer system.

a) Elongation of pipe, is used to evaluate the potential for a pipe pulling out. Summarize the maximum pipe elongation case, with catch basin ID No. and load ID No. information.
b) Opening angle of pipes at catch basins, is used to evaluate potential ruptures. Output the maximum opening angle case for pipes at catch basins (in vertical and horizontal planes) with catch basin ID No. and load ID No.
c) Maximum strain at catch basins, is used to evaluate potential rupture. Output the maximum strain case for catch basins with catch basin ID No. and load ID No.

The above results are output according to a Sekisui standard form that designers use. The table is output in HTML format. The user may also obtain deformation/stress and strain contour plots for the maximum cases by selecting the displayed load case hypertext link. The output HTML summary table is convenient for electronic communication with others.

4.0 Implementation of the Sekisui Analysis Scenario as an Application for the New Technology Platform

As stated before, the goal for this particular application development is to make seismic analysis of PVC sewer systems practical for design engineers. Sekisui intends to have all new layout designs checked for earthquake resistance by the layout designer. A requirement for this application is therefore to build robust ABAQUS models that are consistent with the models developed by the experts at Kyoto Technology Center. No ABAQUS solution failures are acceptable because the novice users will not be able to understand the causes, or to repair the ABAQUS run decks.

The application must have all special knowledge required for solution built into the automation functions, and dialog, and available to guide the user as required. The application must require no specialized FEA knowledge, or knowledge of earthquake engineering or of soils engineering.

The application was also written to work efficiently for the targeted user. A technical manager, Mr. Masahiro Tahara from the Sekisui Tokyo plant, who is involved in PVC catch basin design and system layout design, provided valuable consulting to help us design the application. We thank Mr. Tahara for guiding us to use a logical sequence, a terminology, a set of units, and a mode of presentation that makes the application easy to use and successful for the layout designers.

A view of the browser like user interface displaying dialog from the second analysis step, "Select Basic Configuration" is shown in Figure 4-1 below. Note that the UI form has general action buttons on the very top, and dialog specific action buttons on the very bottom. The rest of the form is divided into three scroll frame panels: 1) The analysis step selection panel, 2) The HTML dialog panel, and 3) The special user inputs panel. The panels resize themselves for display as necessary.

As evidenced in the figure, the analysis steps are designed to first gather all required information about the system layout. All information is gathered and reviewed before automated modeling is performed. Upon reviewing the layout, the user may correct any mistakes. Also, input checking functions stop the user from violating certain rules of system layout.

The HTML dialog displayed in Figure 4-1 requires a simple hypertext selection for the user to specify a basic layout configuration. This illustration shows the advantage that an HTML display offers. Text and graphic illustrations are easily implemented to provide the user with clear instructions. The dialog in this example is very simply amended in the future to include additional layout configurations. HTML is easy to edit. By first selecting a basic configuration, all remaining dialog for the user is simplified, because several facts become known once the configuration is selected.

After the basic configuration is selected, the user must tell the application what the overall dimensions of the layout are, and how many catch basins are included on each side or “leg” of the system to complete the second analysis step. Figure 4-2 below shows an example of the dialog asking for the overall dimensions. Since numerical values are required from the user, input data boxes appear in the “Inputs” panel located below the HTML dialog. The data boxes appear with default values that the user may edit.

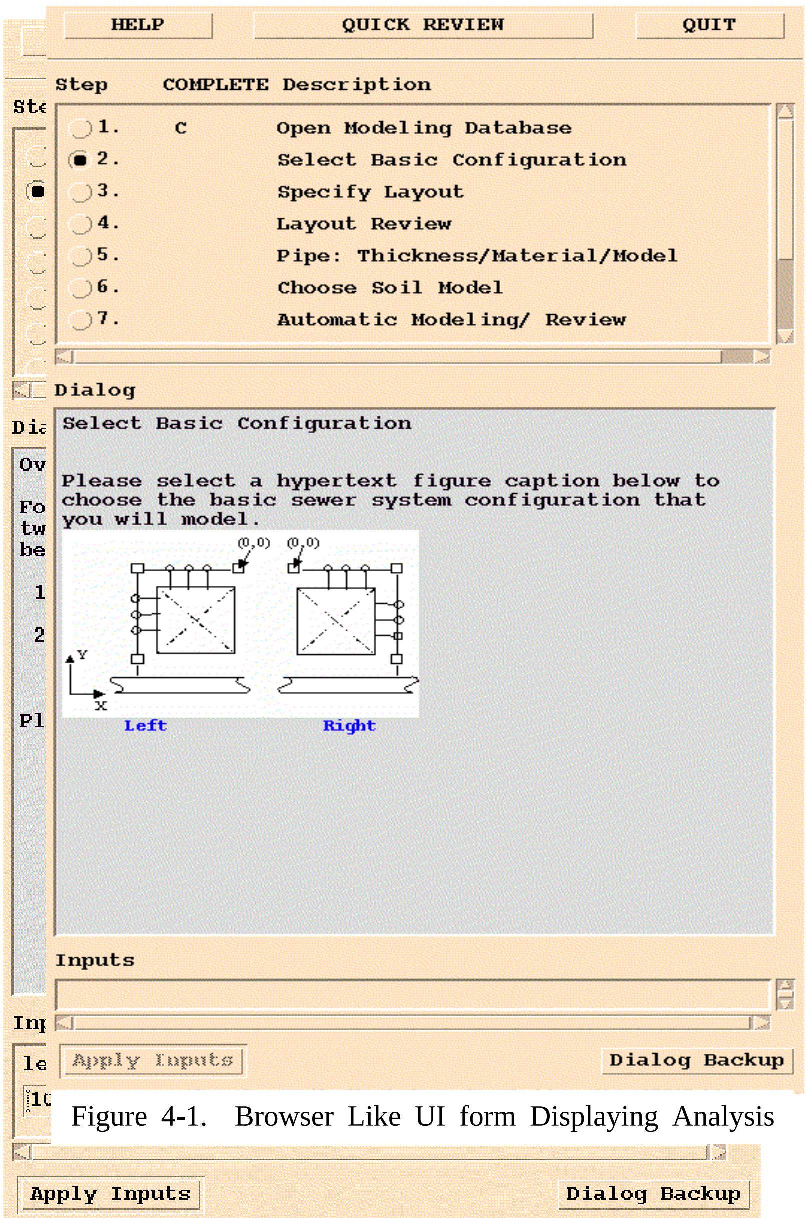

Figure 4-1. Browser Like UI form Displaying Analysis

Figure 4-2. Example Dialog Requesting Overall Dimensions

Subsequent analysis steps query the user to find out the catalog number of catch basins, and the location of the catch basins along the system “legs”. The dialog speaks the designer’s language. It asks for quantities in terms of the units and conventions used on the available blueprint drawings. Figure 4-3 below shows an image of the graphics screen during the Layout review step. Graphic symbols are used to represent catch basin location and catalog number. No system modeling has taken place yet. The Netscape browser automatically opens to provide a summary table of inputs.

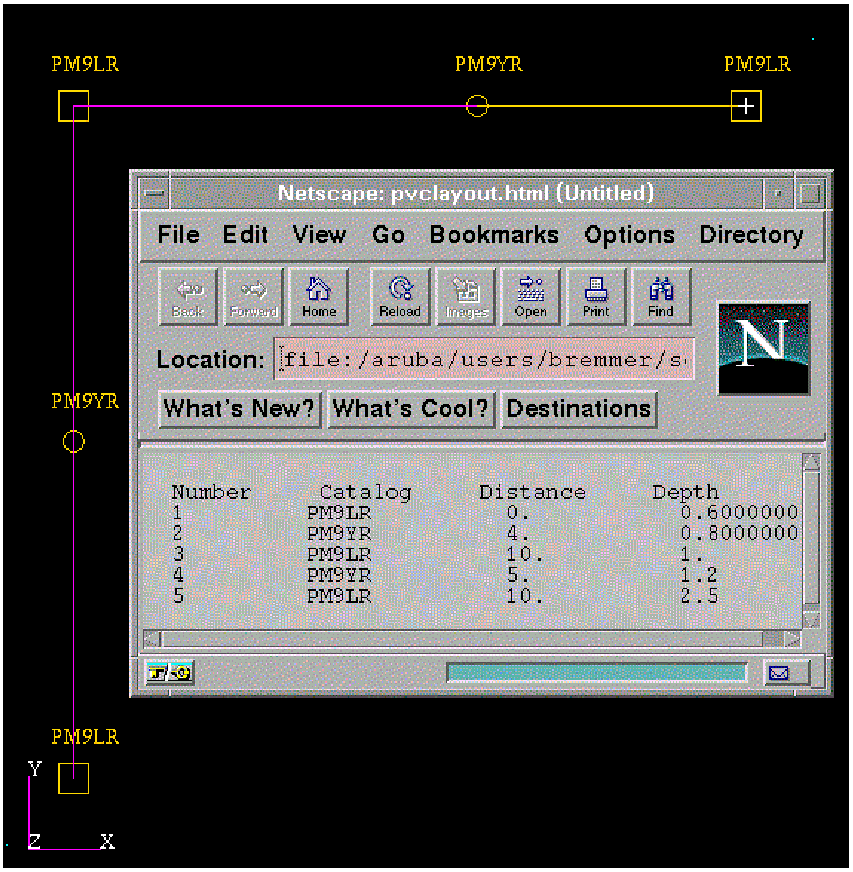

Figure 4-3. Graphic Screen Image During the Layout Review Step

Simple hypertext selections in HTML dialog are used to allow the user to specify the pipe used in the system, and the type of soil to model for the site. Figures 4-4, below shows one example of this HTML dialog.

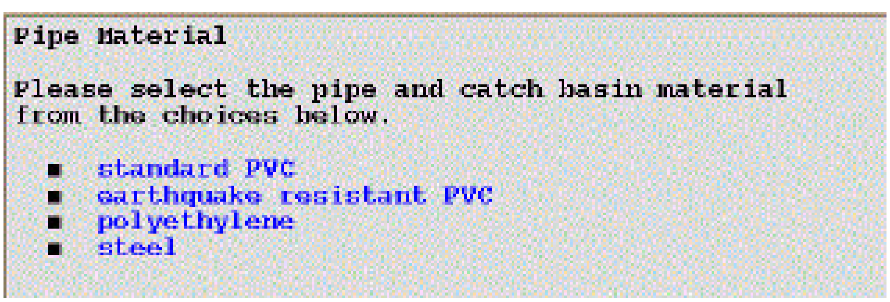

Figure 4-4. HTML Dialog Allowing the Selection of Pipe Material

After information is gathered and reviewed, the system model is constructed by automation functions. A "Start Modeling" hypertext in this dialog is quite powerful because upon selection it initiates functions to construct an entire system model.

After the system model is constructed, the HTML dialog allows a visual review. Figure 4-5 below shows an example image of an elbow joint catch basin that was automatically modeled.

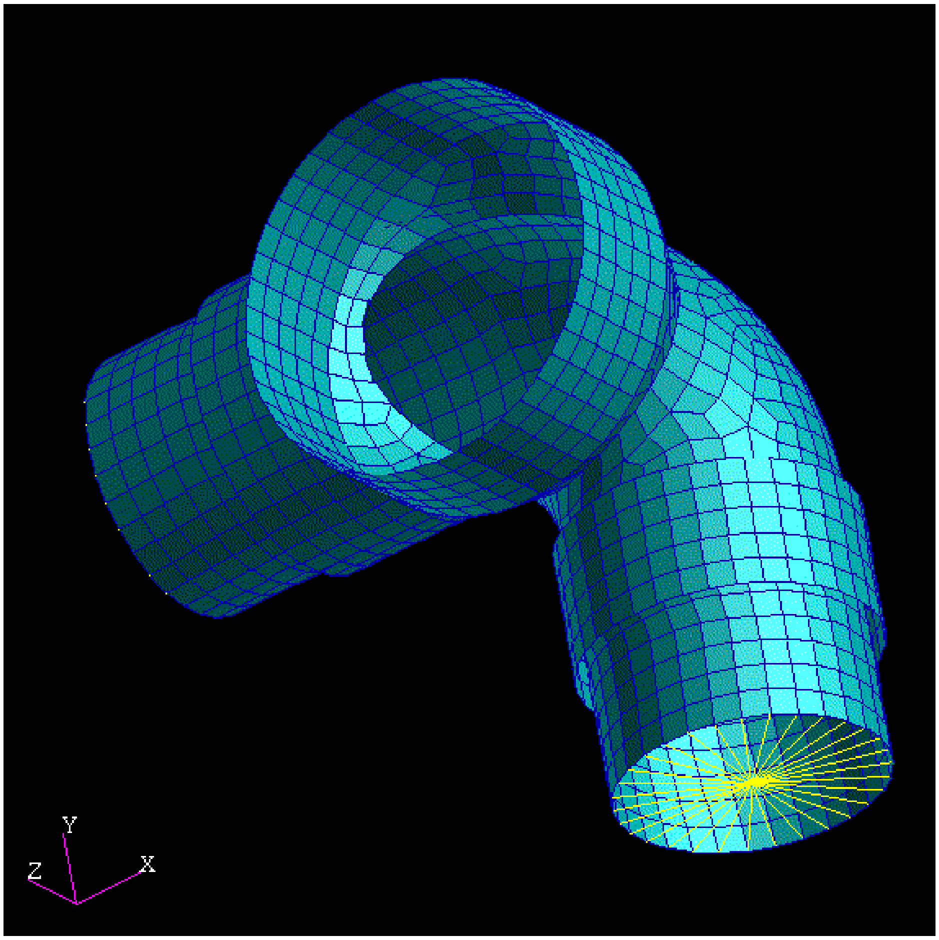

Figure 4-5. automatically Modeled Elbow Joint Catch Basins

The subsequent analysis steps allow the user to select the earthquake loading cases to use, to submit the ABAQUS run, to read in the analysis results and to display summary output. The result summaries identify the region of maximum pipe elongation, and the catch basin experiencing the greatest angle change between connecting pipes. Strain contour plots are available for the peak loaded catch basins.

5.0 Conclusions

Sekisui and MSC worked together, driven by the vision that a new technology idea could meet the challenge of making sophisticated FEA practical for non-experts. Indeed it did meet the challenge. What previously took 40-days to model, can now be accomplished in less than one-day. The user performing the simulation is not required to have any specialized FEA knowledge or knowledge of how to operate general FEA software tools. The knowledge and methodology of FEA experts is captured in the application that guides the user and performs the modeling. English and Japanese language versions of the application were written. The application communicates to Sekisui users in native Japanese language text, with a methodology that is understood and easily followed by system layout designers.

Acknowledgements

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This technology development would not have happened without the driving vision and continuous support that was provided by the "Rapid Response Manufacturing" (RRM) industry consortium sponsoring a proof-of-concept prototype development. Members of that consortium who gave generously of their time and talents are: GM Delphi-Saginaw: Mr. Joe Streng, Mr. Ravi Pathy, GM Delphi-Chassis: Mr Rich Wells, Eastman Kodak: Mr. Ron Auble, Mr. Steve Podyma, Pratt & Whitney: Mr. Andrew Jay.

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