**Table (7) Comparison the results of envelope response method to multiple excitation method by Epipe (problem 6)**

| Program | Node / Direction | 1 | 4 | 7 | 14 | 20 | 26 | 28B | 36 |
|---|---|---|---|---|---|---|---|---|---|
| Simflex | X | 102 | 0 | 108 | 79 | 79 | 214 | 0 | 124 |
| | Y | 111 | 244 | 0 | 0 | 0 | 0 | 232 | 61 |
| | Z | 96 | 0 | 92 | 42 | 30 | 66 | 95 | 66 |
| Epipe | X | 93 | 0 | 100 | 78 | 78 | 185 | 0 | 120 |
| | Y | 107 | 234 | 0 | 0 | 0 | 0 | 221 | 57 |
| | Z | 89 | 0 | 84 | 39 | 28 | 59 | 89 | 56 |

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**Table (4) Flexibility and stress intensification factors of the elbow (problem 5) .**

| BY | $k_p$ | $c_p$ |
|---|---|---|
| simflex | 7.45 | 1.84 |
| solvia (shell element) | 7.14 | 1.98 |
| solvia (pipe, 4 node) | 6.86 | 1.82 |
| ASME Sec. III. NB | 7.44 | 5.32 |
| ANSI B31.1 | - | 2.46 |
| Dodge - Moore | 7.15 | 5.92 |

**Table (5) Comparison of SimflexII and Epipe results in modal analysis (problem 6)**

| Program | ω1 | ω2 | ω3 | ω6 | ω10 | ω15 |
|---|---|---|---|---|---|---|
| Simflex | 6.045 | 6.26 | 7.69 | 12.88 | 18.59 | 33.94 |
| Epipe | 6.642 | 6.26 | 7.79 | 12.83 | 18.54 | 33.84 |

**Table (6) Spring support reactions of envelope response analysis (problem 6).**

| Program | Node / Direction | 1 | 4 | 7 | 14 | 20 | 26 | 28B | 36 |
|---|---|---|---|---|---|---|---|---|---|
| Simflex | X | 102 | 0 | 108 | 79 | 79 | 214 | 0 | 124 |
| | Y | 111 | 244 | 0 | 0 | 0 | 0 | 232 | 61 |
| | Z | 96 | 0 | 92 | 42 | 30 | 66 | 95 | 66 |
| Epipe | X | 93 | 0 | 100 | 78 | 78 | 185 | 0 | 120 |
| | Y | 107 | 234 | 0 | 0 | 0 | 0 | 221 | 57 |
| | Z | 89 | 0 | 84 | 39 | 28 | 59 | 89 | 56 |

Table (2) Displacement and acceleration responses to impact load . Comparing Simflexll to Solvia results in several analyses (problem 2) .

| Program | Element | Method | Modes used | Max. Displacement @ 51 (mm) * | Max. Accelearation @ 51 (9) |
|---|---|---|---|---|---|
| simflex | Pipe | Modal | 2 | 174.80 | 48.87 |
| simflex | Pipe | Modal | 3 | 174.79 | 49.02 |
| simflex | Pipe | Modal | 10 | 174.76 | 66.46 |
| simflex | Pipe | Modal | 30 | 174.76 | 190.59 |
| simflex * | Pipe | Numark | - | 174.84 | 117.91 |
| solvia | Beam | Modal | 30 | 174.72 | 147.36 |
| solvia | Beam | Numark | - | 174.73 | 125.56 |

Table (3) support reactions of Hovgaard bend (problem 4).

| Node | Reaction (lb) or (lb-in) | Simflex | Epipe | Analytical |
|---|---|---|---|---|
| 1 | $F_x$ | - 1711.3 | - 1711.0 | -1750 |
| | $F_y$ | - 1669.4 | - 1666.9 | -1710 |
| | $F_z$ | - 629.0 | - 628.2 | - 640 |
| | $M_x$ | - 4578.3 | - 4573.0 | - 4670 |
| | $M_y$ | 1195.4 | 1194.7 | 1200 |
| | $M_z$ | 10846.4 | 10847.1 | 11090 |
| 4 | $F_x$ | 1711.4 | 1711.0 | 1750 |
| | $F_y$ | 1669.5 | 1666.9 | 1710 |
| | $F_z$ | 629.1 | 628.2 | 640 |
| | $M_x$ | 7720.4 | 7708.7 | 7941 |
| | $M_y$ | - 6546.6 | - 6546.2 | - 6697 |
| | $M_z$ | - 5192.6 | -5188.0 | 5348 |

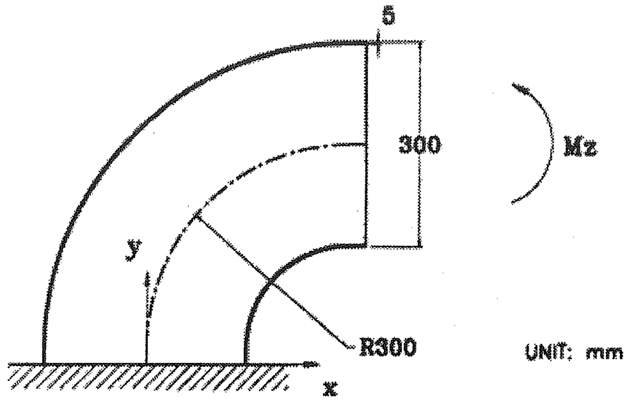


Figure (5) A 90° elbow (problem 5).

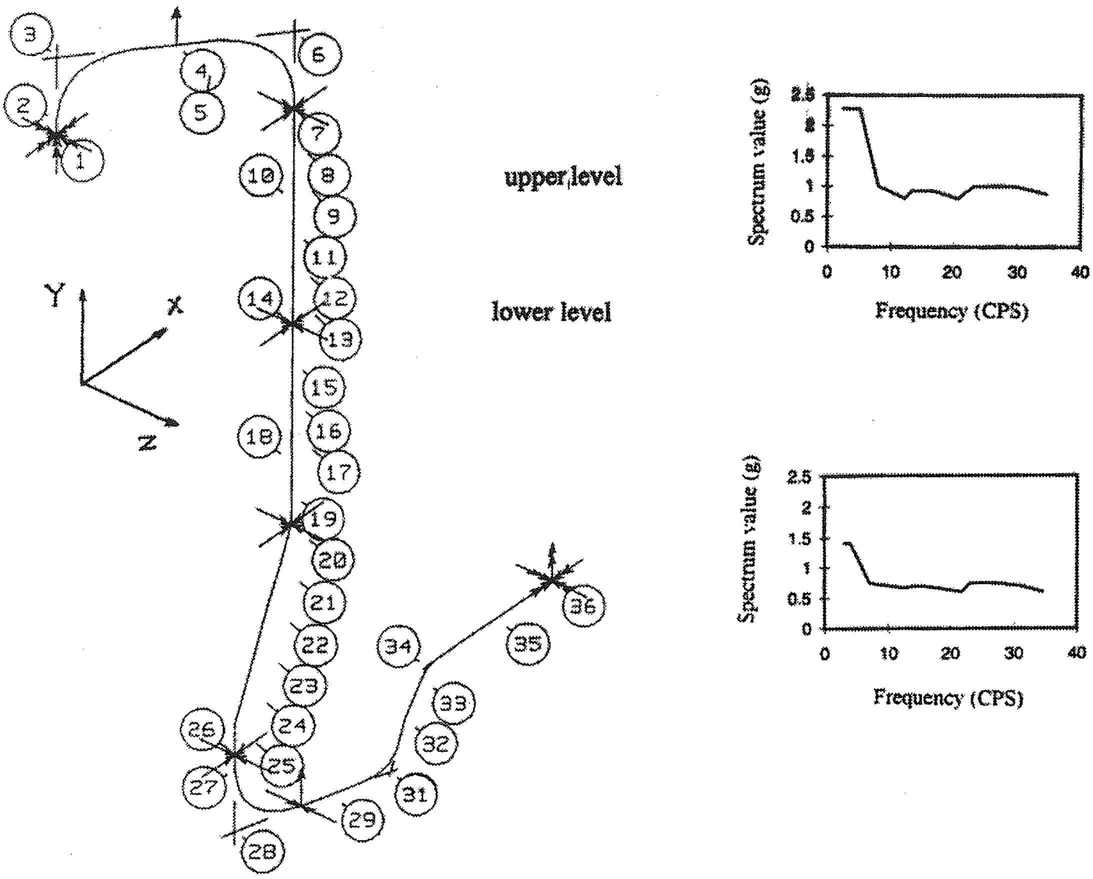


Figure (6) A large piping system , multiple support excitation with upper and lower level response spectra (problem 6).

Table (1) In - plane frame , natural frequencies (problem 1).

| Program | Element | ω1 | ω2 | ω3 | ω4 | ω5 | ω6 |
|---|---|---|---|---|---|---|---|
| simflex | Pipe | 3.30 | 34.79 | 68.98 | 118.92 | 207.23 | 234.86 |
| solvia | Pipe | 3.30 | 34.96 | 69.79 | 121.28 | 211.29 | 240.92 |
| solvia | Beam | 3.30 | 34.77 | 68.94 | 118.86 | 207.10 | 234.79 |

flexibility factor and stress intensification factor in elbows and attachments. Stress intensification factor of elbow element may be not satisfactorily selected, so in sensitive design conditions user should check the factors and modify them if needed . Stress reported in output file of Simflex II are not detailed enough, so it is not applicable for designing safety systems where more sophisticated design is needed. Because of the lack of multiple support excitation analysis option in Simflex II , the analysis of largely distributed piping systems will be over estimated by envelope response spectrum method, so not suitable for safety systems which should be more sophisticated. The algorithms of Simflex II are more efficient than general programs like Solvia are working with simflex II is more easier and faster than general programs. Simflex II is a good program for analyzing and designing commercial piping systems and works well within the range of its abilities. For analyzing the safety systems, this program may be used as a pilot program to make good estimations. Approaching to more accurate results may be provided by general programs which have more options and capabilities in analysis but more difficult to handle and more risk of user mistake. So the correctness of the analysis is depended to the knowledge and experience of the designer who should be sophisticated at all.

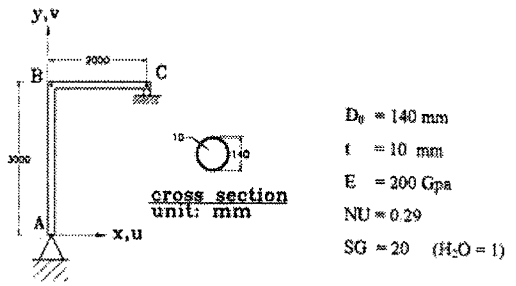


**Figure (1) In - plane frame, modal analysis (problem 1).**

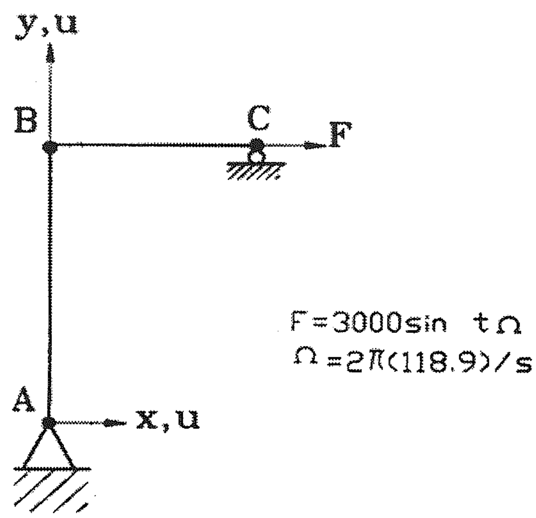


**Figure (2) Inplane frame, harmonic excitation (problem 2).**

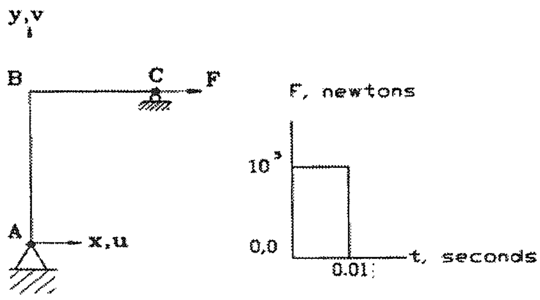


**Figure (3)- In plane frame, Impact load (problem 3 ).**

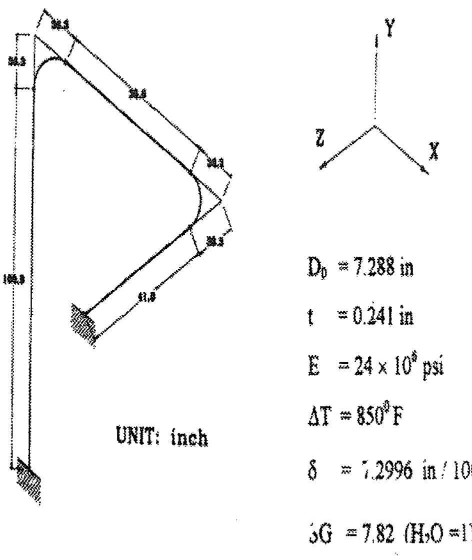


**Figure (4) Hovgaard bend (problem 4).**

point C,.3 The maximum displacement of point C during 0.4 sec is considered and compared to Solvia result. Two methods named 'Mode superposition' and 'Numark' are performed taking x =0.02 as damping ratio for all modes and two first modes respectively. The results listed in table 2 show a good agreement between the programs. Mode superposition method is not effective to determine acceleration response as shown in the table.

## Problem 4, Hovgaard bend

A 3-D piping structure with two ends fixed made up of 7.288 in pipe, named 'Hovgaard bend' [6,7] is considered ,. 4. The piping system is loaded by a temperature difference dT=850 °F. The resulting forces and moments at the anchor points are considered. There is a comparison between Simflex II, Solvia, Epipe and Algebraic techniques [6,7].

**The results** are listed in table 3. A good agreement is found between the programs as you see.

## Problem 5, A 90° Elbow

A 90° elbow is considered to study the flexibility and stress intensity factors used in Simflex II. The elbow is loaded by an in-plane moment Mz,. 5. The factors used in SimflexII are compared with the values obtained of Solvia in two cases; 1-Modeled by pipe 4 node element. 2-Modeled by shell element. They are all compared to the proposed valuse of piping standards [8,9] and Dodge - Moore results [5].

**The results** can be found in table 4. Kp and Cp are flexibility factor and stress intensification factor respectively. The results show a good agreement between Simflex II and Solvia but not agree with nuclear standards. So the user should modify the flexibility and stress intensification factors according to the applicable standards if required.

## Problem 6, Large piping system, Multiple support excitation

A large piping system distributed and supported in several elevations. 6 is loaded by response spectrum seismic load. Upper level supports are loaded different to the lowers. This model is the same as the model solved in [12] by Epipe . An accurate calculation requires multiple support excitation terchnique. In Simflex II because of lack of this technique, envelope response method is employed . The results of Simflex II are compared to the results of Epipe in both techniques of envelope spectra and multiple support excitation .

**The results** of SimflexII are compared to the epipe in tables 5 and 6. Comparison of The support resations listed in table 6 shows a maximum deviation of 6.7% between each two software results. This relatively large deviation is because of response spectrum method sensitivity to natural frequencies found by the software. A study on the multiple support excitation with respect to envelope method is performed in table 7. It' s found that the envelope method produces a more conservative result in most cases but for a sophisticated design it' s not applicable.

## Conclusions

Based on the numerical experiments of the benchmark problems the following conclusions can be reached. Simflex II employs simple beam element with round section as pipe element and considers already provided benchmark problem sets and verified some such programs [10, 11, 12, 13, 14]. These programs are not general and the accessibility is restricted . At this time one of the best accessible programs here for analyzing power plant piping systems is Simflex II.

## Introduction

Because of lack of any confirmation on the performance of Simflex II verifying the accuracy of the program and considering its capabilities for analyzing the nuclear power plant piping systems was needed. The foundation of this work is based on knowledge of dynamics of structures, finite element method and knowledge of piping systems design. The required skill and capability are provided by pilot studies on programs and parametric studies on dynamic behavior of piping systems. A genral FEM program , Solvia is used to check the answers of Simflex II [4]. In some cases the results of the program Epipe [12] are employed as references. More over hand calculations are used to estimate the answers and check the programs in simple problems [6,7] . A summary description of each problem including a description of the input parameters, pertinent output results and the reasons for problem selections are included . Six benchmark problems are developed ranging from simple configurations to configurations similar to actual power piping systems. The simple configurations were included as they allow ready hand calculation checks of all the pertinent results. A sketch of the finite element grid of each problem is shown in figures 1 through 6. A brief description of each problem is presented below . Solution of dynamic problems including a determination of system natural frequencies, participation factors mode shapes,nodal displacements and piping support forces. A complete presentation can be found in the reference [1].

## Problem 1,in-plane frame,modal analysis

An in - plane frame similar to a riser is considered,. 1. The model is divided into 50 straight pipes of 0.1 m length . The natural mode shapes of the structure are fonud by Simflex II and compared to the Solvia answers and hand calculations. The results of modal analysis of the system are listed in table1. It is found that Simflex II employs conventional beam element with round section as pipe element. The first natural frequency of the structure is estimated by hand calculations as w1=3. 20, so approves the program results.

## Problem2,in-planeframe, harmonic excitation

The structure of problem 2 is excited by a harmonic excitation force F=3000 sin ( $\Omega \tau$ ) at point C,.2. A damping ratio of $\zeta$ =0.02 is applied to the structure. The excitation frequency $\Omega$=118.9 Hz is equal to the forth natural frequency of the structure. The results of Simflex II are compared to hand calculation [2] using modal solution techniques of forth mode shape of the structure.

**The results** are $U_{is}$ = 0.08 mm and 0.077 mm by hand calculation and program respectively and shows a good agreement.

## Problem 3, In-plane frame, Impact load

The structure of problem 2 is considered under impact load . The load is employed at

# Providence And Development Of Piping Benchmark Problems To Evaluare And Verify SimflexII Computer Code For Designing And Analyzing Nuclear Power Piping Systems

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## Abstract

*A set of benchmark problems and solutions have been developed and applied to verify the accuracy of computer package used for static and dynamic analysis and design of nuclear power piping systems. The problems range from simple to complex configurations which are assumed to experiences a linear elastic behavior. The dynamic loads consist of harmonic excitation, impact loading and uniform support motion response spectrum which is compared to independent support motion response spectra. Thermal expansion loading is employed too. An investigation on flexibility and stress intensification factors is also provided. The benchmark problems are applied to the Simflex II computer code as a test problem. This package is licensed "as is" [3] by the supplier and may be used to analyze nuclear power piping systems. The results show that Simflex II is a good program for analyzing and designing of commercial piping systems and works well within the range of its capabilities. For analyzing the systems such as the nuclear power plant piping systems, this program may be used as a pilot program to make good estimations . A more accurate results may be provided by general programs which have more options and capabilities in analysis but is more difficult to handle and therefore higher risk of mistake being committed by the user.*

## Background

Dynamic structural analysis of piping systems is one of the most extensive engineering tasks especially for the safety design of nuclear power plants . Such analysis is normally performed by using computer programs which can handle complex system geometries and various loading conditions, static or dynamic . Applicants for nuclear power plant licenses are required to provide confirmation of the adequacy of the programs, as prescribed by the guidelines of the standard review plan Appendix B, section lll of IOCFR50 [15]. These programs are generally large programs, based on the finite element method, which experience small displacements and rotations. International specialized committees like ASME and Brookhaven national laboratory (BNL) have