SPREADSHEET SOLUTIONS

FOR

VIBRATION ANALYSIS AND MODELLING

by

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ABSTRACT

The use of a tuned absorber to control the vibration amplitudes of a secondary system subjected to base excitation via a primary system is investigated computationally. A second investigation considers the use of an impact damper mounted on the tuned absorber to control vibration amplitudes of secondary system subjected to base excitation via the same primary system.

A series of spreadsheet programs have been written to assist in the investigation of the two vibration control problems. Techniques for solving both closed form and numerical integration problems using spreadsheet macros are presented. The graphics capabilities of spreadsheets are used to present the results of batch case runs of different system parameters.

User manuals for both series of programs have been written, fully explaining the programs and how they can be used as a basis for continued investigations of these and similar situations.

ACKNOWLEDGEMENTS

This thesis is dedicated to my wife, Colleen, for giving me the support and for providing me the time required to accomplish it. It is offered to our children, Sarah and Julie, as an explanation of why the only Daddy they have ever known has spent much of his time sitting in front of a computer screen. I now surrender to the distraction of their ever present charms.

The challenges and assistance rendered by Dr. S. E. Semercigil throughout this learning experience are acknowledged and hopefully reflected in the final product. I hope we can continue our relationship, albeit at a less driven pace.

The use of the computing facilities of M. R. Byrne & Associates Limited is gratefully acknowledged.

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CHAPTER 1.0

INTRODUCTION

The advantages of using computers to perform engineering calculations (as opposed to handwritten or manual calculations) has long been recognized. Programs such as Fortran or Pascal have been taught in most universities for many years. Most often however, they are reserved for complicated problems involving significant computation or repetition. In recent years, spreadsheet programs such as LOTUS 123[1] or EXCEL[2], have become more and more popular as an engineering tool. Because of their ease of use and accessibility, they are often used to solve once through calculations that could be done "by hand". The prime advantage is that after the program has been written, any changes in the parameters requires only minimal (re)work by the engineer to obtain a new answer. Most spreadsheet programs include data tables. These are "what if" tables which calculation and retain the values of chosen output variables based on variations of either one or two input variables.

The problems that have been solved using spreadsheet is growing in both size and complexity. These include examples in chemical engineering [Rosen and Adams 1987], [Cassolato 1989], civil engineering

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1 Trademark: LOTUS Development Corporation, Cambridge, Mass. USA

2 Trademark: MicroSoft Corporation, Redmond, Virginia, USA.

[Neis, Neis and Wigham 1988], physics [Crow 1987], and electrical engineering [Hagler 1987], [Bredenkamp 1987]. Papers have also been written specifically on spreadsheet calculation techniques [Ronen, Lucas and Palley 1989], [Parlar 1989], [Ho 1987].

The motivation for this thesis was to demonstrate the use of spreadsheet programs to solve problems that involve significant computation and utilize two strengths that are not as familiar to the average user: macro programming and graphics. Spreadsheet programs allow the writing of "macros" which in many ways emulate more traditional programming languages and provide the versatility necessary to model the more complex problems. They can use "if statements", "do loops" , "subroutines" etc. which can continually manipulate a base spreadsheet program to allow complex modelling. Spreadsheets also have graphics capabilities. These can display results without transferring the data to another program as is required with Fortran or Pascal. The use of macros can make the generation of these graphics simpler. In addition, they may include all the data required to fully relay the problem.

The focus of this thesis is the investigation into two specific vibration control problems, dealing with the use of tuned absorbers and impact dampers. The method for generating all data required for the investigation are two packages of programs written using LOTUS 123, a popular spreadsheet program. The body of this thesis presents the investigations and results. Each technique is described within a chapter which is essentially a self-contained report. Chapter 2.0 presents an investigation into the control of vibration of a secondary system, excited by vibrations from the primary system on which it is mounted. An example is the installation of equipment (secondary system) within a building (the primary system). The effect of mounting a vibration absorber onto the secondary system is discussed, and conclusions about its effectiveness are made. The equations of motion for the resultant three DOF system are written into a spreadsheet program and solutions for different input parameters were generated. A paper, presenting this investigation, has been accepted for publication [Van Berkel and Semercigil 1991]. Chapter 3.0 takes the system researched in Chapter 2.0 and examines the effect of adding an impact damper to the vibration absorber. The purpose of this addition is to possibly enhance the characteristics of the conventional absorber. The system of equations requires numerical solution using integration and iteration methods. The results are plotted for varying system parameters to illustrate the basis of potential future investigations. The majority of the effort for this thesis was spent on preparing the spreadsheet programs as (computer-aided) design tools. These tools were then used to investigate the vibration control techniques mentioned. Therefore, a full spectrum of all possible variations of the system parameters was not the primary intention of this work. However, useful conclusions were drawn from the parameters investigated.

The two spreadsheet program packages used to generate and manipulate the data are presented in Users Manuals included as Appendices A and B to this thesis. The intention is that the programs be used to further the investigations presented in the main body. Within these manuals reference is made to some of the information or figures contained within the main body. This has been done to reduce repetition although some is inevitable.

Other appendices include information pertaining to both the vibration control investigations and the User Manuals. Several of these would be included as appendices to the User Manuals when they are published as "stand alone" documents. Reference is made to them as required. Of primary interest is Appendix C, which contains several spreadsheet programming formats and techniques used in the programs.

Throughout this thesis reference is made to terminology assuming that the reader is familiar with using computer spreadsheet programs. However, it should be stressed that only a basic understanding of spreadsheets is assumed. The reader is directed to the references for training and further instruction if required [LOTUS 1985].

CHAPTER 2.0

TUNED VIBRATION ABSORBER FOR SECONDARY STRUCTURES

2.1 INTRODUCTION

A tuned vibration absorber is a classical method for passively controlling the vibrations of light structures subjected to dynamic loads close to their resonant frequencies. The absorber, when tuned to the frequency of operation, counteracts the excitation at the tuning frequency. However, the absorber adds a new DOF to the combined system. The new frequency response characteristics may contain resonance frequencies with large amplitudes on either side of the original resonance frequency. To control these peaks damping can be introduced to the absorber system. The compromise is that the more damping is used to control the peaks of the combined system the less attenuation there is at the tuning frequency [Hunt, 1979]. The techniques are well documented when the system to be controlled is a SDOF. This study evaluates the use of a tuned vibration absorber to control the excessive vibrations of light secondary systems.

The term secondary system is used to describe a small structure mounted on a larger primary structure (or system). Therefore, the response of the secondary system is largely dependant on the response of the primary system. Examples of this situation might be a nuclear power plant as the primary structure supporting other small, secondary, components such as pieces of equipment or piping. Secondary components like gears, pulleys, motors etc. mounted resiliently on a transmission shaft, where the shaft is excited due to its own unbalance and flexibility, constitute similar configurations. Another example may arise from transporting delicate components in a trailer truck in which the truck is the primary system excited by the irregularities of the road. The primary structure would be excited, perhaps by an earthquake in the case of a building, and would in turn excite the light secondary structures within it.

There has been a reasonable amount of investigation into the response of secondary systems in the literature [Hunt 1979], [Hernried and Sackman 1984], [Schriver and Heidebrecht 1989], [Chen and Soong 1988], [Kelly and Tsai 1985]. Similarly, significant work has been undertaken with both the linear and non-linear type of tuned absorbers attached to resonant (primary) structures [Seto and Takita 1987], [Seto 1987], [Ebrahimi 1988]. Seto and Takita suggest a technique for controlling the response of a MDOF primary system by using several tuned dynamic absorbers for each DOF of the system. They are attempting to control each coordinate individually by designing an absorber specifically for it. The combined primary and secondary systems discussed in this study would be considered their primary system and their procedure would attempt to control both DOF by the addition of absorbers. This study takes the simpler approach of accepting the fact that the primary structure and its excitation already exist. The primary system's dynamic response to the excitation, in turn excites the secondary system which should be protected by using the tuned vibration absorber. In many cases, it would be impractical to control the motion of an entire building to protect a secondary structure within it.

2.2 SYSTEM

The system considered in this study is shown in Figure 2.1. The primary system is a SDOF oscillator consisting of a mass mounted on a spring and damper in parallel. A sinusoidal external force is considered to act on the mass. The mass will oscillate with great amplitude when the excitation frequency is near or at the natural frequency of the system. The secondary system is modelled as another SDOF oscillator attached to the first or primary. The ratios between the primary and secondary masses and the critical damping ratios are chosen to be 200:1 ($m_1:m_2$) and 0.01 (Z_1) and 0.01 (Z_2), respectively, to represent a shear building and a light equipment system [Hernreid and Sackman 1984].

The vibration absorber is modelled as a SDOF oscillator mounted on the secondary system. The mass ratio between the absorber and the secondary system is chosen to be 10:1 ($m_2:m_3$) in order not to disturb the existing structure significantly. The results of some numerical experiments are presented in this study to investigate the effectiveness of the absorber in reducing the displacement amplitude of the secondary system.

2.3 EQUATIONS OF MOTION

The equations of motion of the three DOF system shown in Figure 2.1 may be written as

(2.1) $$m1 \frac{d^2x_1}{dt^2} + (c_1+c_2) \frac{dx_1}{dt} + (k_1+k_2)\ x_1 - c_2 \frac{dx_2}{dt} - k_2x_2 = F_0 \sin Wt$$

(2.2) $$m_2 \frac{d^2x_2}{dt^2} + (c_3+c_2) \frac{dx_2}{dt} + (k_3+k_2)\ x_2 - c_3 \frac{dx_3}{dt} - k_3x_3 - c_2 \frac{dx_1}{dt} - k_2x_1 = 0$$

(2.3) $$m_3 \frac{d^2x_3}{dt^2} + c_3 \frac{dx_3}{dt} + k_3x_3 - k_3x_2 - c_3 \frac{dx_2}{dt} = 0$$

The expected solution in the steady state can be obtained by assuming that

(2.4) $$x_i(t) = \bar{x}_i \sin Wt \qquad i = 1,2,3$$

where the complex amplitude $\bar{x}_i$ also contains the phase difference due to the presence of damping. The amplitude, $|x_i|$ and the phase difference, phi_i, may be obtained from

(2.5) $$|\bar{x}_i| = [\ [Im(\bar{x}_i)]^2 + [Re(\bar{x}_i)]^2\ ]^{1/2}$$

and

(2.6) $$phi_i = \tan^{-1}\ [Im(x_i)/Re(x_i)]$$

where abbreviations Re and Im indicate the real and imaginary components of the complex $\bar{x}_j$. The solutions to these equations are presented in Appendix D.

2.4 INVESTIGATION METHOD

The expressions for the transfer functions given in Appendix D were evaluated for different system parameters, to produce the steady state displacement spectrum of the system's coordinates for different frequencies of excitation. This was done by designing a spreadsheet program which solved the equations for one forcing frequency at a time. Then a spreadsheet data table function generated the mass displacements and phase angles over the spectrum of forcing frequencies which covered the natural frequencies of all three systems.

To check and verify both the solution and the spreadsheet program, the masses were combined with different spring and damping values so that the system as a whole would emulate either a single or two DOF system for which solutions are available. By increasing spring and damping rates the individual masses can be made to act with very little relative motion as virtually a single mass. In addition, any mass can be reduced almost to zero. Reducing the upper two masses to about 0.1% of the total mass and using spring constants approximately 100 orders of magnitude larger than the base spring, duplicates the results of a program specifically written for a single DOF system within less than 0.05% error. There are finite limits to these numerical manipulations since the numerical process will not allow division by zero and division by a very small value or multiplication by a large value will cause numeric overflow.

Two different parameters of the secondary system were calculated from the displacement spectra. The first parameter, the RMS amplitude of the displacement, represented the average response of the secondary system to an equivalent random white noise excitation. A macro within the primary program was used to determine the RMS displacement amplitude. A description of how this was determined is given in Appendix E. The second parameter, the spectral peak amplitude, on the other hand is the response of the secondary system to a frequency sweep type of excitation. Such excitation may be encountered during the start-up of a (primary) machinery structure. It should be noted that the rate of the frequency sweep is assumed to be relatively slow, since the spectral peak amplitude at any frequency neglects the effect of the transient contribution to the solution.

Batches of different model variables parameters were run utilizing a macro which allowed "unattended" operation and generation of graphs and data bases. The displacement and phase relationships of the masses for each set of input variables were saved as spreadsheet graph files. Graph files can be printed and reviewed without accessing the spreadsheet program that generated them. Therefore, the results of numerous different model runs could be plotted, ready for analysis, without requiring significant preparation by the researcher. Information regarding RMS and peak displacements was extracted from each model database by utilizing a separate compiling program. A complete explanation and listing of the programs is given in the User Manual (Appendix A).

To determine which systems would present the most critical vibration situations that had to be controlled with a tuned vibration absorber, case runs were made for the uncontrolled two DOF system (with the third mass reduced to a minimal amount and stiffly held to the second mass). Solutions were generated with the ratio of the resonant frequency of m_1 to m_2 (W_1:W_2) at values of 0.2, 0.5, 1, 2 and 5. This resonant frequency ratio was treated as the excitation parameter.

Further investigation involved the affect of the addition of the absorber. The system parameters were considered to be the stiffness and damping of the absorber. The mass was held constant at the ratio m_2:m_3 equals 10:1. By selecting the appropriate stiffness, k_3, the absorber could be tuned to any one of the two resonant frequencies of the two DOF system. This results in a displacement versus frequency plot with three peaks due to the addition of the absorber. The second absorber parameter, the critical damping of the absorber, Z_3, was varied over the spectrum of 0.1%, 1.0%, 10%, 30%, 60% and 100%. The effectiveness of the absorber was determined from how much smaller, if at all, the RMS amplitude and spectral peak amplitude became after the introduction of the absorber. Through the investigation, the forcing amplitude, F_0, was kept constant.

2.5 RESULTS

It was determined that at the resonant frequency ratios 0.2 and 5, the response of the primary and secondary systems at their respective resonance frequencies was as a SDOF system; the resonance zones were too far apart to interact. Given the premise of investigating control of the vibration of a secondary system when subjected to excitation by a primary system, these ratios were not fully investigated. Initially therefore, the interim excitation parameters ratios of 0.5, 1 and 2 were used. Results of the initial computations are presented in Figures 2.2 (a), (b) & (c) and 2.3 (a), (b) & (c). In these figures, different values of the critical damping ratio, Z_3, are shown in the horizontal axis. The vertical axis represents the ratio of the two performance parameters, x/x_0, where x and x_0 are the response of the secondary system with and without the absorber, respectively. Hence, any value of x/x_0 smaller than unity represents attenuation of the response of the secondary system due to the presence of the absorber. The excitation parameter (the ratio of the natural frequencies of the primary to the secondary systems), W_1/W_2, varies from 0.5 to 2.0 from the top row to the bottom row. The results presented in Figure 2.2 versus Figure 2.3 correspond to the absorber being tuned to the first and second natural frequency of the (uncontrolled) two DOF system, respectively.

Figures 2.2 (b) and 2.3 (b) show attenuations of both the RMS and the spectral peak response of the secondary system of about 80% where the natural frequency of the primary system coincided with that of the secondary system (W_1/W_2 = 1.0). Where the two frequencies are different, attenuation is much less, varying from only 10% to 50%. However, this relative ineffectiveness of the absorber for cases other than W_1/W_2 = 1.0 does not pose a problem practically, since control is hardly needed for these other cases. The RMS and peak response of the uncontrolled secondary system is shown in Figure 2.4 for the W_1/W_2 values of 0.2, 0.5, 1.0, 2.0 and 5.0. Owing to the relatively light damping ratio of the secondary system, its response is significantly smaller when there is a difference between the natural frequencies of the primary system (excitation) and the secondary system.

Having established that the critical excitation parameter is when $W_1 = W_2$, a more detailed investigation was performed at this excitation by varying the tuning ratio of the absorber, W_3/W_2 , over the range of 0.5 to 1.5. The reduction ratio , x/x_0 is shown in Figures 2.5 (a) through (e) for five selective cases of W_3/W_2 = 0.5, 0.8, 1.0, 1.2 and 1.5. In addition, part of the information in Figure 2.5 is compiled in Figure 2.6 for a constant Z_3 of 0.10. This value of Z_3, appears to offer the highest attenuation overall, producing attenuations in the order of 80% provided that the tuning frequency is within the range from 0.93 to 1.08. This feature is quite significant practically, as it demonstrates that the absorber's performance is not a very strong function of its tuning.

The displacement spectra of the system's coordinates corresponding to the cases presented in Figure 2.5, are presented in Figures 2.7 (a) through (e) for W_3/W_2 = 0.5, 0.8, 1.0, 1.2 and 1.5, respectively. In addition, the response of the uncontrolled two DOF is shown in Figure 2.7 (f). Without the absorber, the secondary system behaves like a classical vibration absorber tuned at the natural frequency of the primary system. This tuning, of course attenuates the response of the primary system at the expense of producing very large displacements in the secondary system. As demonstrated for different values of W_3/W_2 in Figure 2.7, these large displacements may be controlled most effectively when $W_3 = W_2$ (or $W_3 = W_1$ for this case). As expected, effective attenuation of the secondary system coincides with large displacement amplitudes of the absorber system. In addition, controlled amplitudes of the secondary system result in the de-tuning of the secondary system as an absorber to the primary system. The primary system is no longer affected by the presence of the secondary system and it exhibits a behaviour much like an independent SDOF system due to the relatively large mass ratio between m_1 and m_2.

2.6 CONCLUSIONS

The tuned vibration absorber is found to be quite effective in attenuating the dynamic response of a light secondary system for the critical case when the resonance frequencies of the secondary and the primary structures coincide. Attenuation in the order of 80% may be obtained with a relatively small absorber whose mass is 10 times smaller than the secondary system's, when the mass of the secondary system is 200 times smaller than that of the primary system. Hence, building-equipment types of systems where the secondary system is significantly smaller than the primary system may benefit from the suggested absorber.

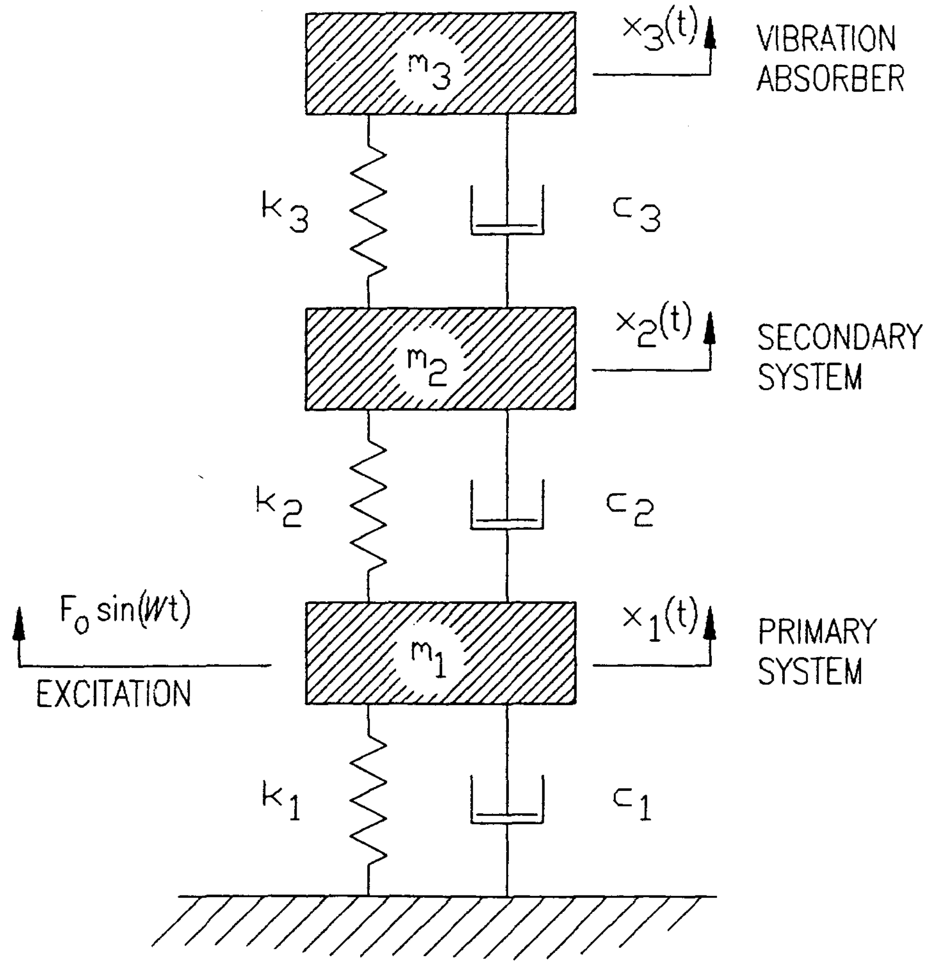

FIGURE 2.1: 3 DOF spring/mass/damper system with the absorber

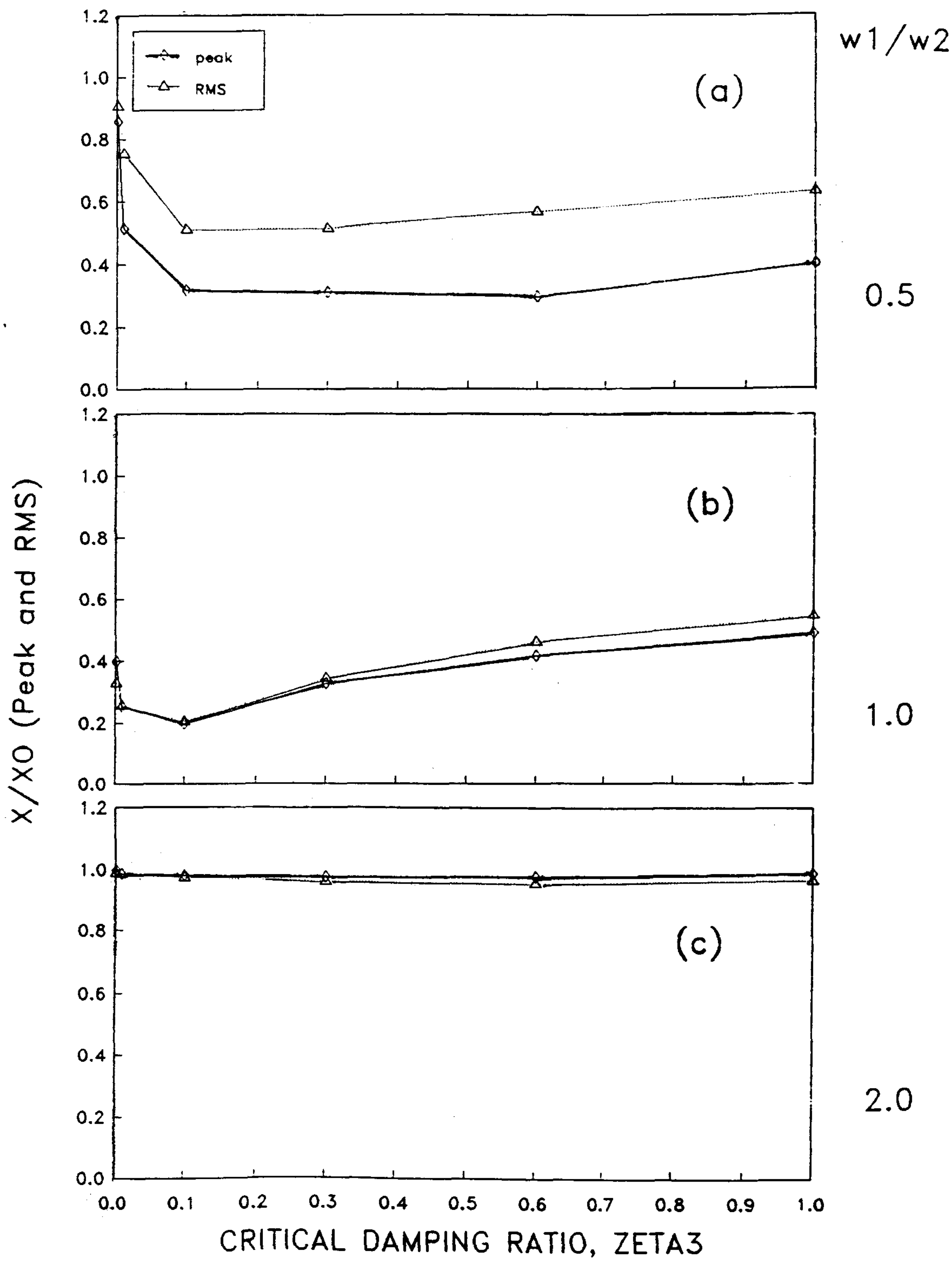

FIGURE 2.2: Variation of the displacement reduction ratio with the critical damping ratio of the absorber with the absorber tuned to the first resonance frequency: $W_1 : W_2$ = (a) 0.5, (b) 1.0, (c) 2.0.

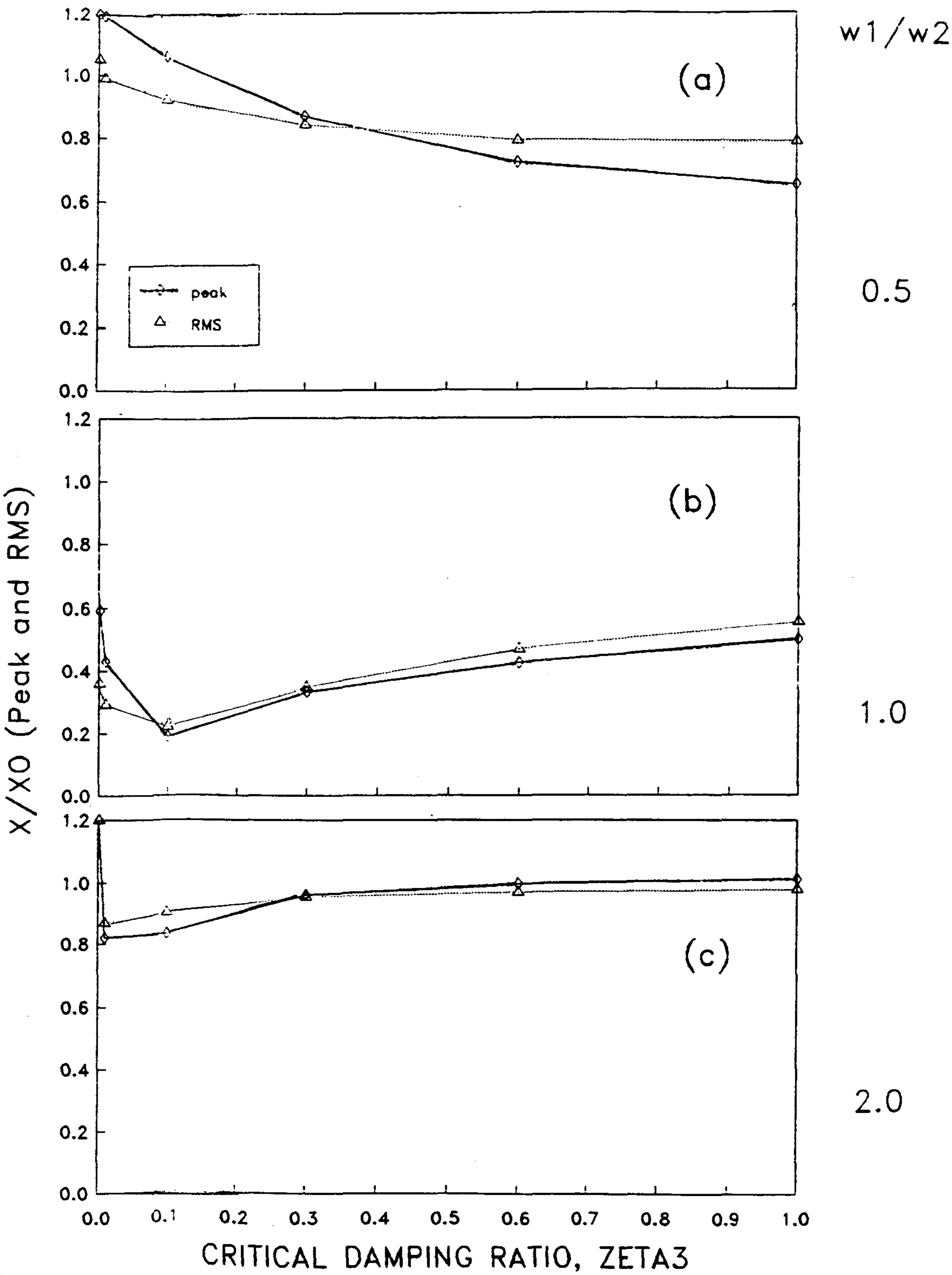

FIGURE 2.3: Variation of the displacement reduction ratio with the critical damping ratio of the absorber with the absorber tuned to the second resonance frequency: $W_1:W_2$ = (a) 0.5, (b) 1.0, (c) 2.0.

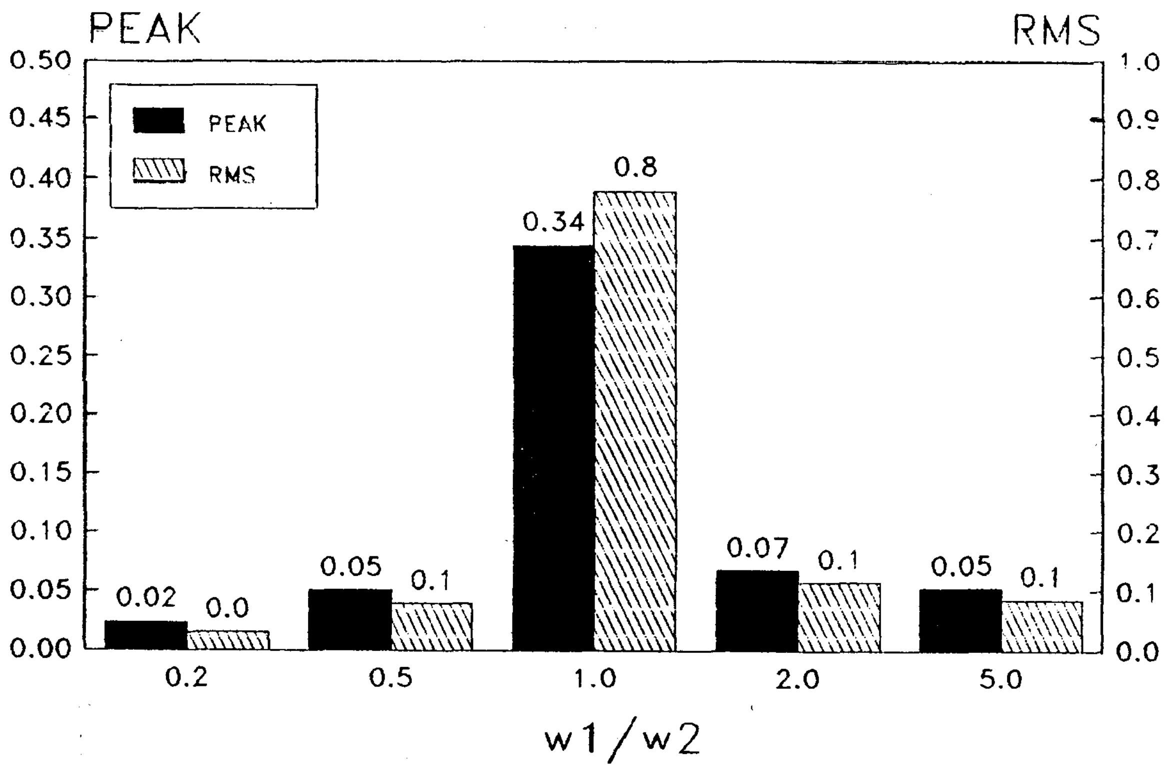

FIGURE 2.4: Uncontrolled secondary system response

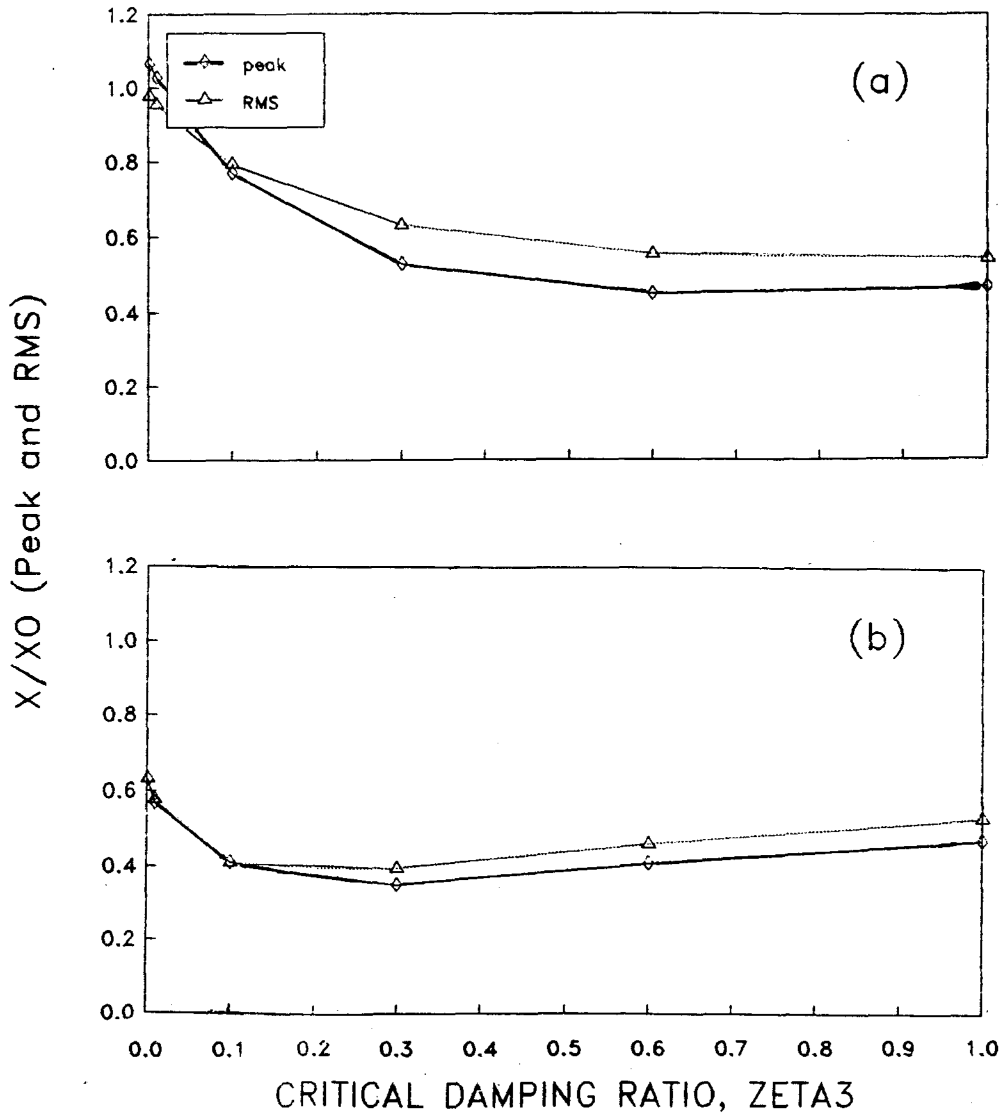

FIGURE 2.5: Variation of the displacement reduction ratio with the critical damping ration of the absorber for $W_1 = W_2$ and $W_3 =$ (a) 0.5 W_2, (b) 0.8 W_2, (c) 1.0 W_2, (d) 1.2 W_2, (e) 1.5 W_2.

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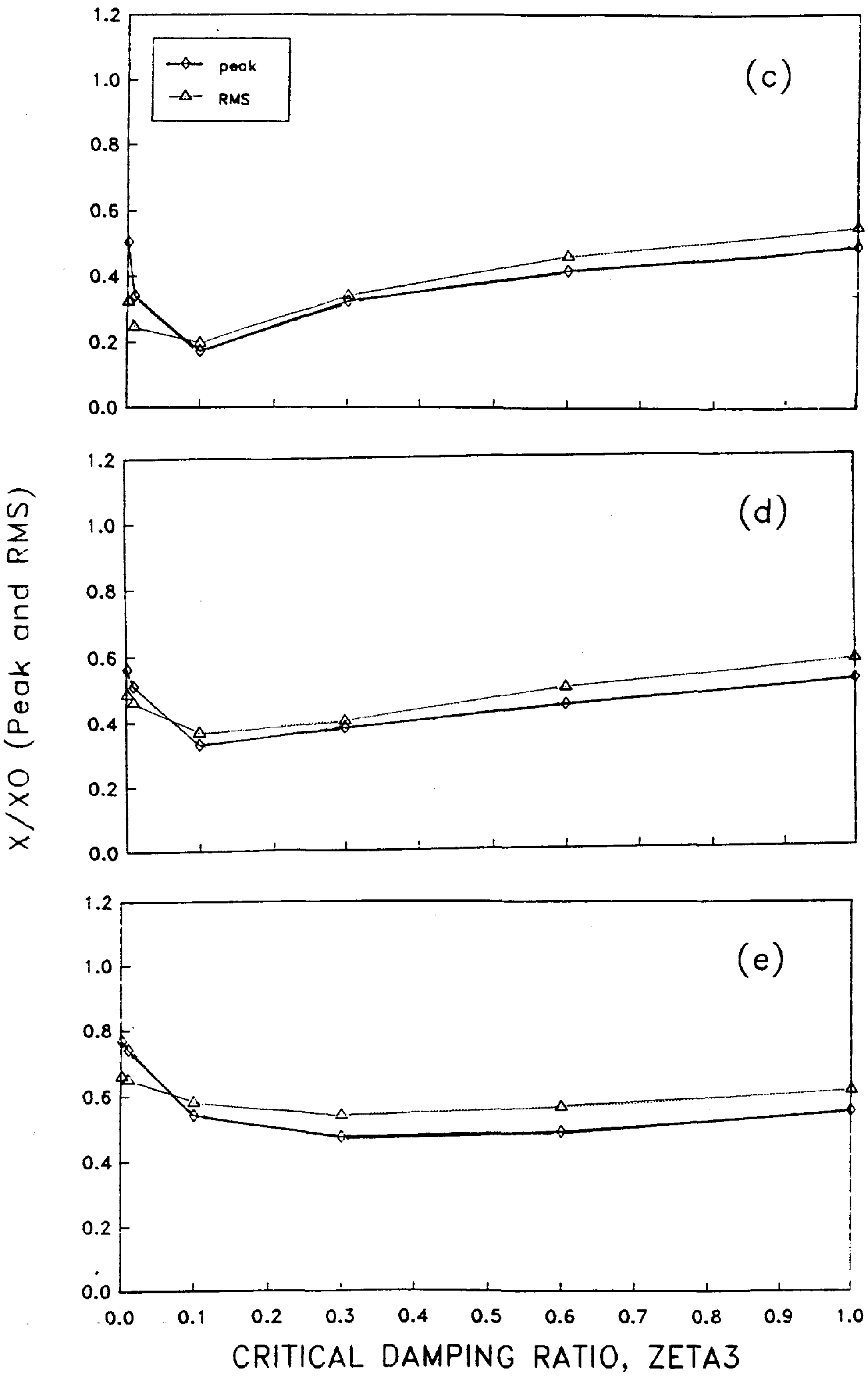

FIGURE 2.5: (continued from previous page)

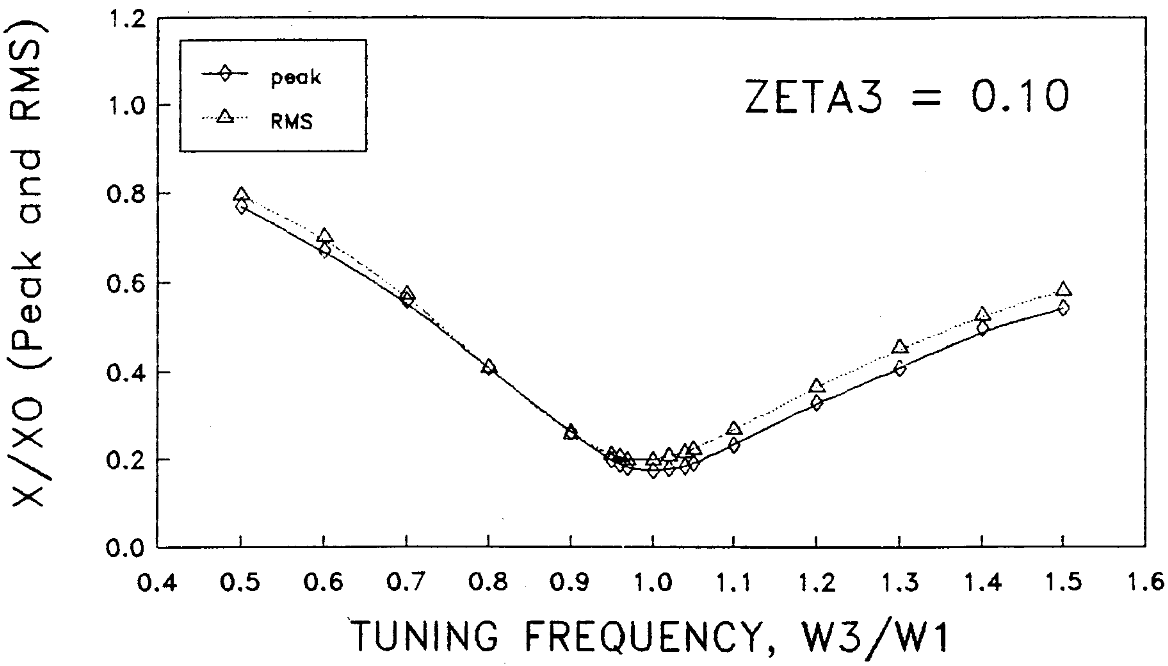

Figure 2.6: Variation of the displacement reduction ratio with the tuning ratio of the absorber but for a constant Z_3 = 0.10

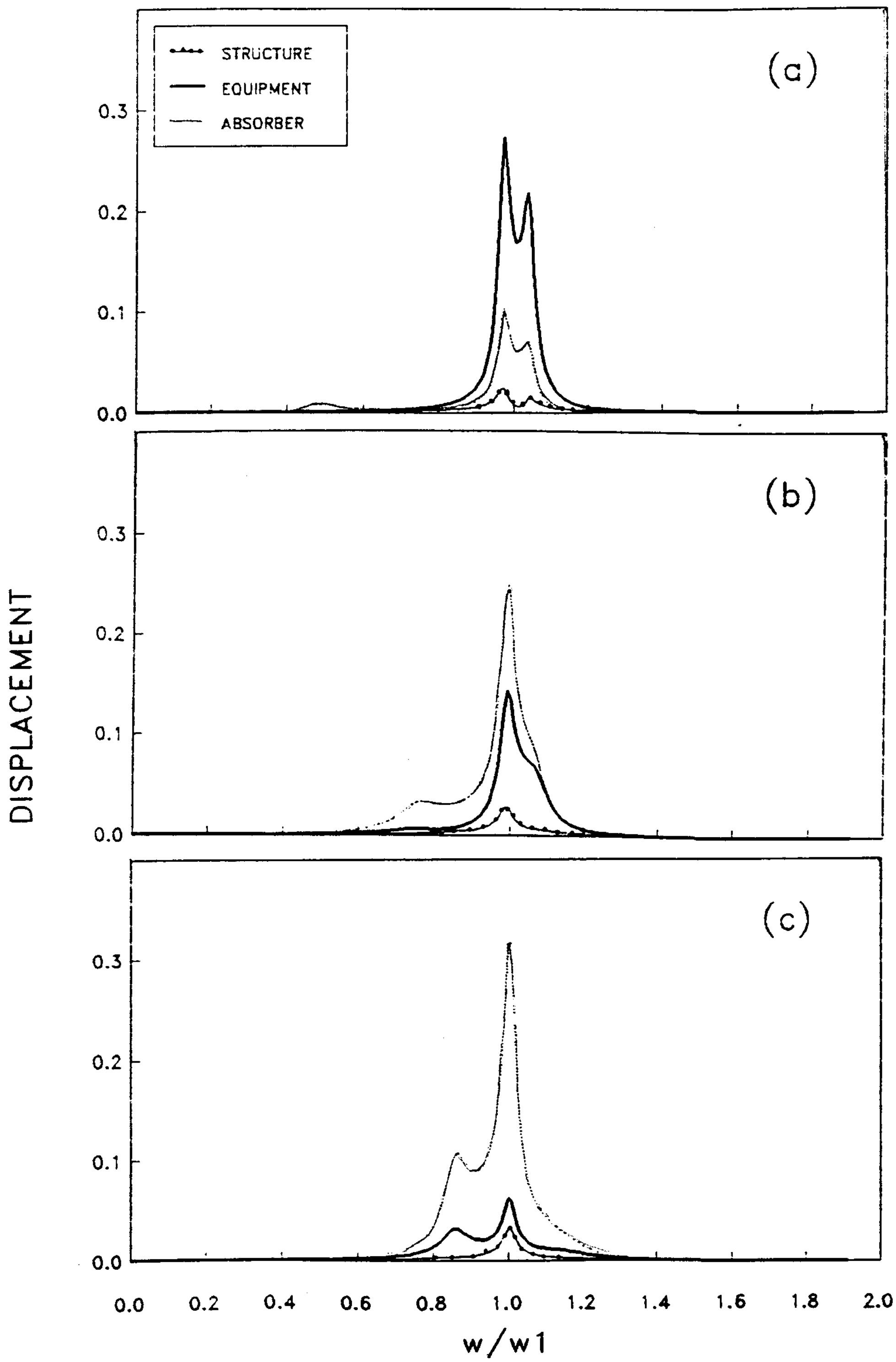

Figure 2.7: Displacement spectra of the three DOF system for constant Z_3 = 0.10, for constant $W_1 = W_2$ and W_3 = (a) 0.5 W_2, (b) 0.8 W_2, (c) 1.0 W_2, (d) 1.2 W_2, (e) 1.5 W_2. (f) Displacement spectra for uncontrolled two DOF system. (continued)

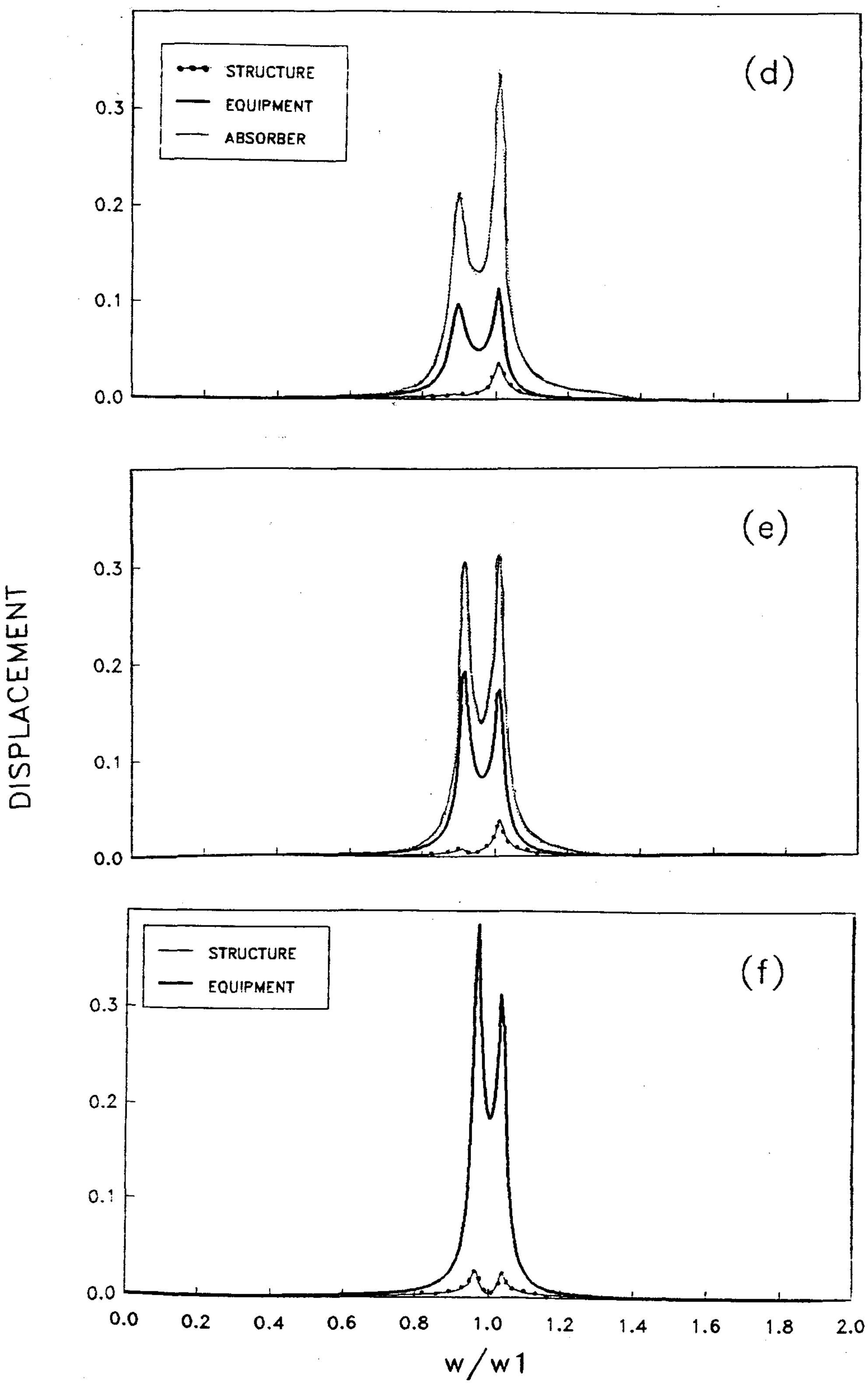

Figure 2.7: (continued from previous page)

CHAPTER 3.0

THE ADDITION OF AN IMPACT DAMPER TO A TUNED VIBRATION ABSORBER FOR SECONDARY STRUCTURES

3.1 INTRODUCTION

In Chapter 2.0, investigations into controlling the vibrations of light secondary systems with a passive tuned vibration absorber were discussed. Significant attenuation in the order of 80% may be obtained in the vibration amplitudes of the secondary structure at the tuning frequency (the resonant frequency of the secondary mass). However, as with an absorber mounted on a primary system, there are two new resonance peaks created for the secondary mass, one on either side of the original resonance frequency.

Another passive vibration control device, often used on lightly damped resonant systems, is the impact damper. This is a small rigid mass, free to move within the confines of a container rigidly attached to another primary mass. The impact damper is slightly smaller than the container within which it is confined which leaves a clearance. As the primary mass displacement exceeds the clearance, the impact damper starts to collide with the walls of its container. As a result of a collision, there is a momentum transfer between the damper and the primary mass. With proper selection of the clearances within the container; the mass; resilience of the impactor, these impact dampers can reduce the maximum displacement amplitudes of the primary mass

[Masri and Ibrahim 1973], [Popplewell, Bapat and McLachlan 1983], [Bapat and Sankar 1985]. These parameters are derived both by computer modelling and experimentation. Successful application of impact dampers include controlling the excessive vibrations of turbine blades [Paget 1937], printed circuit boards [Steinberg 1977] and machine tools [Hunt 1979]. Previous work has shown that effective vibration control, near the resonant frequencies, can be obtained with an impact mass of about 20% of the primary mass [Bapat and Sankar 1985]. These studies were for a SDOF oscillator around its resonance frequency.

Investigations have been undertaken on combining the impact damper with the vibration absorber to control the excessive resonant vibrations of a SDOF primary system [Semercigil, Lammers and Ying 1991]. The absorber is added to the primary system to control the excessive vibrations of the primary system. The impact damper, mounted on the absorber, attenuates the resonance peaks of the primary mass caused by the absorber. Two advantages are claimed for this indirect application of the impact damper rather than simply replacing the absorber with an impact damper. First, isolating the impact damper on the absorber should allow its weight to be reduced to a percentage of the absorber mass. Instead of being 20% of the primary system mass if it were used in place of the absorber, the impact damper is 20% of the absorber mass. If the absorber's mass is 10% of the primary mass, the impact damper need only be an additional 2%. Secondly, the main mass is isolated from the collision discontinuities. Research to date shows promising results for lowering the resonance peak amplitudes on either side of the tuning frequency. Significant attenuations, in the order of 85% to 90%, are obtained as compared to the response of using only the absorber. This attenuation of the displacement of the primary resonant system occurs over approximately the whole frequency range.

An extension of this work is determining what affect there might be if the external excitation was transmitted through yet another, third mass. The primary system would be subjected to dynamic excitation. The secondary system is a small structure, mounted on a larger primary structure and it is the system to be protected. The response of the secondary system is largely dependant on the response of the primary system. The secondary system would have a combination vibration absorber and impact damper mounted on it. The configuration would be as shown in Figure 3.1. A practical application is the installation of equipment within a building. The building might be subjected to excitation such as an earthquake. The movement of the building is unavoidable (or beyond the scope of mechanical engineering) for a situation such as this. Therefore, no attempt is made to control the motion of the structure. The function of the absorber and impact damper is to protect the equipment.

This study initiates an investigation into a probable situation and whether such an approach might warrant further investigation. The results of some numerical investigations are presented in this chapter. These are compared to the results attainable with optimal damping of the absorber discussed earlier in Chapter 2.0 as well as other methods of utilizing the additional mass required for the impact damper.

3.2 SYSTEM

The system considered in this study is shown in Figure 3.1. The first three components are the same as described in Chapter 2.0 but the information is repeated here for completeness. The primary system is a SDOF oscillator, consisting of a mass mounted on a spring and damper in parallel. An external excitation force is considered to act on this mass. The mass will resonate when the excitation frequency is near or at the natural frequency of the system. The secondary system is a second SDOF oscillator attached to the first or primary. The ratios between the primary and secondary masses and the critical damping ratios are chosen to be 200:1 (m_1:m_2) and 0.01 (Z_1) and 0.01 (Z_2), respectively to represent a shear building and a light equipment system [Hernried and Sackman 1984].

The vibration absorber is modelled as a SDOF oscillator mounted on the secondary system. The mass ratio between the absorber and the secondary system is chosen to be 10:1 (m_2:m_3) in order not to disturb the secondary system significantly. Mounted on the absorber is an impact damper. The mass ratio between the damper and the absorber has been chosen to be a small but reasonable ratio of 10:1 (m_3:m_4). The combined additional mass ($m_3 + m_4$) in this case is therefore 11% of the secondary system's mass. This figure is assumed to be reasonable since the protection is required due to external excitation of the primary structure; the overall incidence of such an occurrence would normally be infrequent[1] and not warrant significant alterations to the secondary

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1 For example, an earthquake.

system design. This amount of mass (11%) could likely be added to the secondary system without any significant modification.

The investigation discussed in Chapter 2.0 concluded that the most critical case, for a two DOF system, is with the equipment, or secondary system, tuned to the excitation or natural frequency of the structure (primary system), that is $W_1/W_2 = 1.0$ where

(3.1) $$W_1^2 = k_1/m_1$$

(3.2) $$W_2^2 = k_2/m_2$$

Figure 3.2 gives the displacement and phase angle relationship of this two DOF system. It can be seen that, to a certain extent, the equipment acts as a classical tuned absorber with respect to the structure due to the tuning of $W_1 = W_2$. This relationship of the primary and secondary systems is an excitation parameter of the secondary system, and is held constant for these numerical experiments.

The addition of the absorber (third DOF), tuned to natural frequency of the primary system ($W_1/W_3 = 1.0$), attenuates the response of the equipment significantly at the tuning frequency. But as Figure 3.3 shows, new resonance peaks for x_2 are created, in this case at forcing frequencies of approximately 0.85 and 1.175. It is the use of the impact damper to control these resonant displacement peaks that this investigation is undertaken. The absorber also has peaks at these two frequencies, as well as at the natural frequency of the equipment (and the primary system). Figure 3.4 contains the same spectra as Figure 3.3, but the frequency range has been narrowed to between 0.8 and 1.2 where the most significant contribution to the displacement response occurs[2].

The previous work with an impact damper mounted on a two DOF system, indicates that a coefficient of restitution of 0.3 was optimal [Semercigil, Lammers and Ying 1991]. Initially, therefore, this is the value used. This is the characteristic value for a collision between smooth surfaces of hard rubber and metal.

The value of the clearance, d, is considered to be a variable system parameter in this investigation. Within the frequency range between 0.8 and 1.2, the peak steady state vibration amplitude of x_3 varies from approximately 0.05 to 0.48 displacement units. Initially, values for $d/(F_0/k_1)$ from 20 up to 450 were considered where F_0/k_1 represents the static deflection of the primary system. As would be expected, because m_4 is considered to be suspended (frictionless) and the initial values for x_4 and v_4 were always set to zero, the larger values of d only came into play at the peaks. Furthermore, steady state displacements could not be reached because these clearances were too large to maintain a uniform pattern of collisions. This was suggested in the work by Semercigil [ibid] and is discussed in more detail later. Small values of d almost immediately resulted in chatter and intermittent carrying of the damper against the walls of the absorber. Again, carrying will be discussed later in this chapter. As a result of the small clearance, the momentum transfer between m_3 and m_4 during collisions was inadequate to change the motion of x_3 significantly. In fact, taken to the extreme, if $d/(F_0/k_1)$ equals 0.0, it was as if the

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2 The RMS value over the frequency range from 0.8 to 1.2 is 98% of the RMS value obtained in Chapter 2.0 for the full frequency range from 0 to 1.6.

absorber has a mass of 11% m_2 (rather than 10%) and there was no impact damper. Comparisons of this nature are presented later. A set of five values of $d/(F_0/k_1)$ between 100 and 300 were finally chosen for analysis because they sustained impacts over a significant portion of the frequency range. The relationship of these clearances, to the displacement of x_3 for the non-impact damper model, is shown in Figure 3.5. The horizontal lines in the figure represent the initial position of either wall of the container, relative to the initial position of both m_3 and m_4. If the steady state amplitude of x_4 does not exceed the wall position (half the clearance), m_4 will just oscillate within its containment, without impacts. The clearance of $d/(F_0/k_1) = 100$ resulted in impacts over the entire frequency spectrum, while a clearance of $d/(F_0/k_1) = 300$ only comes into play at the two major peaks.

3.3 EQUATIONS OF MOTION

From Chapter 2.0, the equations of motion of the three DOF system without the impact damper may be written as

$$(3.3)\quad m_1 \frac{d^2x_1}{dt^2} + (c_1+c_2)\frac{dx_1}{dt} + (k_1+k_2)\,x_1 - c_2\frac{dx_2}{dt} - k_2x_2 = F_0\sin\omega t$$

$$(3.4)\quad m_2 \frac{d^2x_2}{dt^2} + (c_3+c_2)\frac{dx_2}{dt} + (k_3+k_2)\,x_2 - c_3\frac{dx_3}{dt} - k_3x_3 - c_2\frac{dx_1}{dt} - k_2x_1 = 0$$

$$(3.5)\quad m_{3E}\frac{d^2x_3}{dt^2} + c_3\frac{dx_3}{dt} + k_3x_3 - k_3x_2 - c_3\frac{dx_2}{dt} = 0$$

The equation for the motion of the impact damper between collisions is,

$$(3.6)\quad m_4\frac{d^2x_4}{dt^2} = 0$$

since it is free from all external forces.

The velocities of m_3 and m_4 before and after a collision, can be related by considering a collision between the two masses as an instantaneous but discontinuous process governed by the conservation of linear momentum and by using the concept of coefficient of restitution

[Bapat and Sankar 1985]. This gives,

$$\frac{dx_{3+}}{dt} = \frac{(1 + mu\ e)}{(1 + mu)} \frac{dx_{3-}}{dt} + \frac{mu(1 + e)}{(1 + mu)} \frac{dx_{4-}}{dt} \tag{3.7}$$

and

$$\frac{dx_{4+}}{dt} = \frac{(1 + e)}{(1 + mu)} \frac{dx_{3-}}{dt} + \frac{(mu + e)}{(1 + mu)} \frac{dx_{4-}}{dt} \tag{3.8}$$

where mu is the mass ratio (m_4/m_3) and e is the coefficient of restitution

$$e = \frac{\dfrac{dx_{4+}}{dt} - \dfrac{dx_{3+}}{dt}}{\dfrac{dx_{4-}}{dt} - \dfrac{dx_{3-}}{dt}} \tag{3.9}$$

Subscripts - and + indicate the conditions immediately before and after an impact, respectively.

3.4 SOLUTION METHOD

Because of the discontinuities introduced by the collisions of the impact damper with the absorber, a closed form solution of the steady state amplitudes can not be derived. Rather, a numerical simulation of the problem is required. Equations (3.3), (3.4), (3.5) and (3.6) are integrated by using a fourth order Runge-Kunta procedure [Rao 1986] until a contact between m_4 and the boundaries of its containment is found. Because the integration normally progresses with fixed time steps, it is necessary to use a variable time step to accurately locate the point of collision. A bisection iteration routine [Hornbeck 1975] is invoked to locate the instant of contact. The time step is reduced until the position of the mass, x_4, relative to the boundary is within one millionth of the total clearance, d. Once this criteria has been reached, the collision is considered to have occurred at that instant. When an impact is found, the velocities of m_3 and m_4 are modified according to equations (3.7) and (3.8). The displacements of the masses, as well as the velocities of the primary and secondary systems remain the same because the impact is considered to take place instantaneously. The integration of the equations (3.3), (3.4), (3.5) and (3.6) resumes with the new velocities from the point of contact. The effect of these different velocities is felt indirectly by m_1 and m_2 over time through the spring and damper of the absorber.

The result of each collision of m_3 and m_4 is that their relative velocity is reversed. A system well-suited to control by a properly designed impact damper, would normally have each subsequent collision occur with the opposite wall [Popplewell, Bapat and McLachlan 1983], [Bapat and Sankar 1985]. The displacement and velocity of an impact damper for such a system is shown in Figure 3.6[3]. The displacement, x_3, is shown as the position of the containment walls which bound the displacement of the impact damper, x_4. The absolute velocity of the impact damper, at steady state, alternates in direction after each impact.

For many system parameters, however, the driving force of m_1 can cause m_3 to quickly overtake m_4, resulting in a second collision with the impact damper on the same side. Because this subsequent collision usually occurs with a smaller relative velocity between the two masses, often the momentum transfer is not significant and m_4 will not achieve a high enough separation velocity to increase the relative distance between the two masses. This can result in multiple consecutive collisions on the same side, each one closer in time to the last. This phenomenon is known as chatter and is recognizable experimentally.

Sometimes the integration procedure described in this section effectively stops due to too small a time step between consecutive impacts. Figure 3.7 plots the displacement and velocity history of such a situation[4]. Again, the displacement of x_3 is represented by the position of the impact damper container which bounds the damper. In physical terms, continual chatter is the impact damper being held against one wall of the container; due to the lack of relative velocity,

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3 $F_0 = 1.0$, $m_1 = 1000$, $m_1/m_2 = 200$, $m_2/m_3 = 10$, $m_3/m_4 = 10$, $W_1 = W_2 = W_3 = 1.0$, $Z_1 = Z_2 = Z_3 = 1\%$, $d/(F_0/k_1) = 150$, $e = 0.3$, $W_f/W_1 = 0.85$

4 $F_0 = 1.0$, $m_1 = 1000$, $m_1/m_2 = 200$, $m_2/m_3 = 10$, $m_3/m_4 = 10$, $W_1 = W_2 = W_3 = 1.0$, $Z_1 = Z_2 = Z_3 = 1\%$, $d/(F_0/k_1) = 100$, $e = 0.3$, $W_f/W_1 = 1.0$

the two masses move together for a certain duration. However, the equations of motion (3.3) through (3.9) can not simulate this situation and so the conventional numerical model fails to simulate a collision. This is a deficiency of having modelled the collisions as instantaneous phenomena. A similar situation, called carrying, is discussed by Dalrymple for a SDOF system [Dalrymple 1989]. His investigations included only the gravitational effects. The damper mass was considered to move in contact with its container, to be carrying, when the acceleration was less than gravity. Investigations by Semercigil on MDOF systems omitted situations which exhibited continual chatter [Semercigil, Lammers and Ying 1991].

To overcome this chatter/carry situation, since movement of the physical model can not in fact cease, it was necessary to devise an alternative approach. Hence, the equations of motion are altered slightly. After a number of same side impacts, as Figure 3.7 (b) shows, the velocities of m_3 and m_4 are essentially equal. The exact number of impacts required to achieve this can vary, but a maximum or upset number of impacts after which the velocities are nearly equal can be determined. In this study a value of eight impacts was used. At this point, mass m_3 is assumed to carry (push) m_4 rather than collide with it. Hence, the following conditions are effective,

(3.10) $$m_{3E} = m_{3A} + m_{4A}$$

(3.11) $$\frac{dx_{4+}}{dt} = \frac{dx_{3+}}{dt} = \frac{dx_{3-}}{dt}$$

Again, subscripts - and + indicate the conditions immediately before and after the last impact, respectively. Subscript A indicates the actual mass of the components and subscript E indicates the effective mass. Integration continues as before, but the value used for m_3 in the equation (3.5) is m_{3E}. The motion of the model is as if the absorber is, in this case, 11% of m_2 rather than 10%. Because contact is continuous, equations (3.7), (3.8) and (3.9) are not considered. Furthermore, equation (3.6) is overridden by equation (3.11). This configuration of the masses is integrated until the deceleration of m_3 is detected. Since m_4 is held in position against m_3 only by its own inertia, this deceleration of m_3 would allow the two masses to separate. A bisection iteration routine is again invoked to determine the exact instant of zero acceleration of m_3 (instant at which acceleration turns into deceleration). This is taken to be when the acceleration of m_3 is less than one millionth of one unit length per second squared (L/s^2). At that point m_3 and m_4 are split apart. Therefore,

$$m_{3E} = m_{3A} \tag{3.12}$$

Mass m_4 retains the velocity of m_3 at the point of separation, as suggested in equation (3.6). The integration resumes using the equations of motion, (3.3) through (3.6) until another impact is sensed. Except in rare cases for models with non-symmetrical motion, this next impact will almost always be with the opposite side of the impact damper container. Figure 3.8 gives a longer history of the displacement and velocity of that shown in Figure 3.7 after equations (3.10) and (3.11) are invoked, as well as when the masses are separated by equation (3.12).

The numerical analysis for this investigation was performed and the results evaluated with a series of programs written using the spreadsheet program LOTUS 123 and with an IBM XT compatible computer. A complete user's manual for the program series is presented in Appendix B.

3.5 RESULTS

The three DOF model was simulated numerically, both with and without the impact damper, to investigate the additional vibration attenuation capability of the impact damper over using the tuned absorber alone. The only variables were the clearance, between the impact damper and the containment walls, and the forcing frequency. The masses steady state amplitudes for the values of the non-dimensional clearance $d/(F_0/k_1)$ = 100, 150, 200, 250 and 300, over a wide range of forcing frequencies were computed. Figures 3.9, 3.10 and 3.11 present the steady state peak displacement of each mass, x_1, x_2 and x_3 respectively (normalized by with F_0/k_1), for different values of ω_f/ω_1. In these figures, various $d/(F_0/k_1)$ values as well as the uncontrolled system displacement are presented for comparison. Except when noted otherwise, steady state is assumed when the standard deviation of the last 20 peak values of the displacement of x_2 is within 1% of the average displacement of those 20 peaks. The peak amplitude values reported, however, for all three masses is the average of the absolute value of the last ten displacement peaks of x_2. For any value of $d/(F_0/k_1)$ where the clearance was too large, and therefore, no impacts resulted, the displacement values are the same as the uncontrolled case and are not given in these particular figures. For instance, the gap from approximately ω_f/ω_1 of 1.07 to 1.15 in Figures 3.9 to 3.11, (except of $d/(F_0/k_1)$ of 100), represent no impacts due to too large a clearance.

Referring to Figure 3.9, it can be seen that for all $d/(F_0/k_1)$ values, there is no significant effect on the displacement of the primary mass, m_1. Due to the large mass ratio between m_1 and m_2 (200:1), masses m_2 and m_3 can be viewed as an independent two DOF system with base excitation and an impact damper. This is confirmed by examining the mode shapes for the undamped system. In Figure 3.12 (a), which gives the mode shapes for the undamped three DOF system, at the two resonance peaks on either side of the natural frequency of the primary system (W_f approximately equal to 0.85 and 1.175), the displacement of x_1 is effectively zero. Figure 3.12 (b) gives the modes shapes for the undamped two DOF system consisting of only m_2 and m_3. A comparison of the mode shapes for m_2 and m_3 for the two systems at these two frequencies shows that the displacement of the three DOF system is virtually the same as the two DOF system at these two frequencies.

The motion of x_2, as shown in Figure 3.10, is changed significantly by the inclusion of the impact damper. As compared to the uncontrolled case, a peak is reformed at the natural frequency of the system, W_f/W_1 = 1.0. Conversely, the peaks at excitation frequencies of 0.85 and 1.175 have been reduced, with new, smaller peaks forming at slightly lower frequencies. This shift in the peak frequency towards a lower frequency is a characteristic of impact damper systems [Bapat and Sankar 1985]. The absorber, on the other hand, which was designed to be tuned to the natural frequency of the secondary system, becomes detuned. A similar trend is noted for x_3 (Figure 3.11), with the exception that there has been little change to the peak displacement at W_f/W_1 = 1.0.

The displacement of m_2 and m_3 with decreasing $d/(F_0/k_1)$ values shows an expected trend given the high incidence of chatter with small clearances. Figure 3.13 plots the amplitudes x_2 and x_3 for

$d/(F_0/k_1) = 100$ against their counterparts, from the closed form solution for a three DOF system, with m_3 equal to 0.11 m_2 and with no impact damper. Note that the values for k_3 and c_3 in the closed form solution are kept the same as for the $m_3 = 0.10\ m_2$ (tuned) system. It, therefore, emulates the motion of the system with the impact damper if d were equal to zero (the damper would be continuously carried). The frequencies of the peak displacements have shifted to the left and the peak displacement amplitudes for $d/(F_0/k_1) = 100$ are starting to build to the amplitude of the closed form solution with zero clearance.

The effectiveness of attenuation, over a wide frequency range, can be measured by two parameters, as discussed in Chapter 2.0. The first parameter, the RMS amplitude of the displacement, represents the average response of the secondary system to an equivalent random white noise excitation. The second parameter, the spectral peak amplitude is the response of the system to a frequency sweep type of excitation as may be encountered during the start-up of a (primary) machinery. In this case, the sweep is assumed to be slow; each frequency is held until a steady state response is obtained. These two response parameters of the secondary solution were obtained for the five values of $d/(F_0/k_1)$ over the frequency ratio, W_f/W_1, of 0.8 to 1.2. As mentioned previously, this range of frequencies encompasses the zone of most significant contribution to the total response. The displacement amplitudes for each of the three masses are obtained, but since the affect on x_2 is the most critical, only x_2 is presented here. The RMS amplitude and spectral peak amplitude over the frequency range being investigated, for each value of $d/(F_0/k_1)$, is given is in Figure 3.14.

Also included for comparison are the following cases:

i. No impact damper, $m_3 = 0.1\ m_2$ (0.5) and tuned to the natural frequency of m_2, ($W_3 = W_2 = W_1$).

ii. $m_3 = 0.1\ m_2 + m_4 = 0.11\ m_2$ (0.55), untuned case (equivalent to $d/(F_0/k_1) = 0.0$)

iii. No impact damper but $m_3 = 0.11\ m_2$ (0.55) and tuned to the natural frequency of m_2, ($W_3 = W_2 = W_1$).

iv. No impact damper and $m_3 = 0.1\ m_2$ (0.5) but with the optimal critical damping of the absorber of 10% (from Chapter 2.0).

Cases ii. and iii. represent other alternatives for utilizing the additional mass required by the impact damper without adding the complexity of the impact damper. In case iv., the critical damping ratio of 10% was found (in Chapter 2.0), to be the optimal for the three DOF system. Figures 3.15 (a), (b) and (c) give the complete displacement spectrum of x_2 versus frequency ratio plots for cases ii., iii. and iv. respectively, as compared to the displacement amplitudes for $d/(F_0/k_1) = 150$ which, as will be discussed, offers the best overall attenuation of the impact damper cases. The displacement of x_2 for case i. versus the impact damper cases has been shown in Figure 3.10.

A summary of results from all four cases cases is presented in Figure 3.14. From Figure 3.14 (a), in all cases the RMS values for any of the values of $d/(F_0/k_1)$ investigated are lower than the other options with $d/(F_0/k_1) = 150$ being the lowest[5]. They offer attenuation between

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5 To maintain consistency, the RMS amplitude for all situations was computed in a similar manner. Only those displacement peak values for the discrete points investigated with the impact damper were used. This rough value shows good correlation with the value obtained for the closed form transfer functions, when a

approximately 25% and 40% over the uncontrolled case with 1% damping (case i.). Comparison with case ii. where $m_3 = 0.11\ m_2$ and the absorber is untuned shows attenuations of 28% to 42%. The major contribution to this increase in displacement are at the first and third peaks (Figure 3.15 (a)). This indicates that as the clearance, d, is decreased, attenuation of x_2 can be expected to diminish and eventually the RMS displacement will be amplified when d = 0 as compared to case i. The RMS value for case iii. ($m_3 = 0.11\ m_2$) appears to offer better attenuation than case ii. although still not as good as utilizing the mass as an impact damper. Comparison with the optimally damped case (Z_3 = 10%) shows that only the values of $d/(F_0/k_1)$ = 150 and 200 offer significant improvement (approximately 20%) with respect to the RMS amplitude.

The spectral peak amplitudes achieved by different impact damper cases are essentially equal; the peak amplitude is at the natural frequency of the secondary system (W_f = 1.0). Attenuation of the peak displacement from the uncontrolled case is more than 60%. The largest displacement occurs at the natural frequency of the individual systems, ($W_1 = W_2 = W_3 = 1.0$) were x_2 in the three DOF system does not have a peak. The impact damper decreases the peaks corresponding to the first and third natural frequencies of the system well below their uncontrolled displacement (greater than 50%). In cases ii. and iii., where the additional mass of the impact damper is added to the absorber, attenuations are slightly decreased but still better than 50%. Attenuations as compared to the optimal damped case are not as dramatic

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smaller step size is used.

but still range between 24% and 30%.

To explore the effect of varying d values further, a series of simulations were done at the three resonance peaks with $d/(F_0/k_1)$ values beyond the selected limits of 100 to 300. The displacement amplitudes of x_2 resulting from these simulations are shown in Figure 3.16. The attenuation of x_2/x_{20} is plotted against the value of $d/(F_0/k_1)$. Displacement x_{20} is the uncontrolled peak amplitude at each respective peak. Where steady state motion was achieved but within a periodically varying envelope (see for example Figure 3.17 (a)), the minimum and maximum values of x_2 were plotted in Figure 3.16 rather than a unique value. Figure 3.16 shows that at the first two resonance peaks, there is a slight tendency to increased displacement amplitudes with increased d values. At the third peak (frequency = 1.175), there is a definite low displacement amplitude at $d/(F_0/k_1) = 150$ but this peak contributes the least to the overall RMS amplitude. This overall insensitivity to different values of $d/(F_0/k_1)$ is very important practically. To achieve attenuations of x_2 at a natural frequency of the system, the size of d need not be adjusted very accurately. Errors in initial adjustment are probable when the values of m_1 and k_1 are not easily determined.

At the first displacement peak (frequency approximately equal to 0.85), the response with increased clearance, d, is a steady state within a periodically varying envelope. An examination of the time histories of m_2 and m_3 for $d/(F_0/k_1) = 500$ at this peak, given in Figure 3.17, shows the difference in the system response. The larger peak displacement amplitude of x_2 at this frequency, is caused by the presence of the absorber. Referring back to the difference between the two and three DOF systems (Figures 3.2 and 3.3), it is noted that without the absorber there is no peak at this frequency. The addition of the impact damper introduces an intermittent force which can disrupt the effect of the absorber, m_3, on m_2, thereby reducing the amplitude of x_2 as in the two DOF case. It appears that the amplitude of x_2 decreases sufficiently that, as Figure 3.17 (b) and (c) show, there is then a period of no impact between m_3 and m_4. During this period, m_3 again acts like an absorber, and x_2 slowly increases in amplitude again. After some time, m_3 and m_4 begin to impact again and the cycle repeats. This results in the periodically variation of the steady state envelope. As Figure 3.18 indicates, with smaller values of d (in this case $d/(F_0/k_1) = 150$), the amplitude of x_2 is never reduced sufficiently to stop the impacts between m_3 and m_4. The effect of the impact damper is continuous.

At the natural frequency of the primary and secondary system (frequency = 1.0), the displacement amplitude of x_2 at any value of $d/(F_0/k_1)$, reaches a well defined steady state; there is a unique peak displacement amplitude. Figure 3.19 gives a portion of the time history for $d/(F_0/k_1) = 500$ and $W_F/W_1 = 1.0$. Unlike at the 0.85 frequency peak, it can be seen that a regular sequence of impacts is maintained. At this frequency, there are two causes for the movement of x_2 in a two DOF system: the motion of m_1 and the excitation of m_2 at its natural frequency. The addition of a properly tuned absorber results in m_1 and m_3 moving out of phase and reducing the motion of m_2 ($x_2 = 0$ for the undamped, tuned system). The impact damper detunes the absorber and can change the motion of m_2, through m_3. The absolute motion of m_2 continues however, because of x_1, and is sufficient to maintain the impacts between m_3 and m_4; they are continuous rather than intermittent and a steady state displacement is attained. Examination of the peak displacement amplitude for x_1 and x_2 with $d/(F_0/k_1) = 150$ in Figure 3.20 (a), appears to indicate that the effect of the damper is to cause m_2 to move with m_1. Figure 3.20 (b) displays the relative displacement of x_2 to x_1 for $d/(F_0/k_1) = 150$. There is in fact some relative motion or bounce. This bounce is less than that present for the optimum damping case which is also shown in Figure 3.20 (b). This is significant practically when relative motion of the two systems can cause interference and damage. The addition of the impact damper therefore, attenuates both the absolute displacement amplitude of x_2 and the relative motion of m_2 versus m_1. Figure 3.20 (c) compares the absolute and relative (to m_1) attenuation offered by the impact damper with $d/(F_0/k_1) = 150$. At the peaks near the frequencies of 0.85 and 1.175, because of the relatively small movement of x_1 these values are similar. At the excitation frequency of 1.0, the relative motion of x_2 is reduced but the movement of x_1 results in larger absolute displacements.

3.6 CONCLUSIONS & RECOMMENDATIONS

An impact damper was added to the absorber on a three DOF system with excitation of the primary mass. The ratios between the primary and secondary masses and the critical damping ratios are 200:1 (m_1:m_2) and 0.01 (Z_1) and 0.01 (Z_2), respectively, representing a shear building and a light equipment system. An absorber with a mass corresponding to the ratio of 10:1 (m_2:m_3) was mounted on the secondary system. An impact damper of 10% of the absorber mass was mounted onto the absorber. The coefficient of restitution between the impact damper and the absorber was set at 0.3. Numerical simulations were performed over a range of frequencies for each one of the various clearances.

The impact damper could attenuate the RMS amplitude by up to 40% and the spectral peak amplitude by approximately 60% as compared to the uncontrolled system. Attenuations of RMS displacement of approximately 20% were attainable over an optimally damped absorber (Z_3 = 10%) with a clearance of $d/(F_0/k_1) = 150$. The peak spectral displacement attenuation was relatively insensitive to the clearance used as long as this clearance was small enough so that collisions were sustained. The addition of the impact damper caused the motion of the secondary system to more closely follow the motion of the primary system.

Because of the significant attenuation, continued investigations are warranted. The following areas are suggested:

i. For clearances where the expected motion of the absorber is insufficient to make initial contact, the simulations should be repeated with the initial conditions of the damper mass such that a collision will occur. If the collisions are initiated in this manner, will they continue and result in attenuation?

ii. Different values of the coefficient of restitution, e, should be tried to check for sensitivity. Larger values of e will enable more exchange of momentum between the colliding bodies and should reduce the amount of "carrying" at small clearances.

iii. The numerical investigations were limited to typical parameters of a shear building-machine system. Other practical system combinations should be tried to verify the effectiveness of the impact damper.

iv. Different mass ratios between the impact damper and the absorber should be tried. For instance, increasing the size of the impact damper to 20% might decrease the carrying and allow smaller values of d to sustain impacts.

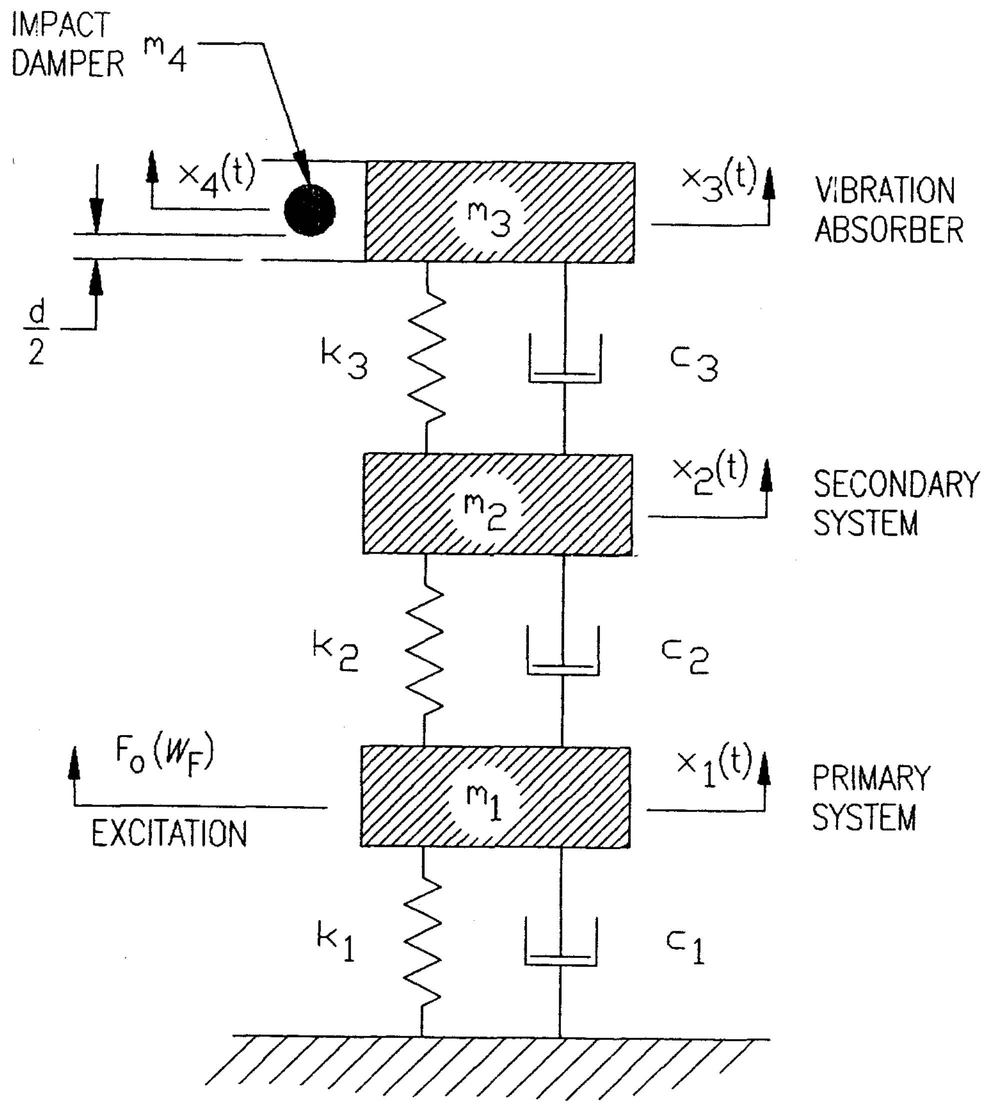

FIGURE 3.1 : 3 DOF spring/mass/damper system with impact damper, nomenclature and values of system parameters.

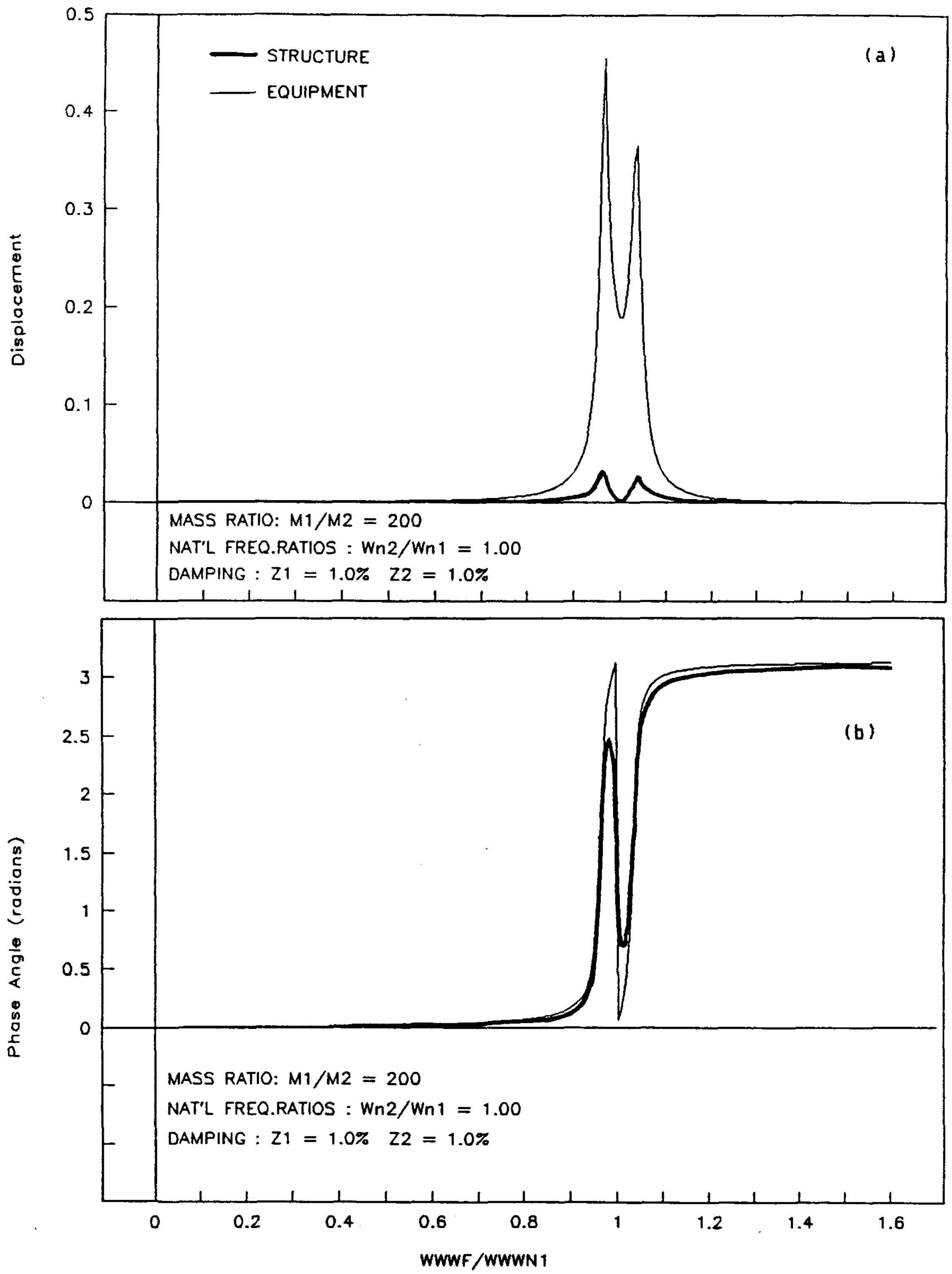

FIGURE 3.2 : Spectra of a 2 DOF system with W_1 : W_2 = 1.0 :
(a) Displacement, (b) Phase angle relationship.

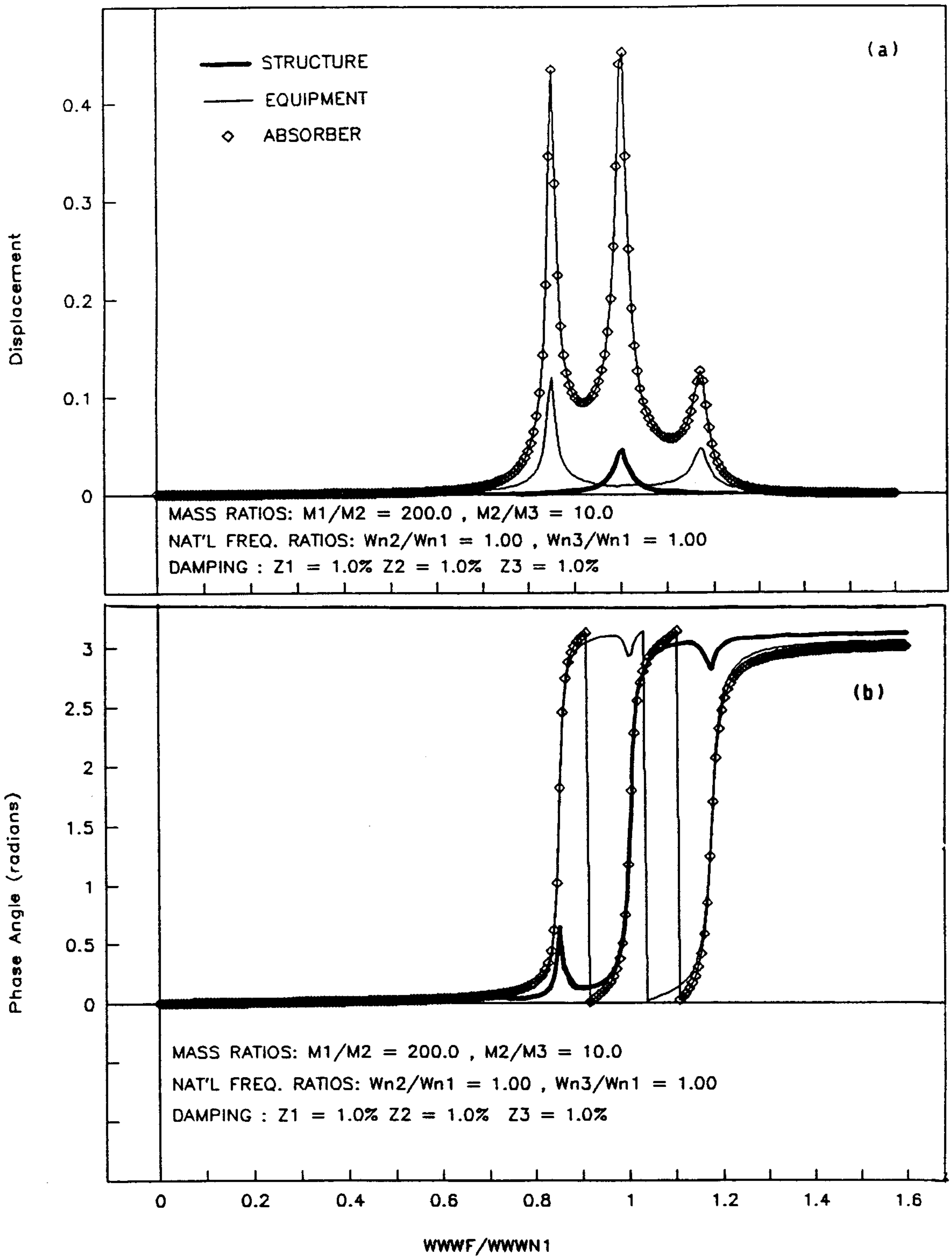

FIGURE 3.3 : Spectra of a 3 DOF system with $W_1 : W_2 = 1.0$, $W_1 : W_3 = 1.0$ over a frequency ratio from 0 to 1.6 : (a) Displacement, (b) Phase angle relationship.

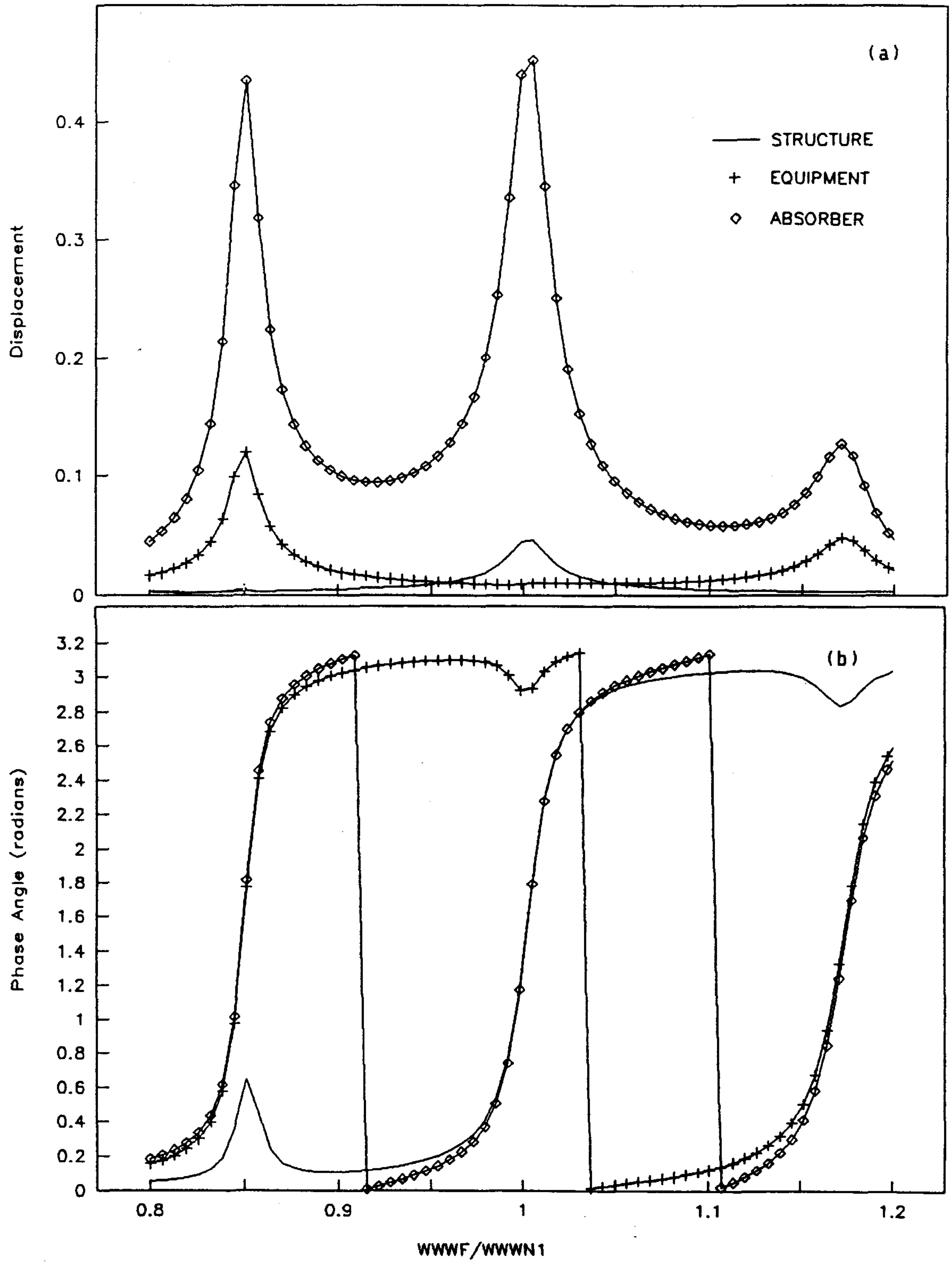

FIGURE 3.4 : Spectra of a 3 DOF system with $W_1 : W_2 = 1.0$, $W_1 : W_3 = 1.0$ over a frequency ratio from 0.8 to 1.2: (a) Displacement, (b) Phase angle relationship.

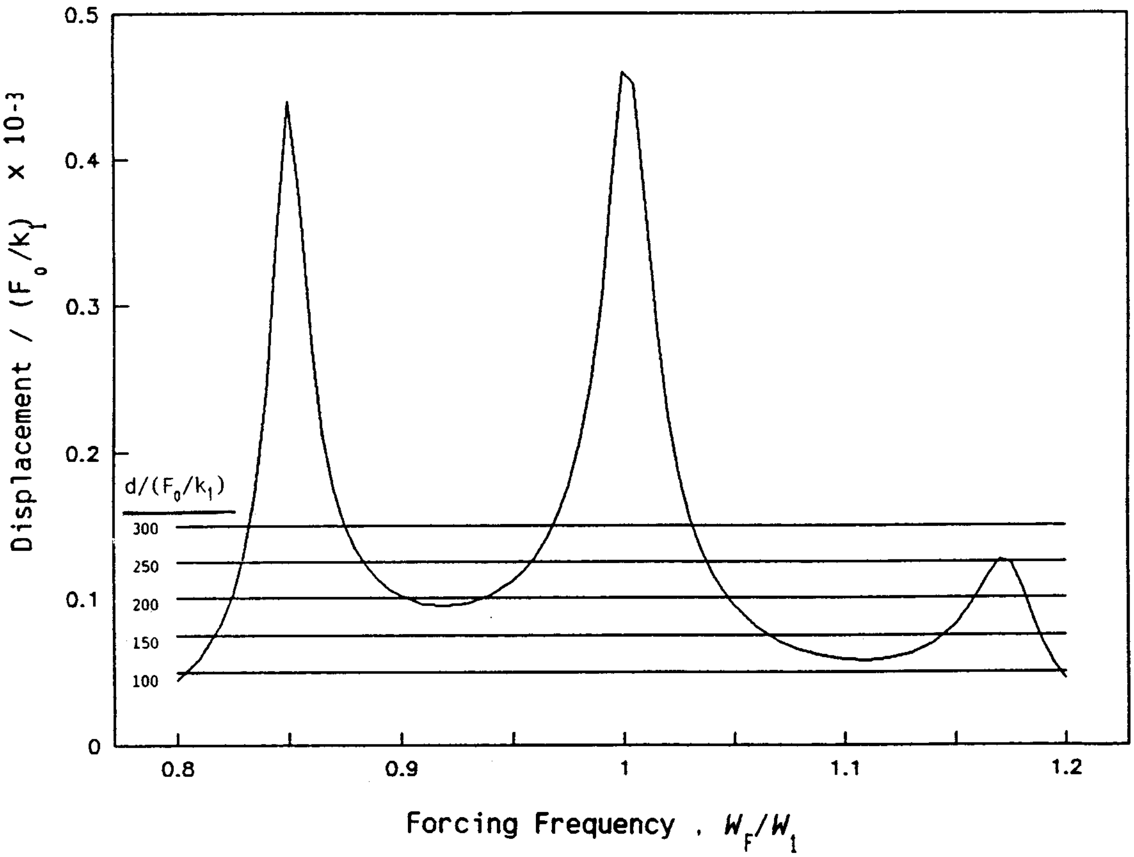

FIGURE 3.5 : Relationship of various impact damper wall spacing, $d/(F_0/k_1)$ to displacement of uncontrolled x_3 motion.

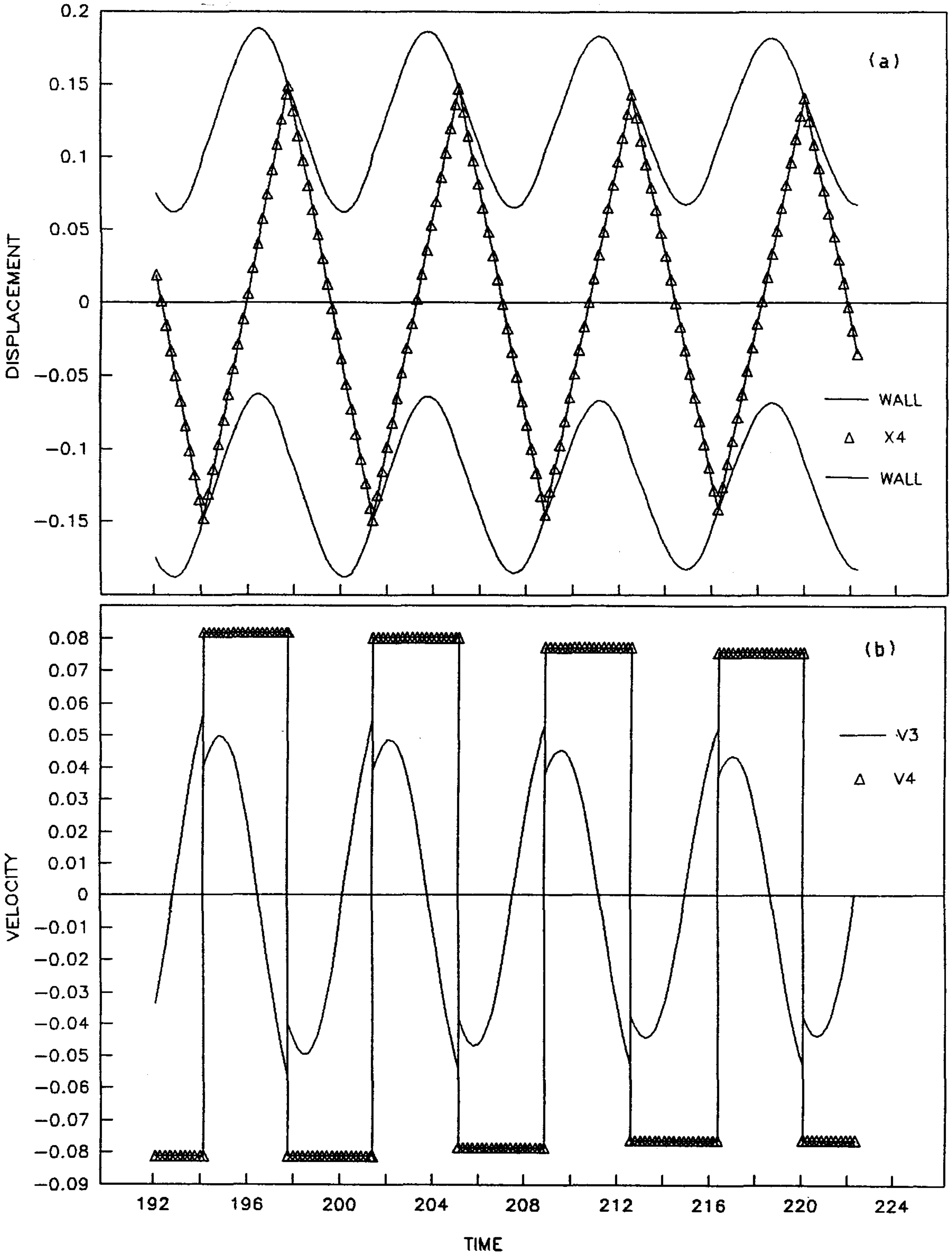

FIGURE 3.6 : Spectra of a good impact damper candidate, a) Displacement of x_4 within containment walls, b) Velocities v_3 and v_4.

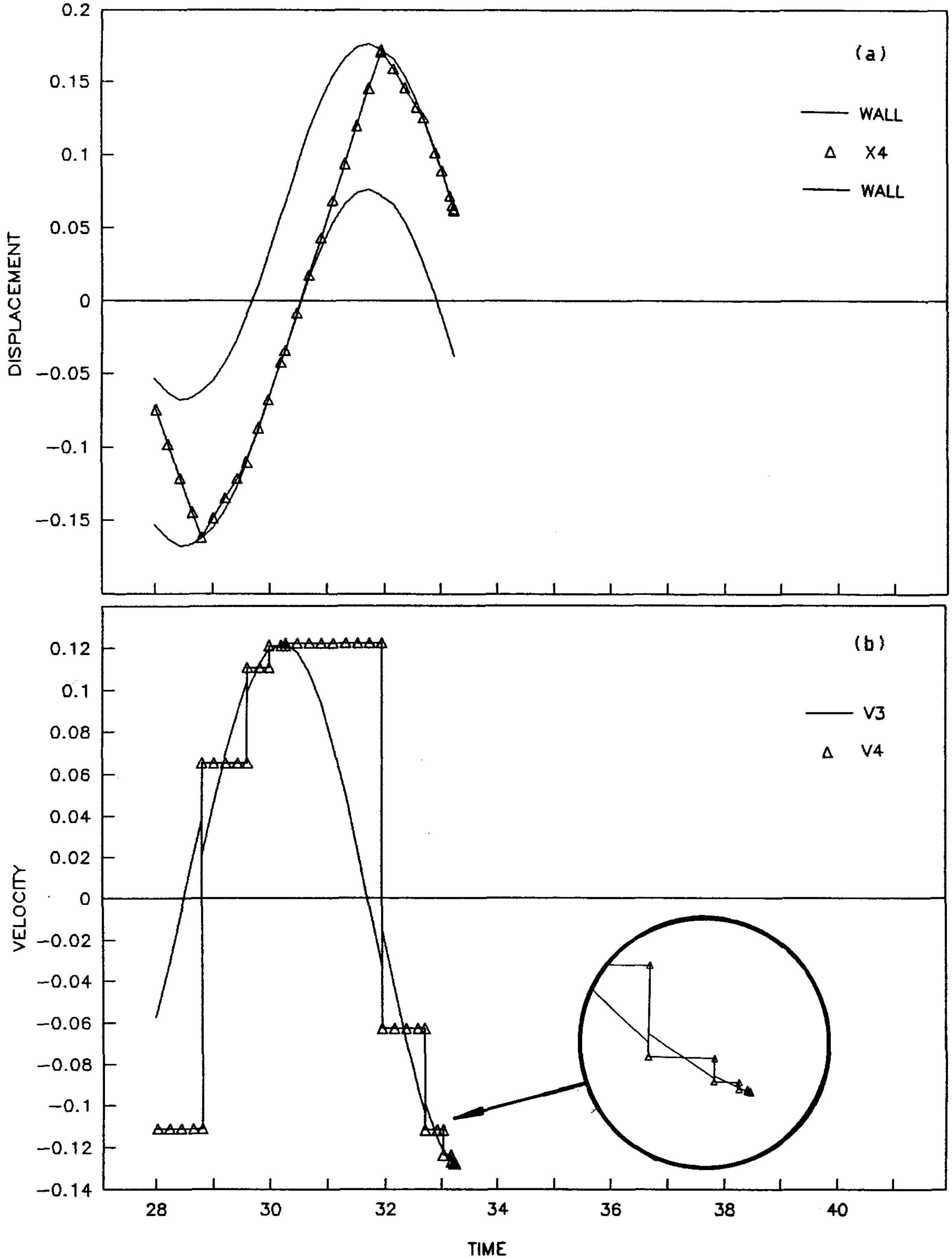

FIGURE 3.7 : A typical model run effectively terminated due to chatter, (a) Displacement of x_4 within containment walls, (b) Velocities v_3 and v_4.

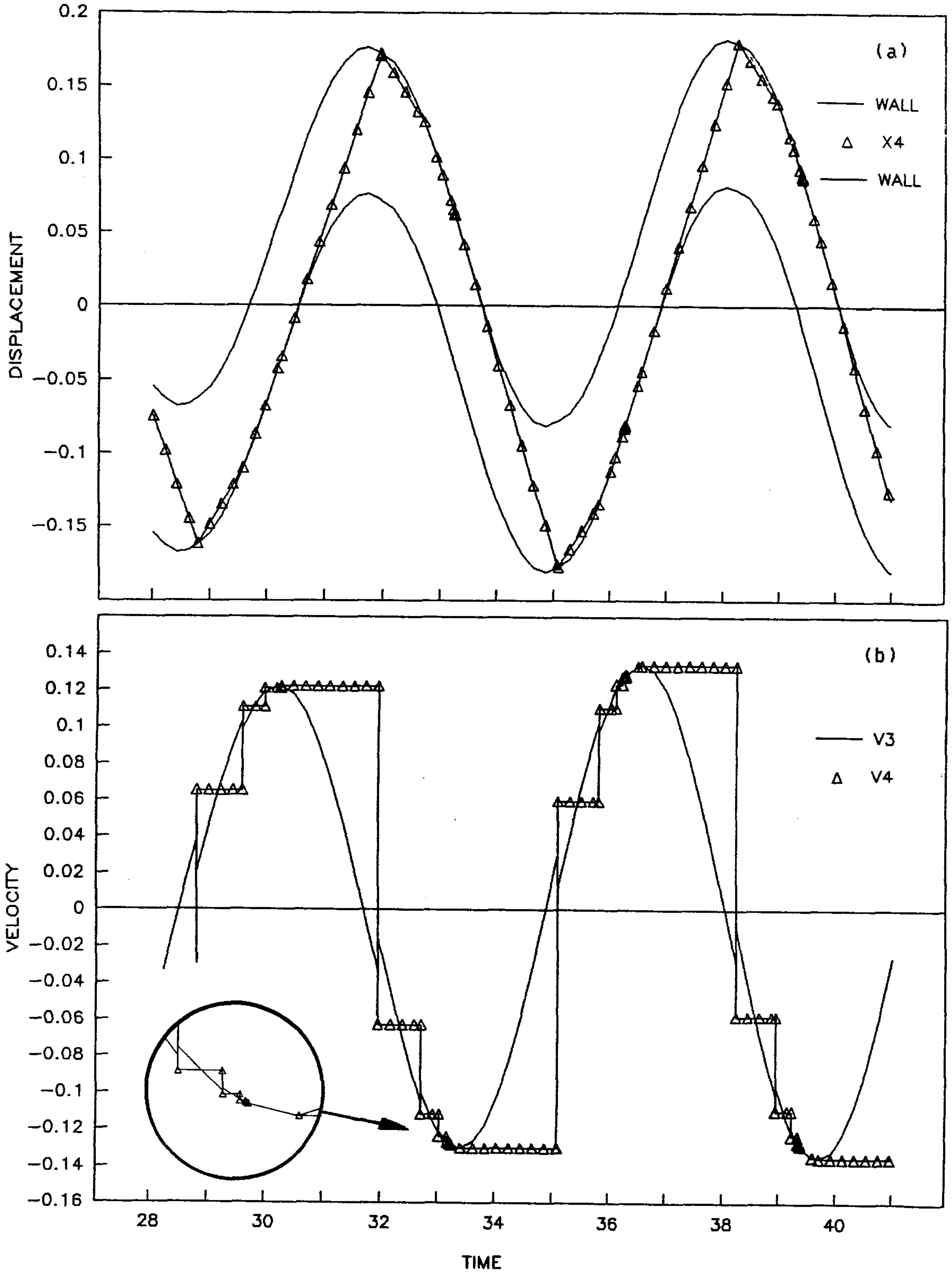

FIGURE 3.8 : A typical model run where chatter is overcome by altering system equations, (a) Displacement of x_4 within containment walls, (b) Velocities v_3 and v_4.

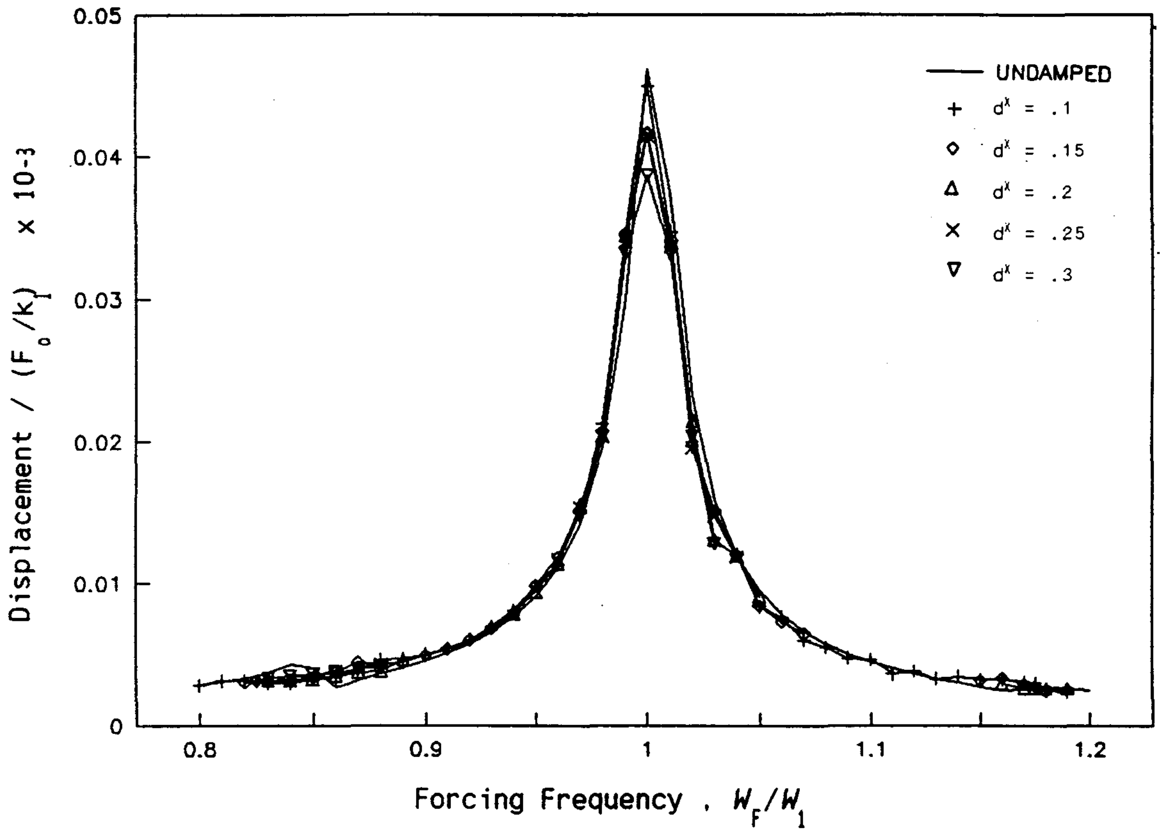

FIGURE 3.9 : Comparison of displacement of x_1 for $d/(F_0/k_1)$ = 100, 150, 200, 250 and 300 as compared to uncontrolled displacement over forcing frequency range of 0.8 to 1.2.

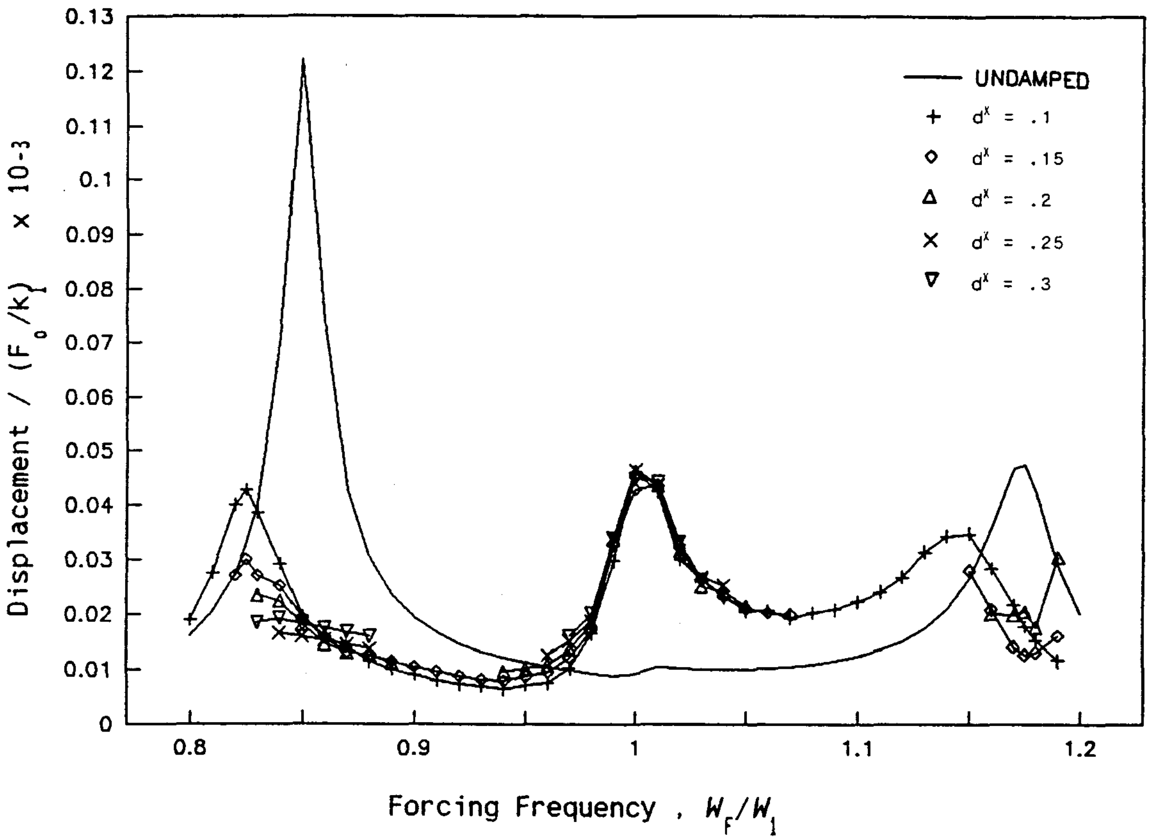

FIGURE 3.10 : Comparison of displacement of x_2 for $d/(F_0/k_1)$ = 100, 150, 200, 250 and 300 as compared to uncontrolled displacement over forcing frequency range of 0.8 to 1.2.

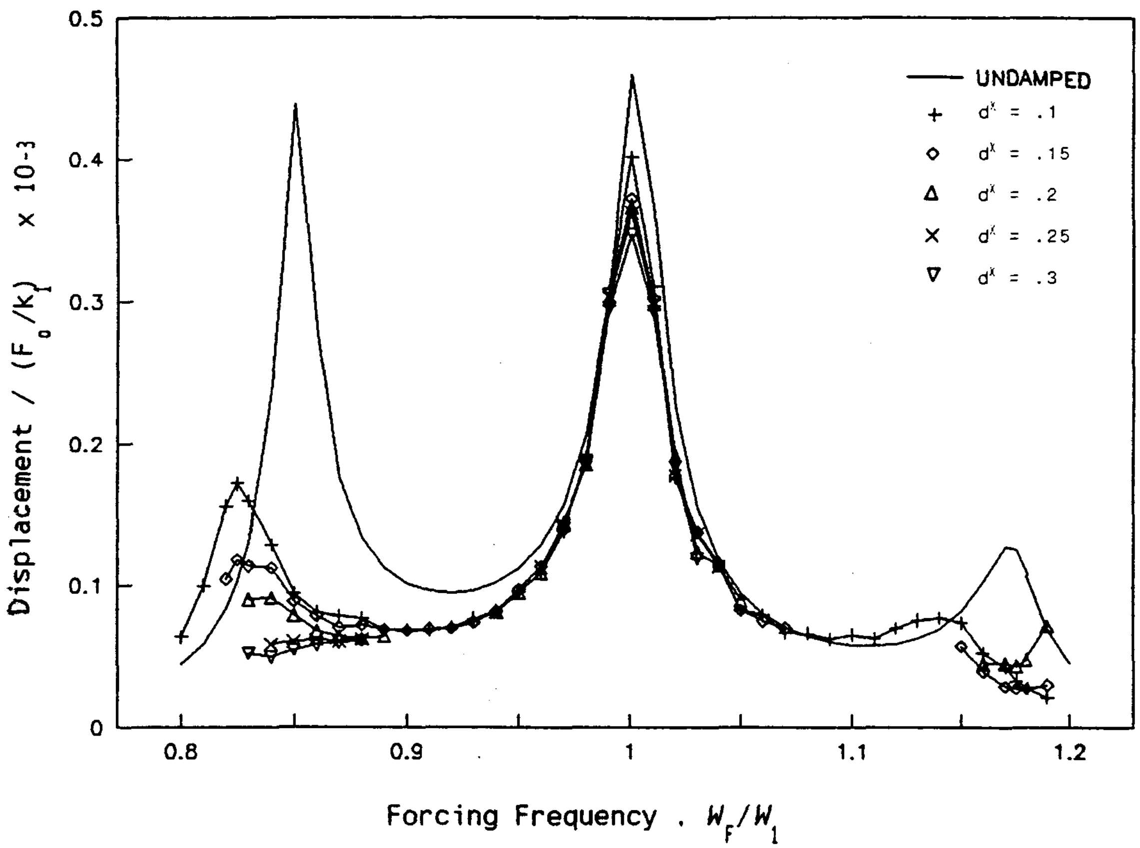

FIGURE 3.11 : Comparison of displacement of x_3 for $d/(F_0/k_1)$ = 100, 150, 200, 250 and 300 as compared to uncontrolled displacement over forcing frequency range of 0.8 to 1.2.

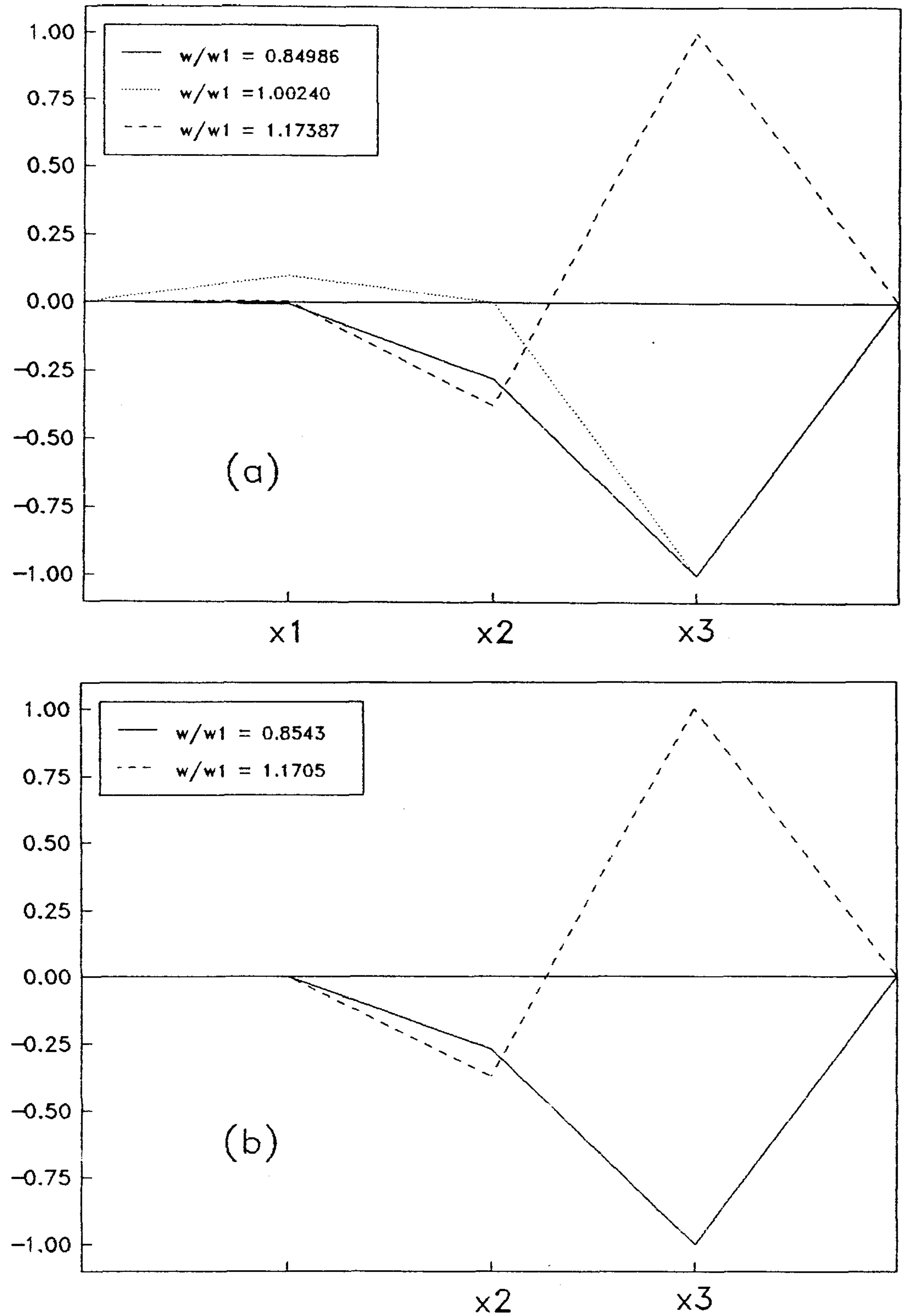

FIGURE 3.12 : Mode shapes for the undamped systems without an impact damper for (a) 3 DOF system with $m_1/m_2/m_3$:2000/10/1 and $W_1=W_2=W_3=1.0$, (b) 2 DOF system with m_2/m_3:10/1 and $W_2=W_3=1.0$.

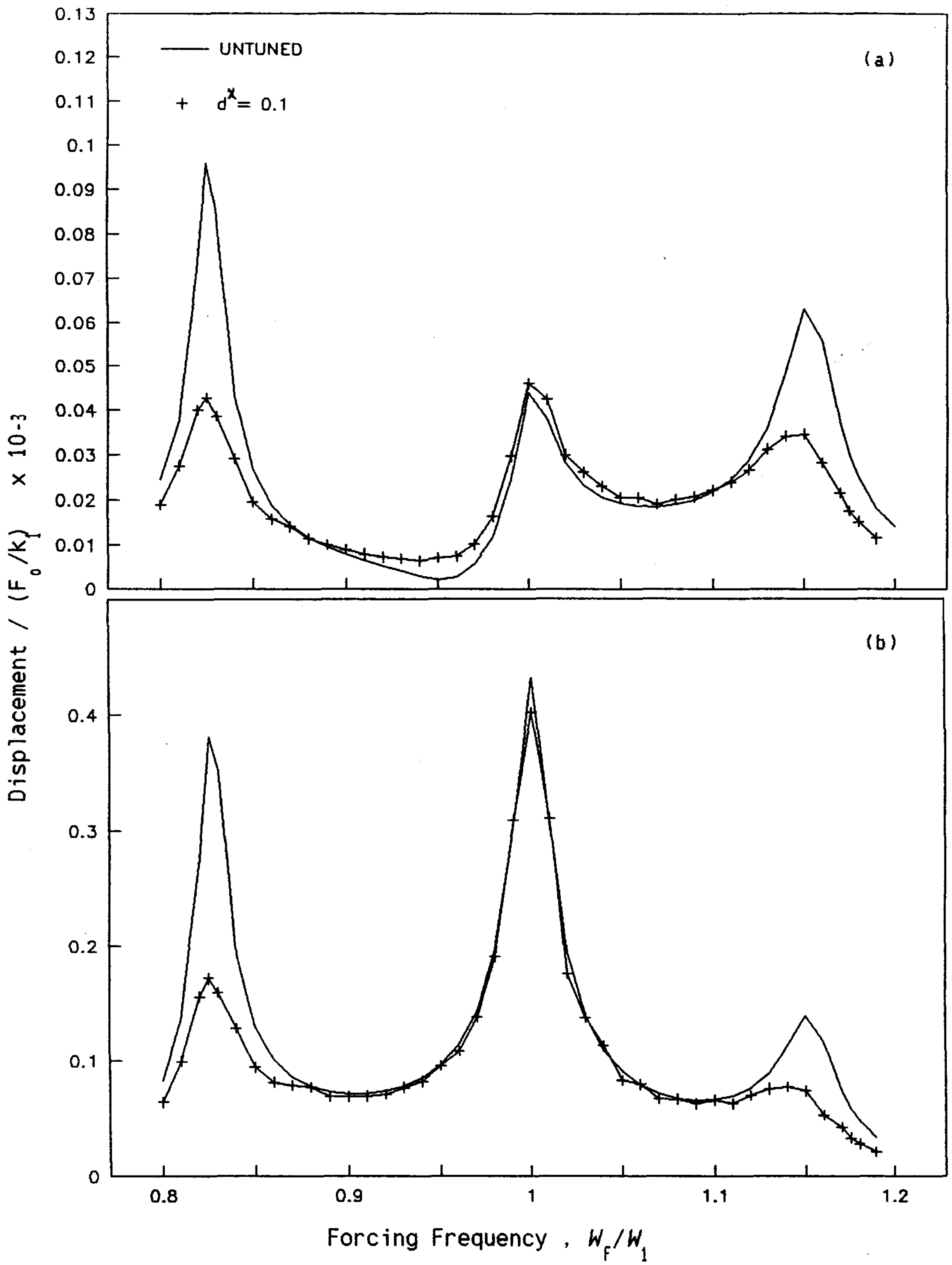

FIGURE 3.13 : Comparison between impact damper system with $d/(F_0/k_1)$ = 100 and untuned 3 DOF system with m_3 = 0.55 for displacements of (a) x_2, (b) x_3.

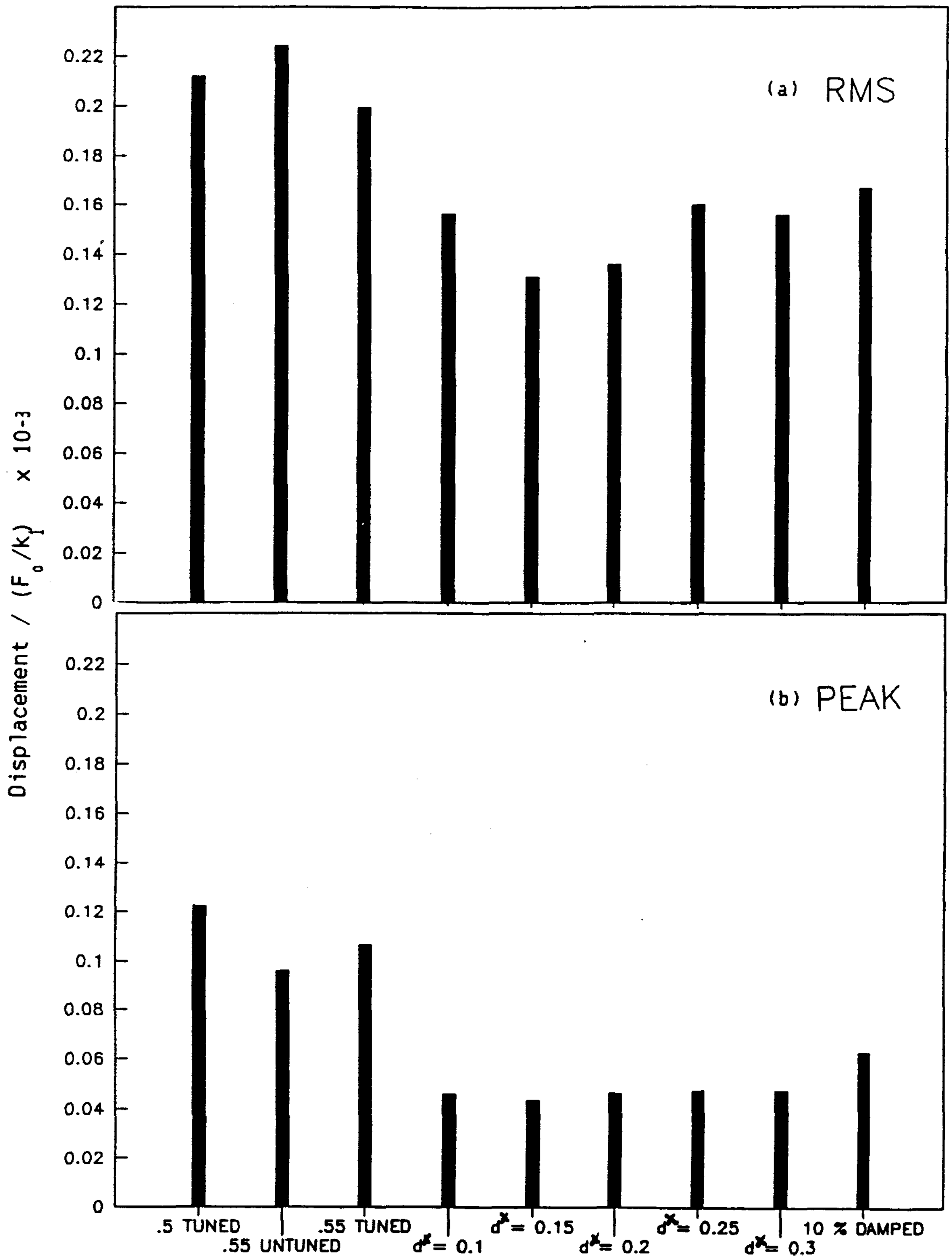

FIGURE 3.14 : (a) RMS and (b) Peak Spectral displacement amplitude values for $d/(F_0/k_1)$ = 100, 150, 200, 250 and 300 as compared to alternate uncontrolled cases of i) m3 = 0.5, ii) m_3 = 0.55, untuned, iii) m_3 = 0.55, tuned and iv) m_3 = 0.5, Z_3 = 10%.

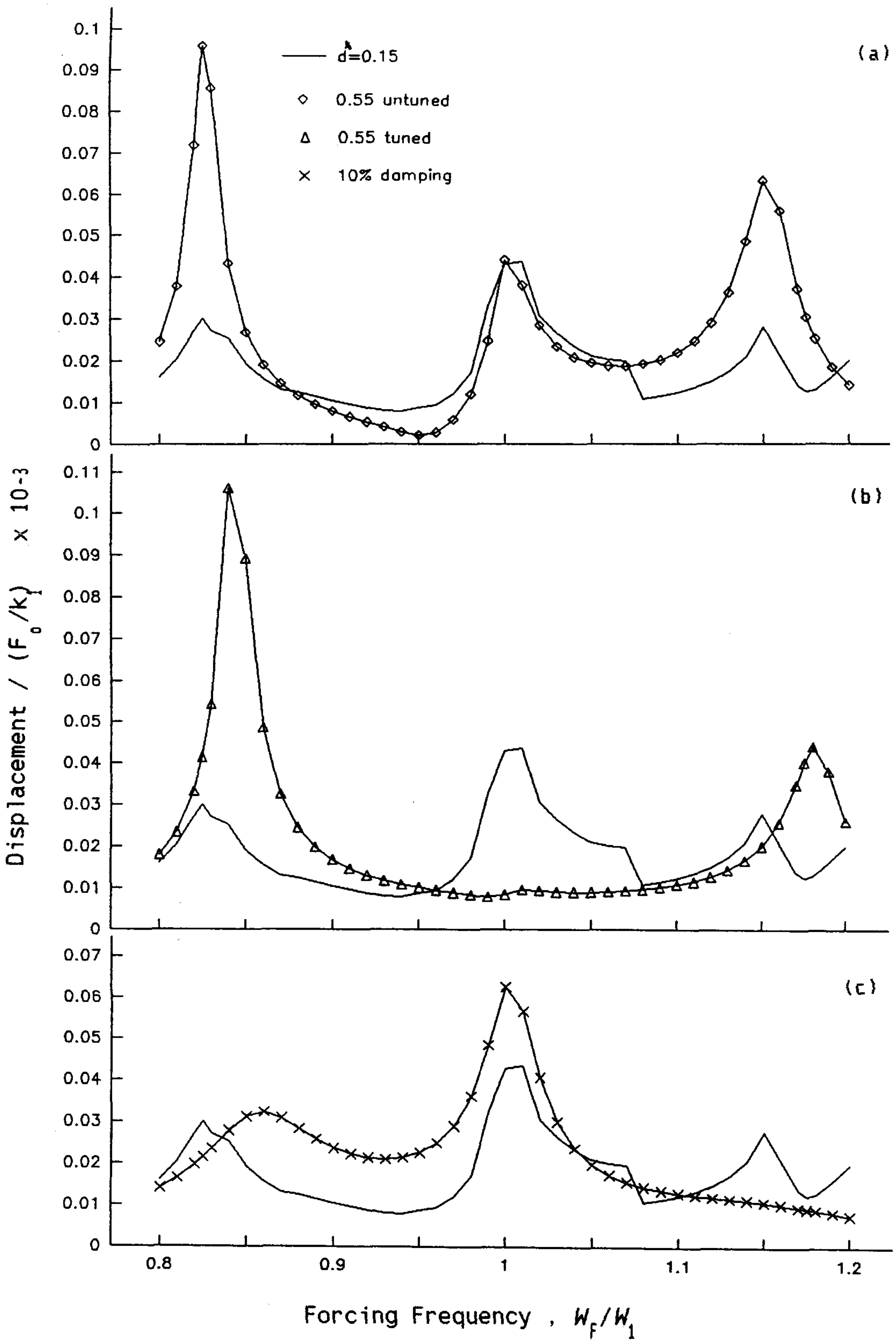

FIGURE 3.15 : Displacement spectra of x_2 as compared to case with $d/(F_0/k_1)$ = 150 for (a) m_3 = 0.55, untuned, (b) m_3 = 0.55, tuned, (c) m_3 = 0.5, Z_3 = 10%.

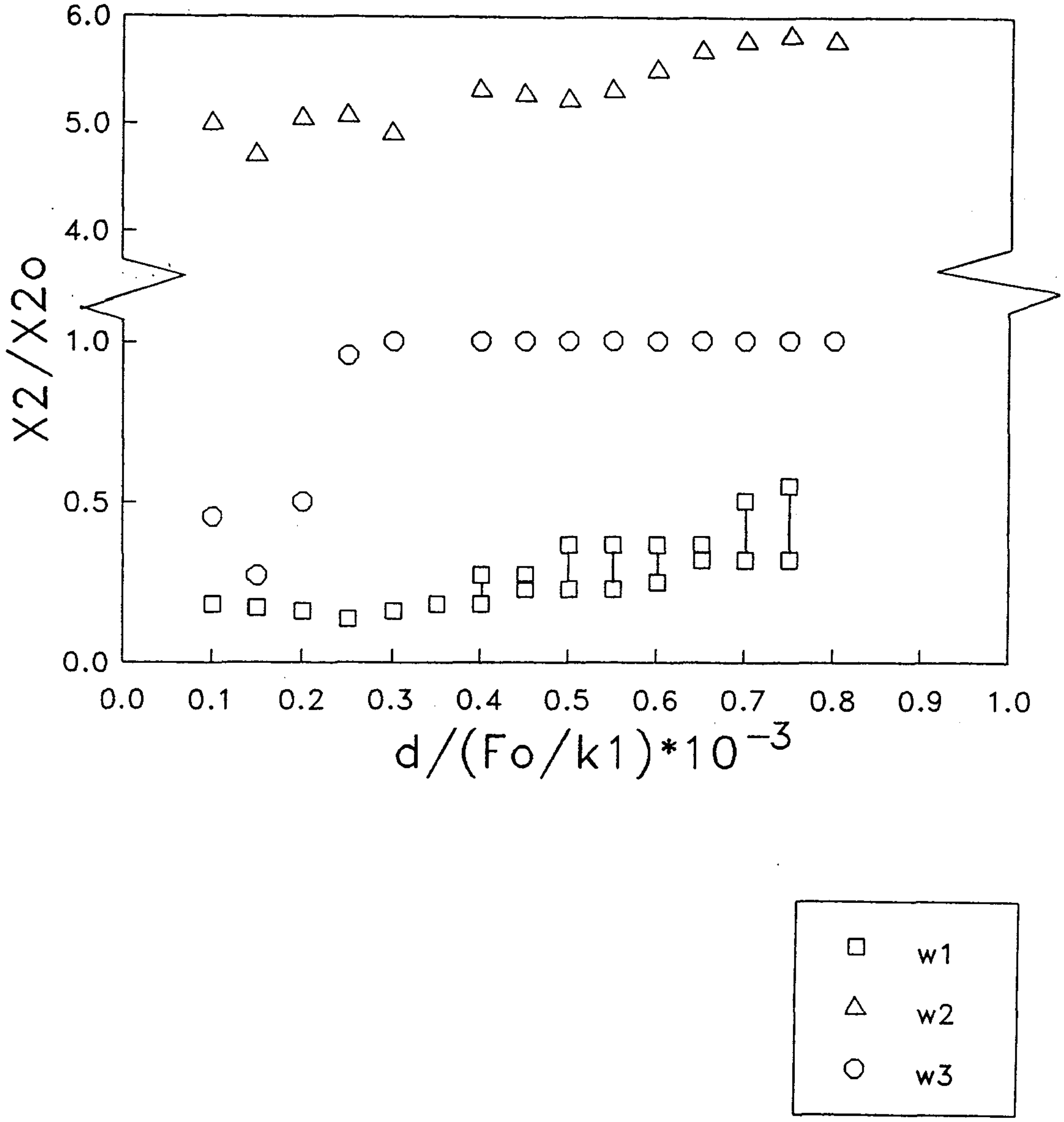

FIGURE 3.16 : x_2/x_{20} ratio at resonance frequencies of 0.85, 1.00 and 1.175 for a range of $d/(F_0/k_1)$ values.

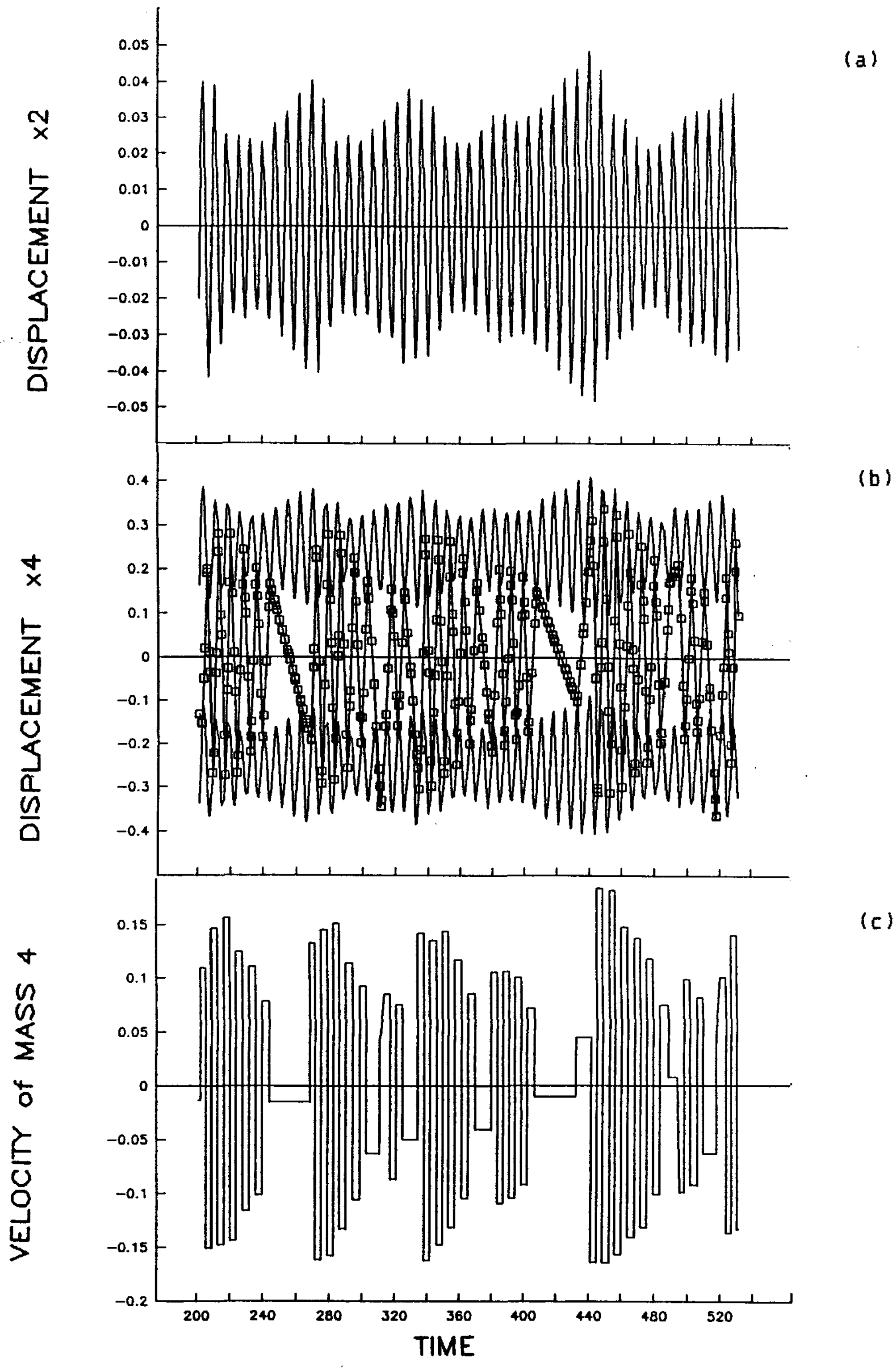

FIGURE 3.17 : Time history of model with $d/(F_0/k_1) = 500$ at frequency ratio of 0.85: (a) displacement x_2, (b) Displacement x_4 within containment and (c) Velocity v_4.

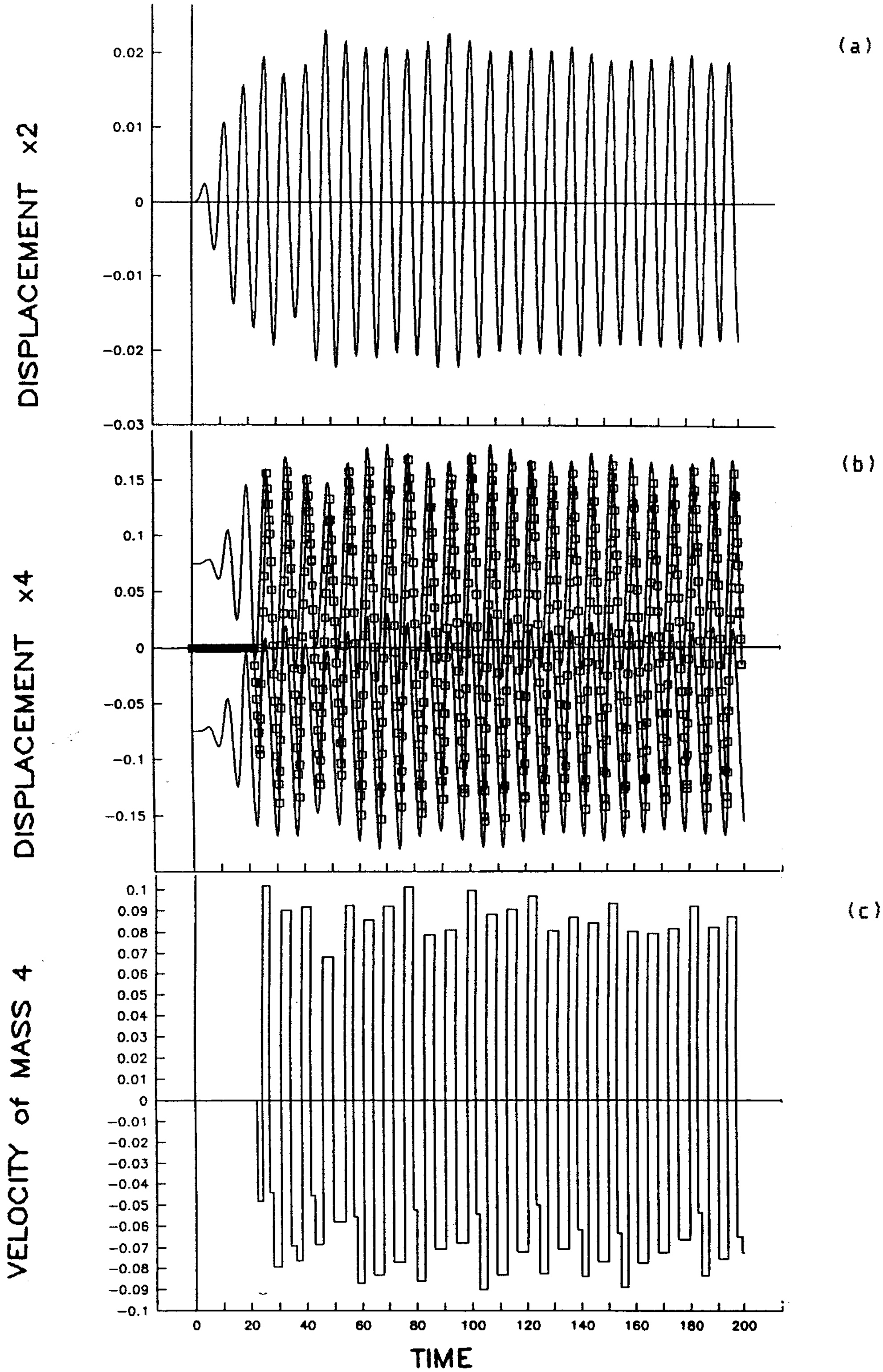

FIGURE 3.18 : Time history of model with $d/(F_0/k_1) = 150$ at frequency ratio of 0.85 for (a) displacement x_2, (b) Displacement x_4 within containment and (c) Velocity v_4.

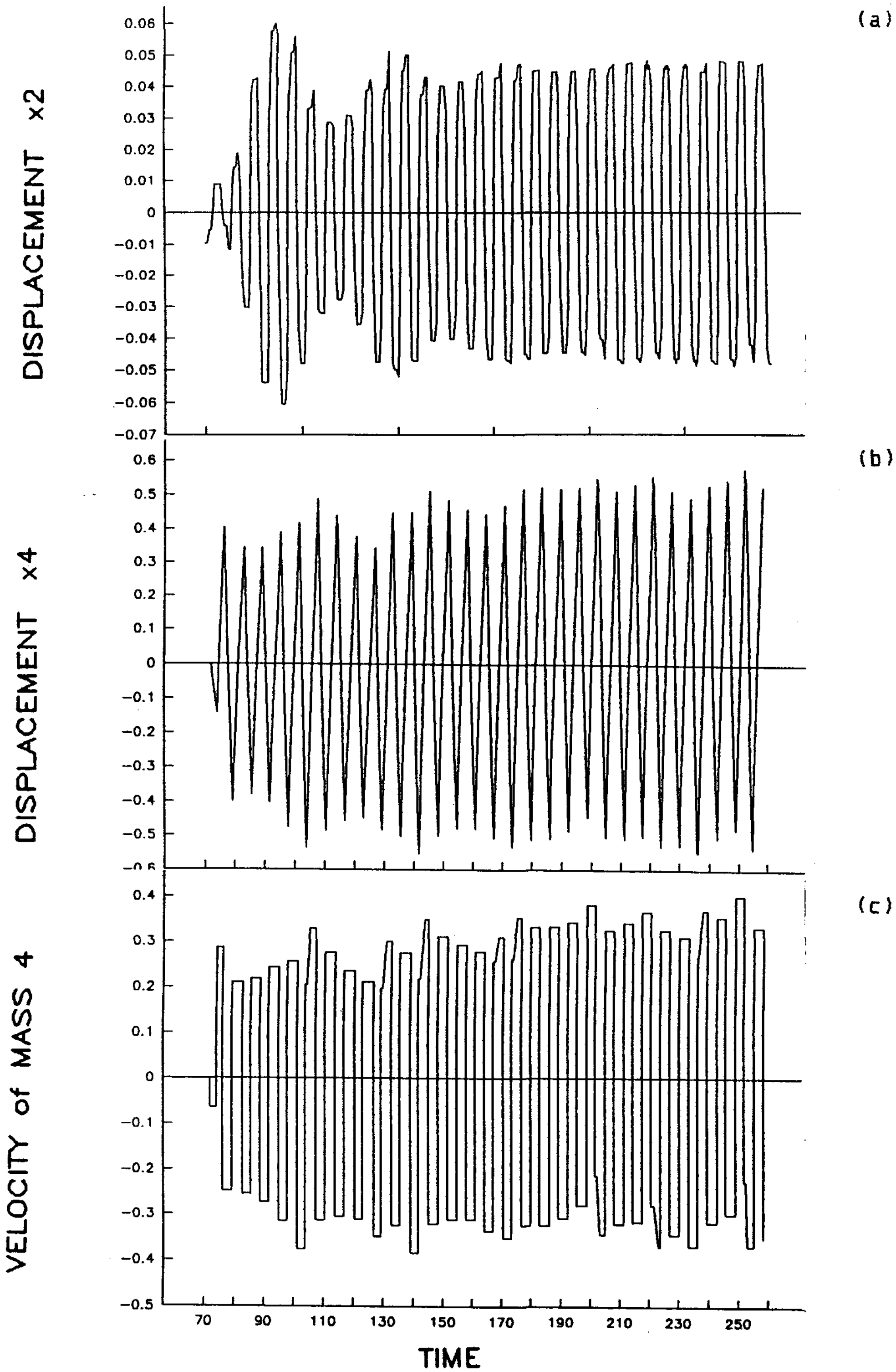

FIGURE 3.19 : Time history of model with $d/(F_0/k_1) = 150$ at frequency ratio of 1.0 : (a) displacement x_2, (b) Displacement x_4 within containment and (c) Velocity v_4.

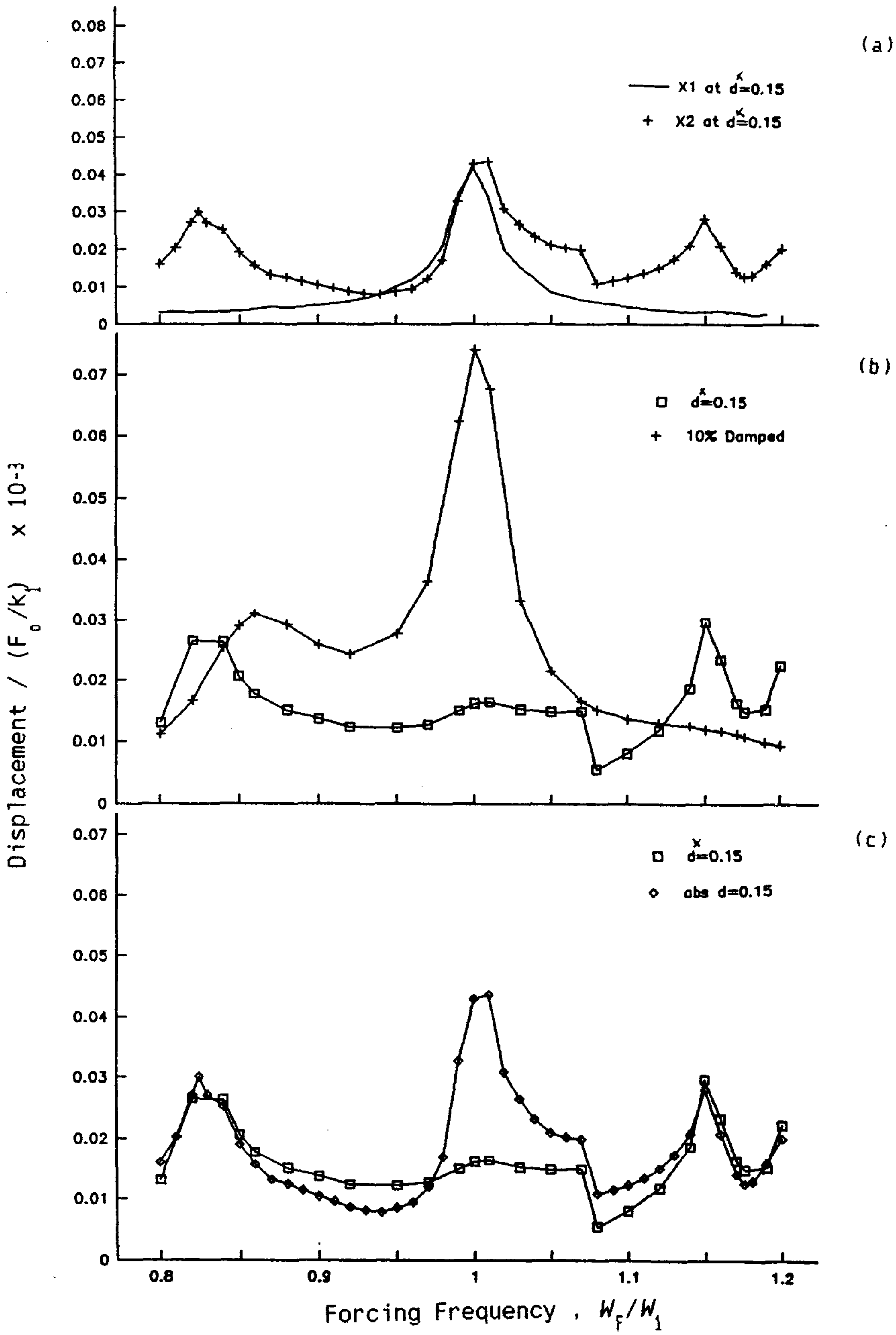

FIGURE 3.20 : Comparison of displacement: (a) of m_1 and m_2 for $d/(F_0/k_1) = 150$, (b) of $(x_2 - x_1)$ for $d/(F_0/k_1) = 150$ versus for $Z_3 = 10\%$ and (c) $x_2 - x_1$ versus x_2 for $d/(F_0/k_1) = 150$.

CHAPTER 4.0

CONCLUSION

The use of spreadsheet computer programs to solve complex problems has been demonstrated by undertaking investigations into two specific vibration control problems. A series of programs, which facilitated the generation and compilation of solutions for different input parameters of the equations of motion of a three DOF system, was used to prepare the data for an investigation into the use of a tuned absorber to control the motion of a secondary system. A second series of programs was written to provide numerical integration solutions, including bisection, for the three DOF system with an impact damper. This series of programs were used to prepare the data for an investigation into using an impact damper to attenuate the resonance peaks of a secondary system caused by an absorber.

All programs were written to be menu driven, user friendly and allow unattended operation. The programs have been fully explained in user manuals and are available for furthering the investigations outlined in this thesis.

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Appendix A

USER MANUAL

FOR

SPREADSHEET PROGRAM SERIES "EXACT"

SPREADSHEET SOLUTIONS FOR THE TRANSFER FUNCTION OF A THREE DEGREE-OF-FREEDOM SYSTEM

This Appendix is written to be a stand alone manual describing the use of the EXACT programs. Throughout this document it is referred to as the "Manual" as opposed to Appendix A. Referenced sections, figures or appendices are contained within this manual except when identified otherwise e.g in the thesis. Stand alone versions of this manual will contain all referenced material as appendices.

Table of Contents

List of Figures

1 INTRODUCTION

The complete program consists of three different spreadsheets. The main program, EX*_MDOF[1], as presently configured, generates the transfer functions for a two or three degree-of-freedom (DOF) mass/spring/damper system with cyclic excitation of the base mass. A schematic representation of the model is given in Figure A.1. A more complete description of the situation being modelled, the development of the equations and examples of some initial investigations are given in Chapter 2.0 of the thesis. The spreadsheet uses a macro to facilitate generating the solutions and presenting the results in a graphical format. The macro allows the solution of single transfer functions or generates solutions for a "stack" of transfer functions saving them to disk for later viewing. The macro also facilitates moving around in the spreadsheet.

The other two programs compliment the main program. The stack of input variables which maybe used by the main program is contained in a separate file called EX_STACK. The variables are imported into the main file at the start of a multiple run. The third spreadsheet, called EX_COMPL is used after completing a multiple run. It uses some of the input variables contained in EX_STACK, but imports the results generated and saved by the main program into a database for comparison of the effects of different input variables on the model.

The programs are written in LOTUS 123[2] Revision 2.0. They are

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1 The asterisk within the program name EX*_MDOF is replaced with a number, which indicates the revision status of the program. For example, revision 3 is given as EX3_MDOF.

2 Trademark LOTUS Development Corporation, Cambridge, Mass. USA

fully compatible with Revisions 2.1 and 2.2. Although the programs are largely menu driven, a basic knowledge of spreadsheet programming is necessary to use these programs. However, a good knowledge of spreadsheet programming is required to understand the macros described herein. A brief description of what macros do and how they are written is given in Appendix C of the thesis. The reader is directed to the references for training and further instruction if required [LOTUS 1985].

2 INSTALLATION AND GENERAL OPERATING PROCEDURES

There are three files included in this program: EX*_MDOF, EX_STACK, and EX_COMPL. Each has the extension .wk1, indicating that they are LOTUS 123 work sheet files.

2.1 Hardware Requirements:

2.1.1 These programs will operate on any computer capable of running LOTUS 123.

2.1.2 The computer should be equipped with a hard disk drive and one 5.25" low density floppy disk drive.

2.1.3 A printer is required for the program graph output.

2.2 Software Required:

2.2.1 A copy of LOTUS 123 Revision 2.0, 2.1 or 2.2 must be installed on the computer hard drive.

2.3 Installation Procedure:

2.3.1 Copy all three programs onto the hard disk drive in a directory called EXACT.

2.3.2 Within the directory EXACT make the following subdirectories: EX_MITT and EX_BIN.

2.3.3 Start LOTUS 123.

2.3.4 Make the LOTUS default directory that which contains the directory EXACT. e.g. If the directory tree is C:\DATA\LOTUS\VIBRATE\EXACT, the default directory should be

C:\DATA\LOTUS\VIBRATE

2.3.5 Ensure that there is adequate spare capacity on the hard disk drive to store any files which will be generated. Depending on the length of the simulation, the complexity of the model movement and the number of data points retained, file sizes of 200,000 bytes can be expected.

2.4 General Operating Procedures:

2.4.1 To use any program retrieve as with any LOTUS file.

2.4.2 Each program begins with an auto start menu macro. To select from the menu either type in the first letter or move the cursor to the desired selection and press ENTER.

2.4.3 If it is necessary to quit the macros, the start-up menu can be recalled by pressing {alt}X.

2.4.4 Programs are set up with manual recalculation (The program will only recalcuate equations when the CALC button (F9) is pressed). Do not change to automatic recalculation. This will slow down operation considerably and may, in some cases, lead to improper operation of the macros.

2.4.5 Data files are saved in directory EX_MITT.

e.g. C:\DATA\LOTUS\VIBRATE\EXACT\EX_MITT

2.4.6 Plot files are saved in the default directory (VIBRATE).

2.4.7 Prior to starting a multiple run of parameters move all data files in directory EX_MITT, into directory EX_BIN. Otherwise, if file names have been inadvertently duplicated, the program will generate an error message and not continue.

3 PROGRAM DESCRIPTIONS

Listings of the three programs are given at the end of this manual. These are a printout of each of the three complete spreadsheets programs. Each page is identified with a header containing three components:

PROGRAM \ SHEET \ PAGE

The program will be one of either EX*_MDOF, EX_STACK or EX_COMPL. The sheet number refers to a section of the program as shown in Figures A.2, A.3 and A.4. The reason for this format is generally described in Appendix C, Section 2 of the thesis. Each sheet has been further split into pages for presentation herein. To facilitate presentation and understanding, some of the sheets have been modified from what would be seen when examining the spreadsheet program file:

i. Where spreadsheet menus are used they have been expanded so that they are readable (as described in Appendix C of the thesis).

ii. Some of the sheets have had range names added where they do not appear in the actual program. These additional range names have been highlighted in **bold** and are either boxed or set in lines.

iii. Where subroutines or menus are called that are not on the same page, the listing page containing the subroutine or menu is given to the right.

The remainder of this section describes the contents and output of each of the programs. Beside the heading for each program and sheet is the User Manual page number where the sheet begins. It is highlighted in bold print.

3.1 Program EX*_MDOF **[Page 136]**

See Figure A.2 for the layout of this spreadsheet. This is main program which, as presently configured, generates the transfer functions for a two or three degree of freedom mass/spring/damper system with cyclic excitation of the base mass.

3.1.1 Sheet 1: Input Variables **[Page 137]**

This sheet is laid out in the standard calculation format described in Appendix C of the thesis. It reflects the relationship of variables chosen for this particular investigation. The user can modify those parameters identified as inputs. The base mass and spring constant are input directly; the second and third mass, spring constants and damping are determined based on satisfying mass and frequency ratios specified by the user. The remainder of the parameters are a function of the input parameters and determined by calculation. The complete sheet serves to define the model parameters. Another printout of this sheet, displaying the formulas which generate the system parameters, is given in Appendix A.1.

3.1.2 Sheet 2: Input Stack [Page 138]

This sheet contains columns of input variables that match the allowable user input described for Sheet 1. Each column is also given a file name and contains instructions for the macro regarding what the input variables represent and what is to be done with the resultant data. This is further explained in conjunction with program EX*_MDOF macro subroutine MULTI (Section 4).

3.1.3 Sheet 3: Equations [Page 139]

This sheet contains the equations which constitute the transfer functions. The equations are as described in Chapter 2 and developed in Appendix D of this thesis. The inputs values for the equations are input or calculated in Sheet 1.

The sheet is divided into two columns. The left column contains the equations displayed in spreadsheet "TEXT" format. This format and the use of range names greatly facilitates the input checking. The right column contains the numerical results of the equation component to the left. To facilitate checking and confirmation of the input each component of the equation between plus or minus signs is entered in it's own cell. These are then totalled. At the bottom of the sheet the various terms are gathered and the resultant displacement and phase angles for the particular forcing function frequency value given in the Input Sheet (WWWF) are displayed.

3.1.4 Sheet 4: Macros [Page 142]

The macros in this spreadsheet facilitate three operations:

i. Movement of the cursor around the spreadsheet

ii. Varying input data to generate an output table

iii. Presentation of the output as graphs

The first 3 pages of this sheet contain menu macro for moving about the spreadsheet and selection of options to be undertaken. These are fully explained in Appendix C of the thesis. For purposes of presentation the menu macros are staggered; again see Appendix C. Starting at Page 4 the main macro begins. The flow of this macro is explained in detail in Section 4 of this manual.

The output table that the macro generates is contained in Sheet 5 and the various styles of graphs are described below. These sheets and output graphs can be generated without the use of macros and for occasional use this is all that would be required. The macros are used to facilitate the generation of numerous such databases and output graphs.

3.1.5 Sheet 5: Output Table [Page 155]

The section inside the rectangle is a spreadsheet data table titled OUT_TABLE. The top row contains resultant values from the Equation Sheet (Sheet 3) for the input values contained in the Input Sheet (Sheet 1). The left hand column contains values which are substituted, one by one, for the forcing function frequency (WWWF in Sheet 1). The spreadsheet data table function causes the output values for each of the variables noted across the top, as they vary based on the different forcing function frequencies noted on the left, to be recorded on the lines to the right of the frequency. The user can therefore generate a column which reflects, for example, the effect on the displacement of Mass 1 (XXX1) of varying forcing function frequencies. The columns of data XXX1, XXX3, XXX3, ANG1, ANG2 and ANG3 can be presented on the graphs (as described below).

The program was developed primarily to investigate the effect of different situations on Mass 2. As discussed in the main body of the thesis, one method to quantify reactions is to estimate the response of the mass to a wide band of frequencies. The last column on Page 1 is a value used in this calculation. Page 2 of Sheet 5 is actually positioned to the right of Page 1, not below it. The complete table is too wide to be viewed on an 80 character wide screen. The columns containing WWWF, XXX2 and XXX2^2/F are repeated on this Page although they are not repeated in the program. The columns named DRANGE, ERANGE and FRANGE contain data points used only to position three data labels on the output graphs. Each of the cells in the last column, SIGRANGE, contains a calculation of area under the curve of values XXX2^2/F, for that frequency step. The resultant sum of the total area under the XXX2^2/F curve is calculated and stored in the cell named SIGMA located at the top of this column. A explaination of the derivation of SIGMA is given in Appendix E of the thesis.

3.1.6 Output Graphs

Figure A.6 (a) contains a typical output graph which displays the displacement of Mass 1 (XXX1), 2 (XXX2) and 3 (XXX3) versus the ratio of forcing frequency over the natural frequency of M_1 (Column WRANGE in Sheet 5, Page 1). Figure A.6 (b) displays the phase angles (ANG1, ANG2 and ANG3) for the three masses over the same frequency range.

3.2 Program EX_STACK [Page 157]

See Figure A.3 for the layout of this spreadsheet. This is the program where stacks of input parameters, describing different systems are created and stored.

3.2.1 Sheet 1: Macros [Page 158]

The macro for this program is used primarily to move about the spreadsheet. A comment which informs the user of the operation to be performed is displayed. Upon pressing ENTER, the cursor is then moved to that section of the spreadsheet. There is also a short macro which makes modification of the filenames faster. This is modified by the user as required to add and delete letters to the list of filenames. A full description of macro operation is given in Section 4.

3.2.2 Sheet 2: Comments [Page 160]

These comments are highlighted during operation of the macro. This program is simply a list of input parameters and is normally manipulated like any other spreadsheet outside of the control macro. These comments ensure that the user retains the layout of the spreadsheet so that it can be read by the other programs.

3.2.3 Sheet 3: Output Stack [Page 161]

The layout of this sheet conforms to the layout of the input stack sheets in programs EX*_MDOF and EX_COMPL. The section of the sheet given the range name STACK is imported used by the other two programs. It is simpler and faster to develop the stack of input parameters in this smaller spreadsheet. This allows operation of the other two programs to be almost fully contained within the macros. This program, as will be discussed in Section 4, is primarily manipulated outside the macro.

3.3 Program EX_COMPL [Page 162]

See Figure A.4 for the layout of this spreadsheet. This is the program where the output generated by program EX*_MDOF can be compiled. As presently configured, the information compiled is: the amplitude of each displacement peak and the frequency at which it occurs and the value of SIGMA.

3.3.1 Sheet 1: Macros [Page 163]

The first two pages of these macros are used to either move about the program or select the operation to be performed. The two main operations performed are preparing the stack of files to be imported or compiling the data from each file.

Starting on page three the main macro to compile data begins. It extracts information from the files generated by EX*_MDOF and collects it in a manner that allows comparison of the different parameters. In most cases the original data file can be deleted since the information is either contained in this compiled format or in a graph file. This macro operation is described in detail in Section 4.

3.3.2 Sheet 2: Comments [Page 168]

As with program EX_STACK these comments are highlighted during operation of the macro. These comments advise the user of the next step to take so that the program functions properly.

3.3.3 Sheet 3: Output/Input Stack [Page 169]

Down to the line titled ZETA3, the layout of this sheet conforms to the layout of the input stack sheets in program EX_STACK. Normally the record of input parameters is imported from that file. The remaining information in each column is extracted by the macro from the file named at the top of the column. Once the macro is finished operating the file is saved, replacing EX_COMPL. Further manipulation of the data is left to the operator.

4 MACRO OPERATION

For all three programs when the file is retrieved, an auto start macro[3] displays a menu. The basic operations for which the programs were designed are menu driven, but in some cases it is necessary to perform routine spreadsheet manipulations outside of the macro. Operations to be performed outside of the macros are described as "manual".

In the start-up menu, the BROWSE selection moves the user around the spreadsheet. The method is described in Appendix C of the thesis. The QUIT selection exits the macro and returns operation to the keyboard. This is primarily used in conjunction with BROWSE. No further explanation of either of these selects is given in this manual.

When reading this section, it is recommended that the appropriate program be installed and running. If not possible, refer to the program listings in this manual for details of what each operation is specifically being performed. In the program listings, each time a subroutine or menu is called which is not on the same page, the listing page reference is given to the right.

4.1 Program EX*_MDOF [Page 142]

Start-up Menu:

RUN **SAVE** **VIEW** **BROWSE** **QUIT**

---

3 In LOTUS 123, any macro named \0 is automatically called when the spreadsheet file is retrieved.

4.1.1 RUN

Selecting RUN displays the following menu:

SINGLE MULTI ABORT

If for some reason the user does not wish to continue ABORT will return to the main menu. This is a standard command that is repeated in different menus.

SINGLE is selected if the user wishes to generate the transfer functions for a single set of input variables. This function utilizes most of the subroutines and options and will be explained first. The MULTI selection is explained at the end of this section. Upon selecting SINGLE the following menu is displayed:

CHANGE RETAIN Menu 1

If the user wants to retain the existing input variables, RETAIN is selected, whereupon the following menu is displayed:

UPDATE RETAIN ABORT

If the user wants to retain the existing output table then RETAIN is selected. If the variables have been changed at some prior point and the output table is incorrect, then UPDATE should be selected.

Selecting CHANGE in Menu 1 above utilizes all the features of this portion of the macro. The commands executed after selecting CHANGE are the subroutines MANMODS, SPECTRUM, DATABASE, LABELS and TITLES.

4.1.1.1 Subroutine MANMODS:

This routine moves to the inputs (Sheet 1) and goes to each of the "input" cells in turn to allow changes to be made. Each time ENTER is pressed the next input is highlighted. If a mistake is made it is possible to return to that cell using the cursor keys and make the modification. Using the ENTER key activates the macro to move to the next input. At several points through the input procedure, the spreadsheet is recalculated to update the related cells. This allows the user to verify the results of the inputs. It is possible to revise the variables by leaving the macro and make changes without being prompted by the macro. To restart the macro, press {alt}X.

4.1.1.2 Subroutine SPECTRUM

This determines the range of frequencies over which the transfer functions will be generated. It displays a menu giving three options:

AUTO **MANUAL** **ABORT**

The AUTO (automatic) selection takes zero as the start point for the range and 1.6 times the highest frequency as the end point. The highest frequency is selected from the natural frequencies for each mass and its associated spring. The program has been preset to give 250 equally spaced frequencies over this range. The means of altering this constant is given in Section 6. Upon selecting manual, the macro prompts the user to input selections for the lower and upper limits. This range is again divided into 250 equally spaced steps. Either selection copies the resultant step into a range, FREQSTEP, for use in determining the RMS (Root Mean Square) values.

4.1.1.3 Subroutine DATABASE

Here the database is set up and calculated. The input variable is preset to be the forcing function frequency and the depth of the table range, OUT_TABLE, matches the number of frequency data points, again preselected as 250. This can be altered (see Section 6). Next an equation contained in a cell titled SIGMABIT is copied into the column SIGRANGE. This gives the area under the curve for each frequency step. The results are changed from equations to values and totalled in a cell titled SIGMA. A complete description of the derivation of this value is given in Appendix E of the thesis.

4.1.1.4 Subroutine LABELS

This subroutine adds input parameter data to the graph. The graphs given in Figures A.5 contain three lines in the lower left corner. These contain some of the input variables and allow the graph to be interpreted without referring to other sheets containing the input parameters which generated the graphs. The input variables are included in the chart by means of the spreadsheet graph data label function. Since only three output ranges are displayed in the graph at one time, there are an additional three ranges available. The program uses these to position the three lines. The table in Sheet 5, Page 2 contains three columns titled DRANGE, ERANGE and FRANGE. Each contains one point in line with the first frequency data point. These data points are located at the bottom of the graph, below all the other data. The spacing is a preset percentage of the Y-axis displacement range. The percentage is noted above the column range names. These data points are not displayed, but each is assigned a data label. Column FRANGE contains a second point which lowers the Y-axis sufficiently so that the lowest data label is above the X-axis scale. This routine enters the input variables for this run into the cells which have been identified as the data labels. It writes over any previous data label.

4.1.1.5 Subroutine TITLES

TITLES allows quick updating of the graph titles and legends. In addition, it removes indication of the third mass if only a two mass system is being modelled. The subroutine also contains programming code which, when making multiple runs, allows that macro to bypass the user inputs selections. See Figure A.7 where the various changeable titles and labels have been replaced with their identifying range names. Upon entering the routine the user chooses to either retain or change TITLE 1 with the menu:

RETAIN CHANGE

If CHANGE is selected the user is prompted for a new title. A similar menu is displayed for TITLE 2 which records the filename and value of SIGMA on the graph. The next menu asks for a description of the base, Mass 1. The menu is:

TRUCK STRUCTURE OTHER

In this program, the normal choices are that the base is either a TRUCK or a STRUCTURE. These have been stored in the program. The user can type in an alternate choice by selecting OTHER. The user is then prompted to type in a description.

After this last menu selection is made, the program enters the input for TITLE 1, TITLE 2 and LEGEND A onto the graph. The legends for ranges B (EQUIPMENT) and C (ABSORBER) have been previously entered into the program. See Section 6 for how to revise these.

The next menu presented to the user is:

ABSORBER NO_ABSORB

The program can be used to model a two degree of freedom system by selecting the natural frequency ratio for masses 1:3 to be greater than 100 so that the spring for mass three is extremely stiff. Mass 3 can then be selected to be 1/100000 of Mass 2 which will make it relatively insignificant. The damping for mass 3 is then chosen to be 100% of critical. The end result is that masses 2 and 3 are rigidly connected and act as a single mass. In this case, while the equations still generate the transfer functions for the third mass it has effectively the same displacement and phase angle as mass 2. For presentation purposes it is desirable to remove any indication of the third mass from the output graphs. Selecting NO_ABSORB calls up a subroutine called DITCH which does the following:

i. The legend for the graph C range, which is for Mass 3 is deleted.

ii. The display mode for C range is revised so that neither lines or symbols are displayed.

iii. The display mode for mass 1 is set to lines only and for mass 2 to both lines and symbols.

iv. The program moves to each of the data label cells in turn and deletes references to the third mass.

Figure A.8 (b) is a graph of the same data points displayed in Figure A.8 (a) with all indication of the Absorber (mass three) removed.

If ABSORBER is selected, a subroutine called RETAIN reestablishes the legend for C range and confirms all the display modes.

This is necessary because a prior run may have been without an absorber or the user may have manually changed the display modes for the other ranges.

4.1.2 VIEW

Having generated the transfer functions the best method for drawing initial conclusions about the reaction of the model is to view a graph of the results. Upon selecting VIEW from the main menu, Subroutine VIEWER is called and the following menu is displayed.

PH_ANGLES DISPLACE

Depending on which is selected the macro does the following:

i. Places the appropriate suffix in the subroutine SAVER for saving the graph file.

ii. Places the appropriate Y-axis title in the subroutine TITLEY

iii. Calls up the subroutine which sets either the displacements or the phase angles as graph ranges A, B and C.

iv. Copies the minimum and maximum values from the ranges to be plotted into the registers MINYAXIS and MAXYAXIS. These are used by graph ranges D, E, and F to position the input parameter labels set-up by the LABELS subroutine.

The macro then asks the user whether to display the input parameters on the graph by presenting the menu:

DISPLAY REMOVE

If DISPLAY is selected, subroutine INPT_PLT is called up. This sets DRANGE, ERANGE and FRANGE as graph ranges D, E and F respectively. If REMOVE is selected, the macro ensures that those three graph ranges are empty. Figures A.6 (a) and (b) show a typical Displacement and Phase Angle graphs respectively with the input parameters displayed. Figures A.9 (a) and (b) show the same graphs without the input parameters displayed.

The next menu asks whether the user wants to view the full graph or just a portion of the graph. The menu presented is:

FULL ZOOM

Selecting FULL causes the graph scaling option to be set to automatic; all the data points are viewed. Selecting ZOOM presents the following menu:

AS_BEFORE NEW

AS_BEFORE uses whatever values have been previously entered as manual settings for the X and Y scales. The scaling option for both these axis is set to manual and the graph is displayed on the screen. Selecting NEW calls up the ZOOM subroutine. The macro signals that when the graph is displayed, the user should note limits of the area of interest. Selecting ENTER displays the full graph. Pressing any key prompts the macro to ask for the desired maximum and minimum values of both the X and Y axis. These are stored as numbers and then converted to strings so the macro can enter them as the manual scale settings and display the results. Figure A.10 (b) is a graph of a "zoomed in" portion of the complete graph displayed in Figure A.10 (a). It should be noted that ZOOM does not create additional data points. The existing data points within the area of interest are spread over the full screen. If the area is small there will be a noticeable raggedness to the graphs. If greater accuracy is required the database should be regenerated using the zoom limits as the database limits. Then, that range will be divided into 250 steps.

4.1.3 SAVE

This selection allows the user to save the file and/or the current graph configuration under the name given to the plot file. It is assumed that there are no other files with the same name in the target directory. If there are, the macro will stop functioning. The user is presented with the menu:

PLOT FILE

Selecting either will initiate a save and then return to the main menu. Either an D for displacement or a P for Phase angle is appended to the filename to describe the graph that is being saved. This allows both styles of graph to be saved under the same filename.

4.1.4 RUN\MULTI

This selection is the most useful function of the macro. A previously stored stack of input variables can be executed without the user being in attendance. Upon selecting MULTI a flag, indicating that a stack of input variables is being run, is set to "ON". The macro now by-passes any user input requests and take direction from data given in the stack. Where practical, subroutines used by the RUN\SINGLE program are utilized.

The stack of input parameters for a multiple run is stored in the program on Sheet 2, as shown in the program listings. The stack can extend to the right to the limits of the spreadsheet. The cursor is moved to this area, the existing stack is erased and the new stack is imported from file EX_STACK. The limit of the stack is marked to flag completion. Then the following menu is presented:

QUIT **CONTINUE**

The user is asked if the input stack, just imported from file EX_STACK, is properly set-up for the run. If it is not, the user must quit this macro and program to investigate EX_STACK. Assuming that it is the user selects CONTINUE and the subroutine MULTI continues.

Returning to the first column of input parameters at the beginning of the stack, the location of the next set of inputs is marked. The macro then notes the filename and steps down the first set of inputs, copying values into each of the input parameter cells. The titles on the left identify each input. There has to be a value present and the macro assumes the order is correct. The inputs include the title for the graphs and the legend for the first mass. The next two inputs in the stack are the minimum and maximum X-axis points. The MULTI subroutine always sets the database range manually. Therefore, the range of interest should be known when setting up the input stack.

The frequency steps are set up using the subroutine MANADJUST, the frequency step is noted and the database is calculated. The graph labels and titles are set up. A MULTI generated transfer function always contains the input parameter data labels. Since it is necessary for the cursor to leave it's position in the input stack when running subroutine LABELS, the position is marked so that the cursor can go back.

If the system has been designed to emulate a two DOF system the next input will indicate that there is no absorber (Mass 3). If so the DITCH subroutine is called. If not the RETAIN subroutine ensures that the settings reflect a three mass system.

The next three cells in the stack tell the macro what to save. Assuming that all three options are set to yes both the displacement and phase angle graphs are saved as well as the work sheet file itself. Before saving either of the graphs, they must be generated by the macro. The appropriate ranges are selected and the Y-axis title is revised to suit each plot.

The cursor then moves to the position at the top of the next column, which it had marked. Moving down to what should be the next filename, the macro tests if it has reached the end of the stack. If so, the flag is set to "OFF" and the main menu is displayed again. If there is another file, the subroutine loops back to where the inputs are copied into the input sheet. From this point, macro operation is exactly the same as previously described.

4.2 Program EX__STACK [Page 158]

Start-up Menu:

EDIT **NAME** **BROWSE** **SAVE** **QUIT**

4.2.1 EDIT

Selecting EDIT displays the following menu:

INPUTS **FILENAME**

Upon selecting INPUTS, the macro displays a comment advising the user on how to edit or add to the input variable stack. Editing of the stack is done outside of the macro. The rows must remain the same, but any number of columns can be added. The columns must be beside each other, without any blanks.

If FILENAME is selected a comment is displayed which advises the user that the next menu will give the choice of setting up the macro or starting to edit filenames.

SETUP **EDIT**

Selecting SETUP displays the macro for revising the filename and puts the cursor on the line to be revised. It is recommended that a system of filenames be devised that described the contents. Appendix A.2 contains the file name matrix for the research project described in Chapter 2.0 of the thesis. Given this format, each filename will be similar to the next. Using normal spreadsheet practices a template filename could be copied to the top of each input column e.g. TEA312A. By inputting the line:

{left 3}{del}{?}

the macro will delete the "1" in each name in turn and allow the user to type in another character. In this way, each column in turn could be named TEA322A, TEA332A, TEA342A etc. This is much faster than typing in each filename separately, or editing each one manually. If all the files where to be revised in a similar manner, e.g. changing the last character from an "A" to a "B" the macro line would be:

{bs}B

No input would be required from the user.

Assuming that the macro has already been revised, the user would select EDIT. The macro moves the cursor to the stack sheet and waits for the user to move the cursor to the first (furthest left) filename to be revised. Upon pressing ENTER
the macro revises all filenames to the right, stopping only upon reaching the termination code.

4.2.2 NAME

This selection is made to give the output stack the range name STACK. A comment is displayed which advises the user to complete or revise the selection of the range initiated by the macro. This is done in the normal spreadsheet fashion, using the cursor to define a range of cells.

4.2.3 SAVE

This selection saves the spreadsheet under the name EX_STACK, replacing the existing file. If the changes made to the spreadsheet are not saved, then the other programs do not have access to them.

4.3 Program EX_COMPL **[Page 163]**

Start-up Menu:

COMPILE SETUP BROWSE QUIT

4.3.1 SETUP

Initially, the user sets up the stack of files with their input parameters. To these, the program will add the output data generated by the EX*_MDOF program. To do this, the user selects SETUP which displays a descriptive comment and moves to the stack. Manipulations to the stack are done manually because, although often the stack is imported from the file EX_STACK, this is not always the case.

The macro places the cursor in the cell named "START". If there are old data in the stack area this should be removed manually by using the spreadsheet RANGE\ERASE command and defining the extent of the old data. Prior to doing this, be sure that the data has been saved in another file or it will be lost. If the input variables stored in program EX_STACK are the ones to be compiled, the command FILE\COMBINE \COPY\NAME will retrieve them. Ensure that the top of the range is in line with the row PLOTFILE. In addition to input variables the range STACK contains instructions to the macro in EX*_MDOF. These must be removed. Using the RANGE\ERASE command delete all data below the row ZETA3. These rows will then store the compiled data.

Ensure that there is actually a file in directory RK_BIN for each of the PLOTFILE's listed. If not, when compiling, an error message will be generated and the macro will stop. Sometimes, a large stack of files may have been broken up into smaller batches because of limited time or disk space. Insert a column after the last file that has been generated, and put the flag for program completion there. The files to the right can be compiled after the next batch is run.

Having set up the input stack the macro is restarted with the command {alt}X. The start-up menu is again displayed.

4.3.2 COMPILE

Selecting COMPILE branches to the compilation macro. The screen displays COMMENT 1, advising the user on where to position the cursor in the stack. The macro will compile from where the cursor is positioned, and all files to the right until it detects a cell containing the termination flag. The first file is not necessarily in the START position, if compiling the stack in batches.

The macro notes the cell it is on by giving it a range name, MARK1. The graph file name is copied into the COMBINE subroutine and the cursor is moved to the area where data is imported. The column of displacement data for Mass 2 is imported, and beside it the associated frequencies.

Subroutine EVEREST moves down the column of displacements looking for peaks. These are sensed by comparing the value of each cell with those in the cells immediately before and after it. If a cell's value is a peak then it's value and associated frequency are recorded by subroutine RECORD. This routine tracks which peak this is (first, second or third) and saves the values into the appropriate register. The peak count is then increased by one and the cursor is moved back to the correct location in the column. Upon returning operation to subroutine EVEREST, the macro checks if all the expected peaks have been found. The system being modelled can only have a maximum of three peak displacements, so if three have been found there is no point in searching the remainder of the column.

Once all the peaks have been found, subroutine EVEREST returns operation to the COMPILE macro. The imported data is erased. The peak values and frequencies are copied below the stack for this file. The macro then imports the value for SIGMA from the same file. Compilation of this particular file's data is complete.

The cursor moves back to the top of the stack and shifts to the right. If the cell contains the termination flag the program saves itself and stops. If not, the COMPILE macro continues with the next file. After all the file stacks have been compiled, the user has a record of the input variables and the output results. This data should be moved into a new spreadsheet file so that EX_COMPL can be used for the next investigation. Sheets 1 and 2 of the program are no longer required and can be deleted. Further data manipulation is left to the user.

5 Example Problems

To demonstrate the use of the various programs and the user interface, the programs will be used to generate solutions for two different sets of model parameters, using both the multiple and single routines. The models will be as described in Figures A.11 (a) and (b). The order of utilization of the programs is EX_STACK, EX*_MDOF and then EX_COMPL. While reading this section it would be useful to have the various programs available on a computer. The user can then recreate the steps as they are presented. The programs should be installed on the computer as described in Section 2.

Each user step is identified by a number. As indicated previously, the use of the term "manually" means use standard spreadsheet commands, outside of the macro.

5.1 Program EX_STACK

5.1.1 Manually retrieve program EX_GRAPH

Start-up Menu: **EDIT** **NAME** **BROWSE** **SAVE** **QUIT**

5.1.2 Select EDIT.

Menu: **INPUTS** **FILENAME**

5.1.3 Select INPUTS.

Program displays Comment 1

5.1.4 Read Comment 1, Press ENTER.

Menu: **TITLES** **NO**

5.1.5 Select TITLES.

Cursor is moved to position noted below and titles are set.

```
      A          B                          C      D        E       F
 Stack input
 PLOTFILE
 MMM1      Mass 1
 KKK1      Spring Rate 1
 ZETA1     Damping Ratio
 ....
```

5.1.6 Type first file name. In this case SE_1__D.

```
      A          B                          C      D        E       F
 Stack  input
 PLOTFILE                                 SE_1__D
 MMM1      Mass 1
 KKK1      Spring Rate 1
 ZETA1     Damping Ratio
 ....
```

5.1.7 Type model and program parameters. Selections of program parameters are based on experience. Only part of the file is shown here for brevity.

```
      A          B                          C      D        E       F
 Stack input
 PLOTFILE                                 SE_1__D
 MMM1      Mass 1                         1000
 KKK1      Spring Rate 1                  1000
.. ...     .......                         ...
 WRAT2:1   Nat'l Freq Ratio                0.2
.. ...     .......                         ...
 ABSORBER                                   no
 =========================================
 AMP_PLOT                                   no
 PH_PLOT                                    no
 FILESAVE                                  yes
```

5.1.8 Manually copy column as required, in this case twice. Only the top portion of the spreadsheet is shown since that is all that is altered in this example.

```
      A          B                          C      D        E       F
 Stack input
 PLOTFILE                               SE_1__D  SE_1__D SE_1__D
 MMM1      Mass 1                          1000     1000    1000
 KKK1      Spring Rate 1                   1000     1000    1000
.. ...     .......                          ...      ...     ...
 WRAT2:1   Nat'l Freq Ratio                 0.2      0.2     0.2
.. ...     .......                          ...      ...     ...
```

5.1.9 Manually move across columns changing input parameters as required. Although this is a simple example, the macro will be used to alter the filenames.

```
      A         B                             C          D          E     F
   Stack input
   PLOTFILE                               SE_1__D    SE_1__D   SE_1__D
   MMM1       Mass 1                         1000       1000      1000
   KKK1       Spring Rate 1                  1000       1000      1000
..  ...       .......                         ...        ...       ...
   WRAT2:1    Nat'l Freq Ratio                0.2        0.5       5.0
..  ...       .......                         ...        ...       ...
```

5.1.10 Press {alt}X.

Start-up Menu: **EDIT** **NAME** **BROWSE** **SAVE** **QUIT**

5.1.11 Select EDIT.

Menu: **INPUTS** **FILENAME**

5.1.12 Select FILENAME.

Program displays Comment 3.

5.1.13 Read Comment 3, Press ENTER.

Screen display is as below with cursor located as shown:

```
      A          B        C         D        E          F

    LOOP      {edit}            <  \F
                                                  < Edit this line
             ~{right}
              {if @cellpointer("contents")=NOMORE}{menubranch MENU0}
              {branch LOOP}
```

5.1.14 Type new code required to change file name. In this case move left four spaces delete the 1 and wait for user to type the new character.

```
      A          B        C         D        E          F

    LOOP      {edit}            <  \F
              {left 4}{del}{?}                    < Edit this line
             ~{right}
              {if @cellpointer("contents")=NOMORE}{menubranch MENU0}
              {branch L{menubranch MENU0}
```

5.1.15 Press {alt}X.

Start-up Menu: **EDIT** **NAME** **BROWSE** **SAVE** **QUIT**

5.1.16 Select BROWSE.

Menu: MACROS STACKS COMMENTS

5.1.17 Select STACKS.

Start-up Menu: EDIT NAME BROWSE SAVE QUIT

5.1.18 Select QUIT to leave macro.

5.1.19 Manually move cursor to right of last column filename and type 999 (NOMORE).

A	B	C	D	E	F
Stack input					
PLOTFILE		SE_1__D	SE_1__D	SE_1__D	999
MMM1	Mass 1	1000	1000	1000	
KKK1	Spring Rate 1	1000	1000	1000	
...	....	...	...	...	
WRAT2:1	Nat'l Freq Ratio	0.2	0.5	1.0	

5.1.20 Manually move cursor to first filename to be altered, in this case, the one in column D, above 0.5.

5.1.21 Press {alt}F to evoke name change macro.

Cell contents will be altered to SE___D and macro waits for user input.

5.1.22 Type character to replace the 1, in this case 2.

Cursor moves to next cell right (Column E). Cell contents will be altered to SE___D and macro waits for user input.

5.1.23 Type character to replace the 1, in this case 3.

Cursor moves to next cell right (Column E) senses 999 and stops \F macro execution and returns to start-up menu. Display now looks like:

A	B	C	D	E	F
Stack input					
PLOTFILE		SE_1__D	SE_2__D	SE_3__D	999
MMM1	Mass 1	1000	1000	1000	
KKK1	Spring Rate 1	1000	1000	1000	
...	....	...	...	...	
WRAT2:1	Nat'l Freq Ratio	0.2	0.5	1.0	
...	....	...	...	...	

Start-up Menu: EDIT NAME BROWSE SAVE QUIT

5.1.24 Select NAME.

Program displays Comment 2.

5.1.25 Read Comment 2, Press ENTER.

Cursor will move to limits of the range name STACK as presently defined. Use periods (.) and cursor arrows to define STACK as shown (within the rectangular box). Press ENTER to accept.

A	B	C	D	E	F
Stack input					
PLOTFILE		SE_1__D	SE_2__D	SE_3__D	999
MMM1	Mass 1	1000	1000	1000	
KKK1	Spring Rate 1	1000	1000	1000	
...	....	...	...	...	
WRAT2:1	Nat'l Freq Ratio	0.2	0.5	1.0	
...	....	...	...	...	
ABSORBER		no	no	no	
=============	=============	========	========	========	
AMP_PLOT		no	no	no	
PH_PLOT		no	no	no	
FILESAVE		yes	yes	yes	

Start-up Menu: **EDIT NAME BROWSE SAVE QUIT**

5.1.26 Select SAVE.

Program saved as EX_STACK, replacing existing.

Start-up Menu: **EDIT NAME BROWSE QUIT**

5.1.27 Select QUIT.

User can either retrieve next file or perform other functions.

5.2 Program EX*_MDOF (Multiple Run)

5.2.1 Retrieve program EX*_MDOF.

Start-up Menu: **RUN SAVE BROWSE VIEW QUIT**

5.2.2 Select RUN.

Menu: **SINGLE MULTI ABORT**

5.2.3 Select MULTI.

Program imports range STACK from EX_STACK.

Menu: **CONTINUE** **QUIT**

5.2.4 Review STACK and determine if as expected. If okay select CONTINUE.

Macro will now generate solutions for the three files in STACK unattended. The position of program in stack is updated as each set of parameters is input and the file generated. Upon completion, the start-up menu is displayed again. If the user wishes to perform other manipulations with the data from the last run, in this case SE_3__D, this may be done now. See Section 4.1 for a description of the options. This example assumes that the user wants to view the phase angle plot for the last file to ensure that everything has worked properly.

Start-up Menu: **RUN** **SAVE** **BROWSE** **VIEW** **QUIT**

5.2.5 Select VIEW.

Menu: **PH_ANGLES** **DISPLACE**

5.2.6 Select PH_ANGLES

Menu: **DISPLAY** **REMOVE**

5.2.7 Select DISPLAY to see the summary of input data on the graph.

Menu: **FULL** **ZOOM**

5.2.8 Select ZOOM

Menu: **AS-BEFORE** **NEW**

5.2.9 Select NEW to reset the limits of the graph.

Screen panel displays message:

When graph is displayed, note desired limits.

5.2.10 Press ENTER.

Screen displays full extent of plot. See Figure A.9 (a). Note the following limits for the desired plot:

Lower X :	0.4
Upper X :	0.6
Lower Y :	-0.5
Upper Y :	1.0

5.2.11 Press ENTER.

Screen panel displays message: Desired low limit of X scale ?

5.2.12 Type 0.4, press ENTER.

Screen panel displays message: Desired upper limit of X scale ?

5.2.13 Type 0.6, press ENTER.

Screen panel displays message: Desired low limit of Y scale ?

5.2.14 Type -0.5, press ENTER.

Screen panel displays message: Desired upper limit of Y scale ?

5.2.15 Type 1.0, press ENTER.

Screen displays plot as defined with summary of input parameters. See Figure A.9 (b).

5.2.16 Press ENTER.

Start-up Menu: **RUN** **SAVE** **BROWSE** **VIEW** **QUIT**

User can now either quit the program (Select QUIT), view the data in a different format or generate new data. The next section gives an example of a "single" run.

5.3 Program EX*_MDOF (Single Run)

5.3.1 Retrieve program EX*_MDOF.

Start-up Menu: **RUN** **SAVE** **BROWSE** **VIEW** **QUIT**

5.3.2 Select RUN.

Menu: **SINGLE** **MULTI** **ABORT**

5.3.3 Select SINGLE

Menu: **CHANGE** **RETAIN**

5.3.4 Select CHANGE.

Having selected this option the program assumes that the database and the graph labels should also be changed. First, the program moves the cursor to the INPUT Section (SHEET 1) and in turn moves down to each input cell (identified as {input}). The user can accept the value in the cell or type a new value. Pressing ENTER moves the cursor to the next cell until finished. For this example, the values will be:

WWWF	=	1.0
MMM1	=	1000
KKK1	=	1000
ZETA1	=	0.01 (1.0%)
MRAT1:2	=	200
WRAT2:1	=	1
ZETA2	=	0.01 (1.0%)
MRAT2:3	=	10
WRAT3:1	=	1
ZETA3	=	0.1 (10%)

Menu: **AUTO** **MANUAL**

5.3.5 Select MANUAL

Screen panel displays message: Type in lower X axis position :

5.3.6 Type 0.5, press ENTER.

Screen panel displays message: Type in lower X axis position :

5.3.7 Type 1.4, press ENTER.

Program divides the span between 0.5 and 1.4 into 250 data points. The data table is then automatically generated, the value for SIGMA is determined and the summary of input parameters are read in as data labels. The user is then prompted for information re: the graph title.

Menu: **RETAIN** **CHANGE**

5.3.8 Select CHANGE.

Screen panel displays message: Type in new plot title :

5.3.9 Type "STRUCTURE AND EQUIPMENT W/ ABSORBER". Press ENTER.

To prompt for file name:

Menu: **RETAIN** **CHANGE**

5.3.10 Select CHANGE.

Screen panel displays message: Type in new plot file name :

5.3.11 Type "SEA3K3E". Press ENTER.

To prompt for label for primary mass:

Menu: TRUCK STRUCTURE OTHER

5.3.12 Select STRUCTURE.

To determine if there is a third mass:

Menu: ABSORBER NO_ABSORB

5.3.13 Select ABSORBER.

Start-up Menu: RUN SAVE BROWSE VIEW QUIT

In this example, save the displacement plot and then the file itself. To do this, first view the plot to ensure the proper set-up.

5.3.14 Select VIEW.

Menu: PH_ANGLES DISPLACE

5.3.15 Select DISPLACE

Menu: DISPLAY REMOVE

5.3.16 Select DISPLAY to see the summary of input data on the graph.

Menu: FULL ZOOM

5.3.17 Select FULL

The program sets up the range, reads DISPLACEMENT in as the Y axis and displays the graph.

5.3.18 Press any key to escape.

Start-up Menu: RUN SAVE BROWSE VIEW QUIT

5.3.19 Select SAVE.

Menu: PLOT FILE

5.3.20 Select PLOT.

Program saves the configured displacement plot as file SEA3K3ED

Start-up Menu: RUN SAVE BROWSE VIEW QUIT

5.3.21 Select SAVE.

Menu: PLOT FILE

5.3.22 Select FILE.

Program saves complete file as file SEA3K3E

Start-up Menu: **RUN** **SAVE** **BROWSE** **VIEW** **QUIT**

User can now either quit the program (Select QUIT), view the data in a different format or generate new data.

5.4 Program EX_COMPL

5.4.1 Ensure that all files to be compiled have been moved from the EX_MITT directory to the EX_BIN directory.

5.4.2 Retrieve file EX_COMPL.

5.4.3 If data presently contained in the file is to be retained and manipulated separately the file should first be manually saved under a different filename.

Start-up Menu: **COMPILE** **SETUP** **BROWSE** **QUIT**

5.4.4 Select SETUP.

Program displays Comment 2

5.4.5 Read Comment 2, Press ENTER.

Macro moves cursor to STACK sheet.

```
     A         B         C         D         E         F
Stack input file
                    Start
                    VVVVVVVVV
PLOTFILE
MMM1
```

5.4.6 Manually move cursor to the position where STACK data to be imported. Erase data or move if required. In this case, position cursor as shown under START.

5.4.7 Manually combine range named STACK from file EX_STACK.

A	B	C	D	E	F
Stack input file					
		Start			
		VVVVVVVVV			
PLOTFILE		SE_1__D	SA_2__D	SA_3__D	
MMM1		1000	1000	1000	
KKK1		1000	1000	1000	
...		...	...	...	
ZETA3		1.0	1.0	1.0	
...		...	...	...	
ABSORBER		no	no	no	
==					
AMP_PLOT		no	no	no	
PH_PLOT		no	no	no	
FILESAVE		yes	yes	yes	

5.4.8 The results of file SEA3K3E should also be retrieved. This can be done by adding a column with the file name SEA3K3E and typing in the cell values down to ZETA3.

A	B	C	D	E	F
Stack input file					
		Start			
		VVVVVVVVV			
PLOTFILE		SE_1__D	SA_2__D	SA_3__D	SEA3K3E
MMM1		1000	1000	1000	1000
KKK1		1000	1000	1000	1000
...		...	...	...	...
ZETA3		1.0	1.0	1.0	0.1
...		...	...	...	
ABSORBER		no	no	no	
==					
AMP_PLOT		no	no	no	
PH_PLOT		no	no	no	
FILESAVE		yes	yes	yes	

5.4.9 The information in all the columns below the row ZETA3 is not required and must be deleted manually.

A	B	C	D	E	F
Stack input file					
		Start			
		VVVVVVVVV			
PLOTFILE		SE_1__D	SA_2__D	SA_3__D	SEA3K3E
MMM1		1000	1000	1000	1000
KKK1		1000	1000	1000	1000
...		...	...	...	...
ZETA3		1.0	1.0	1.0	0.1

5.4.10 Press {alt}X.

Start-up Menu: **COMPILE** **SETUP** **BROWSE** **QUIT**

5.4.11 Select COMPILE.

Program displays Comment 1

5.4.12 Read Comment 1, Press ENTER.

Screen displays stack.

5.4.13 Manually move cursor to cell to the right of last file to be compiled, in this case SEA3K3E. Press ENTER.

Macro will copy NOMORE (999) into this cell.

A	B	C	D	E	F	G
Stack input file						
		Start				
		VVVVVVVVV				
PLOTFILE		SE_1__D	SE_2__D	SE_3__D	SEA3K3E	999
MMM1		1000	1000	1000	1000	
KKK1		1000	1000	1000	1000	
...		...	...	...	...	

5.4.14 Manually move cursor to first file to be compiled, in this case SE_1__D. Press ENTER.

The program imports data from each file and extracts the information required. The data is stored at bottom of each column against the appropriate descriptive title. When macro senses cell containing 999 it stops compiling and saves the file, replacing the existing EX_COMPL file. Start-up menu is then displayed.

Start-up Menu: COMPILE SETUP BROWSE QUIT

5.4.15 Select QUIT.

5.4.16 If there is no more data to be compiled as part of this batch, save the file under a different name. The new file can be manually condensed to retain only the database. Subsequent manipulation will be totally manual. User can either retrieve another file or perform other functions.

6 Program Revisions

The program revisions covered in this section are generally of a minor nature. They assume the the general purpose of the spreadsheet is retained, i.e. an investigation of a two or three degree of freedom spring/mass/damper system with a single external excitation force. The spreadsheet programs are a good basis from which to develop new programs which investigate completely different phenomena. Before attempting this, it is important to be very familiar with how the program works and how to write spreadsheet macros.

6.1 Program EX*_MDOF

If this program file is significantly changed , it should be saved under the next revision number. The file name is alos printed in a macro located in Sheet 4, Page 13. The new file name should be entered there as well.

6.1.1 The Input Variables:

6.1.1.1 The relationship between any of the parameters which are not identified as inputs can be revised by moving to the appropriate cell and typing in a new value or equation.

6.1.1.2 To add or delete parameters identified as inputs in the INPUT Sheet, they must also be added or deleted from the following locations:

Program EX*_MDOF:	MULTI Subroutine	Sheet 4, Page 12
	MANMODS Subroutine	Sheet 4, Page 6
	Stack	Sheet 2, Page 1
Program EX_STACK:	Stack	Sheet 3, Page 1
Program EX_COMPL:	Stack	Sheet 3, Page 1

The inputs must be added in the same location in each area so that the macros will not get out of synchronization.

6.1.2 The Transfer Functions:

The transfer functions (Sheet 3) are developed to model a particular mass/spring/damper arrangement with external excitation of the base mass. The equations in this Sheet take input parameters from Sheet 1 and calculate output values for displacement and phase angle for the model. These values are contained at the bottom of Sheet 3, Page 4.

6.1.2.1 Using the same inputs, with similar outputs, any appropriate equations can be substituted for those presently in the program. The user must ensure that the output values retain the same range names.

6.1.2.2 As presently configured the program can model either a two or three DOF system. A two DOF system is modelled by choosing spring and damping ratios such that third mass is very small and rigidly connected to the secondary system. The same method can be used to hold all three masses together, but there is no automatic provision for removing indication of the second mass from the graphs. This can be done by quitting the macro and manually changing the graph settings.

6.1.3 Output Graph

6.1.3.1 The preset titles for the graphs are given in Figure A.6. To change these, quit the macro and use the spreadsheet graph menus.

6.1.3.2 The data labels are generated by the LABELS subroutine (Sheet 4, Page 4). This takes various numeric values from the INPUT sheet and converts them into labels so that they can be read by the macro. The user can revise the values recorded by changing the parameters in the @string functions. Ensure that the portion of each label identifying the numeric value is also changed.

6.1.3.3 As presently configured, the output table (Sheet 5, Pages 1 and 2) contains 250 data points. The size of the table can be changed by inserting or deleting rows anywhere below the sixth row or above the bottom row. The associated ranges will be automatically adjusted since the anchor points are not erased. Then the numeric value POINTS contained in subroutine SPECTRUM (Sheet 4, Page 7) must be changed to match the number of rows in the output table. Note that when counting the number of rows do not include the top row, since this contains the equations and is not part of the spectrum of frequencies. After doing this the macro will regenerate the table in it's new size.

6.2 Program RK_STACK

Normally the only reason to change this program is for compatiblity with RK*_MDOF or RK_COMPL.

6.2.1 The comments which provide information to the user can be revised by quitting the macro and typing additional information.

6.3 Program EX_COMPL

This program extracts information from the files generated by EX*_MDOF. Presently, it extracts the peak values for the displacement of Mass 2 and the value of SIGMA.

6.3.1 To extract the peak values of either Mass 1 or 3 rather than Mass 2 involves changing one line. In the COMPILE subroutine (Sheet 1, Page 3) the eighth line down reads:

/fccnX2RANGE~{COMBINE}

Changing the X2RANGE to either X1RANGE or X3RANGE will change the displacement range imported.

6.3.2 To import all three displacement curves so that their peaks can be compiled, the subroutine COMPILE must be enlarged. Below the twentieth line "{down}" insert 28 rows. Then copy the portion of the macro from the seventh to the twentieth line (identified as REPEAT in the macro) into this space twice. It will now be repeated three times. Modify the second to import X1RANGE and the third to import X3RANGE. The titles of the INPUT/OUTPUT stack will have to be shifted down and revised to properly label the compiled data. If only two of the displacements are required, the macro is only repeated twice.

6.3.3 To compile other single values such as SIGMA, insert rows and duplicate the two lines used to obtain SIGMA (Sheet 1, Page 3). A sample of the macro code inserted is highlighted in this example:

```
/fccnSIGMA~{COMBINE}
/rv~~
{down}
/fccn[*****]~{COMBINE}
/rv~~
{goto}MARK!~{right}
```

The section [*****] would contain the range name of the value you wish to retrieve. If the value is not an equation, it is not necessary to have the line: /rv~~. Repeat this code for each value to be imported.

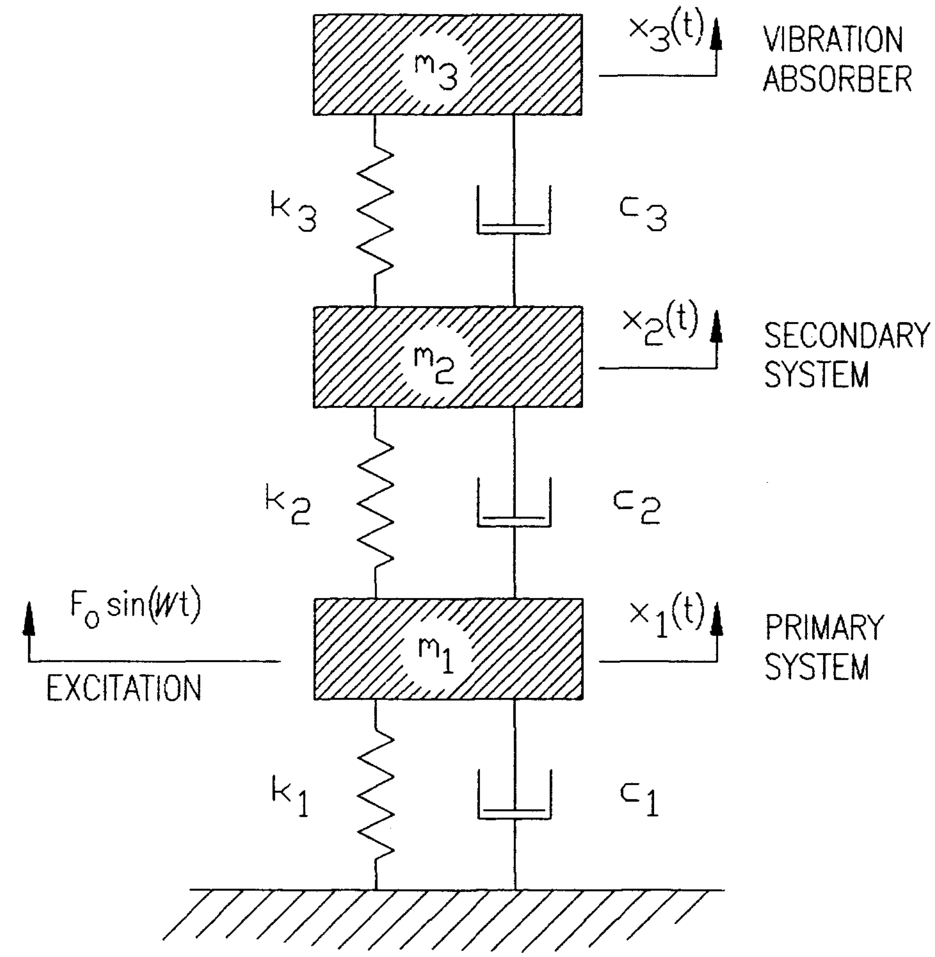


Figure A.1 - Model of Typical 3 DOF System: Sinusoidal excitation of base mass with an absorber mounted on the secondary system.

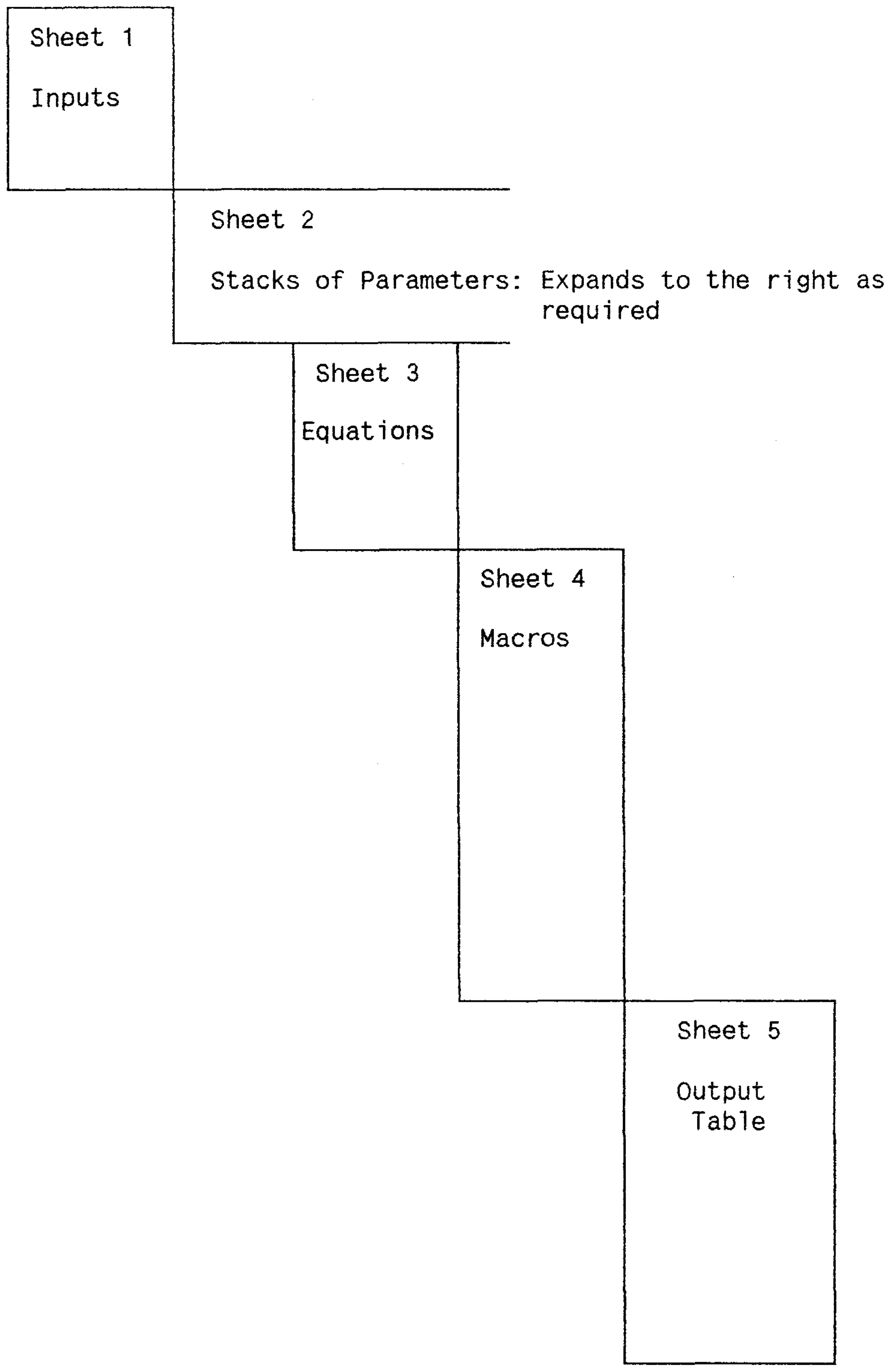


Figure A.2 - Layout of EX*_MDOF Spreadsheet Program

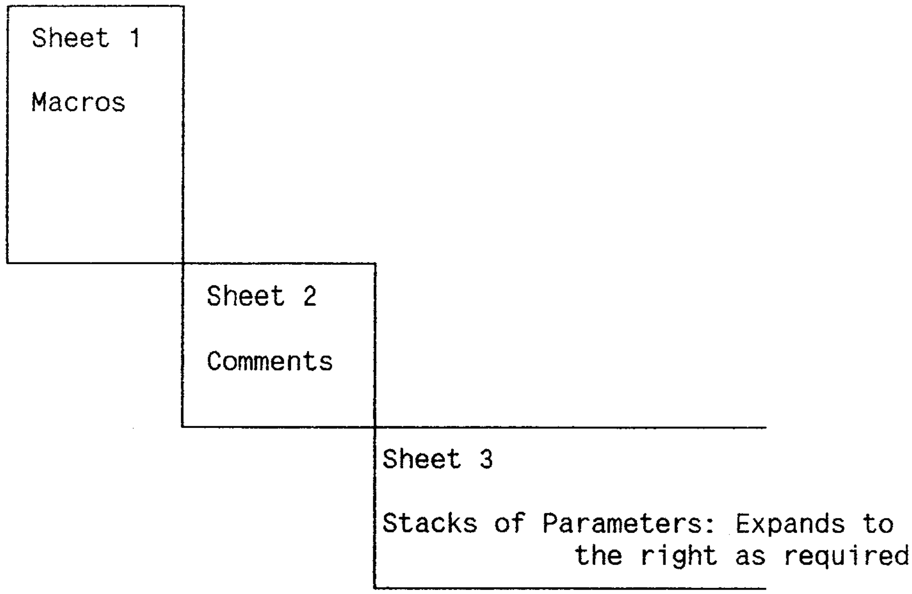


Figure A.3 - Layout of EX_STACK Spreadsheet Program

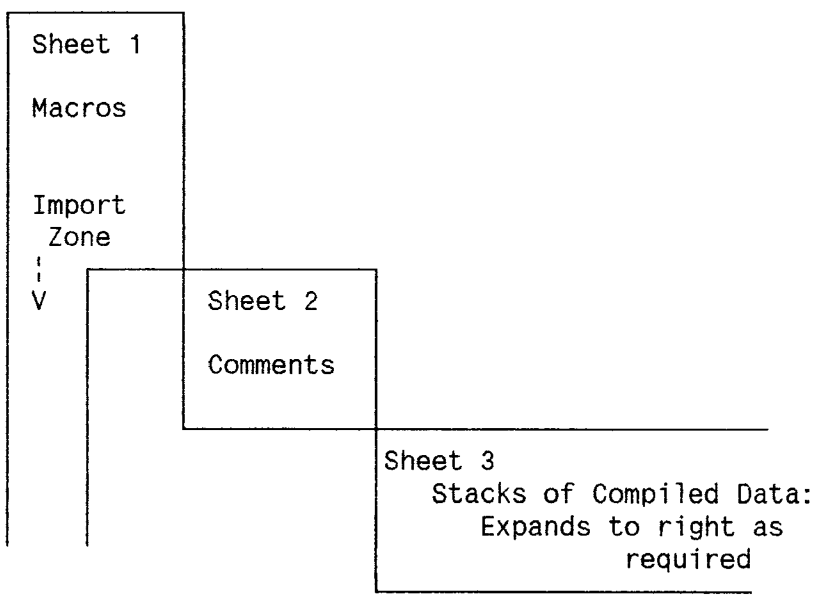


Figure A.4 - Layout of EX_COMPL Spreadsheet Program

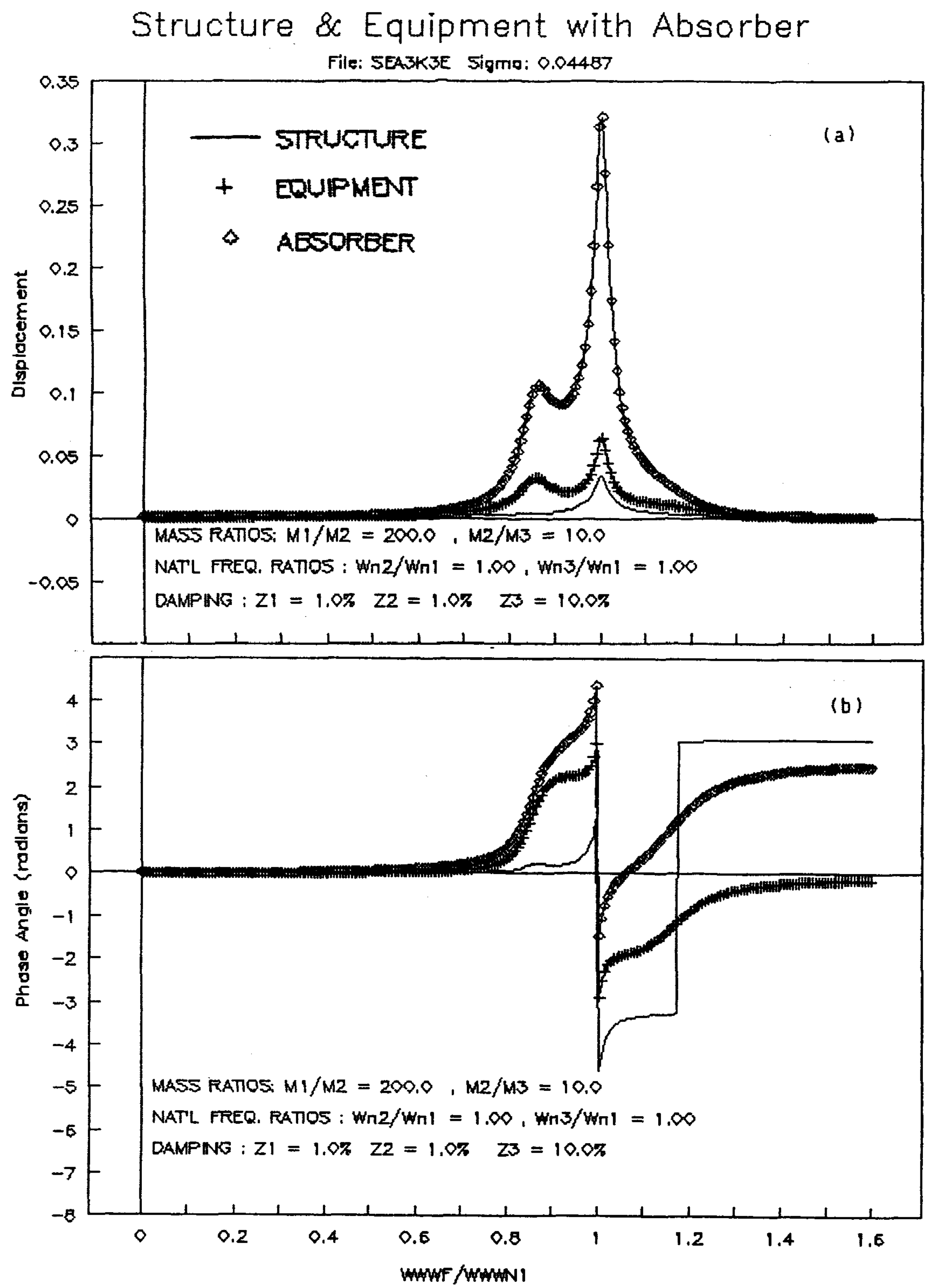


FIGURE A.5: Typical output graphs from EX*_MDOF Program with Parameter Summary: (a) Displacement Transfer Function (b) Phase Relationship

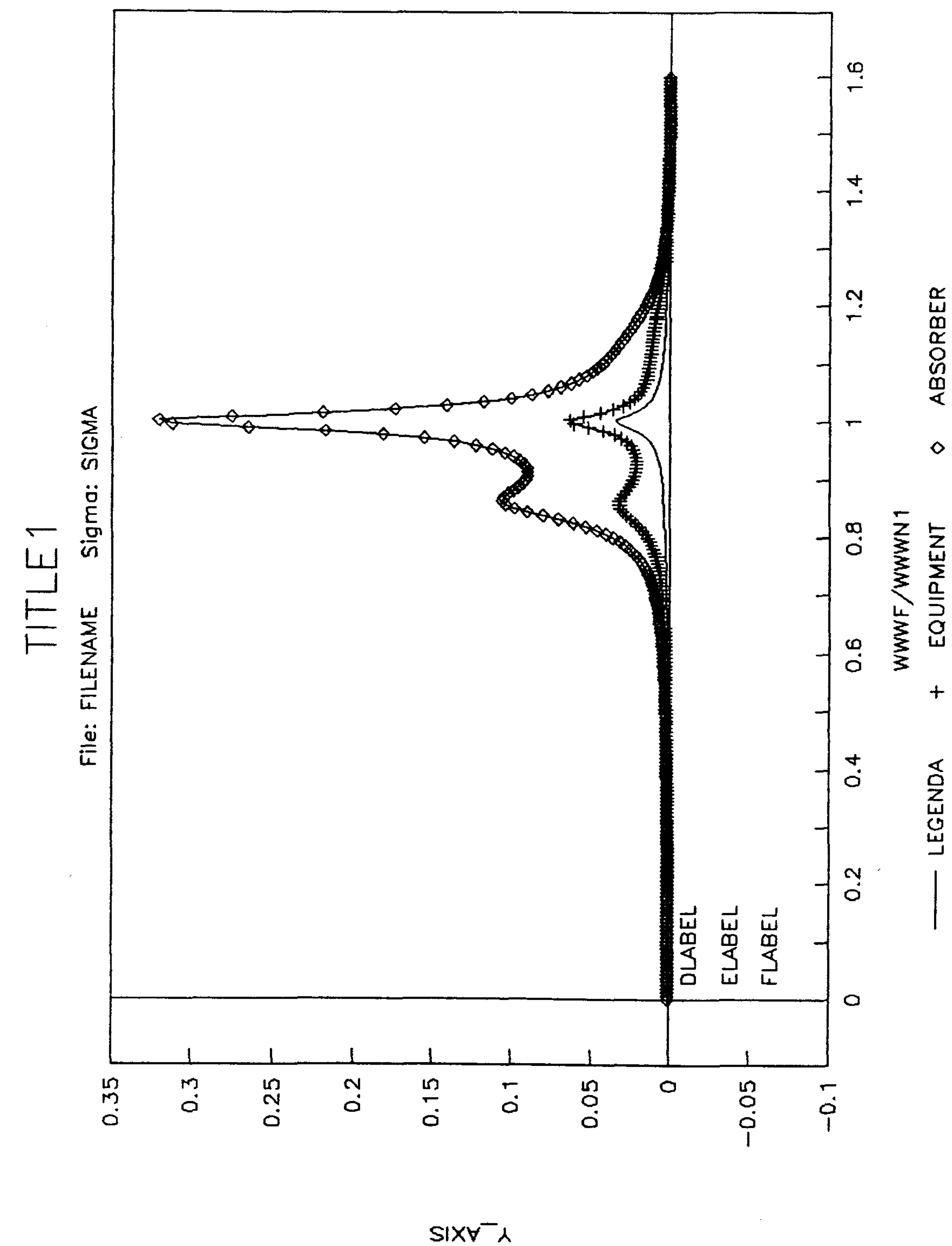


FIGURE A.6: Output graph from EX*_MDOF Program with Macro Labels Indicated

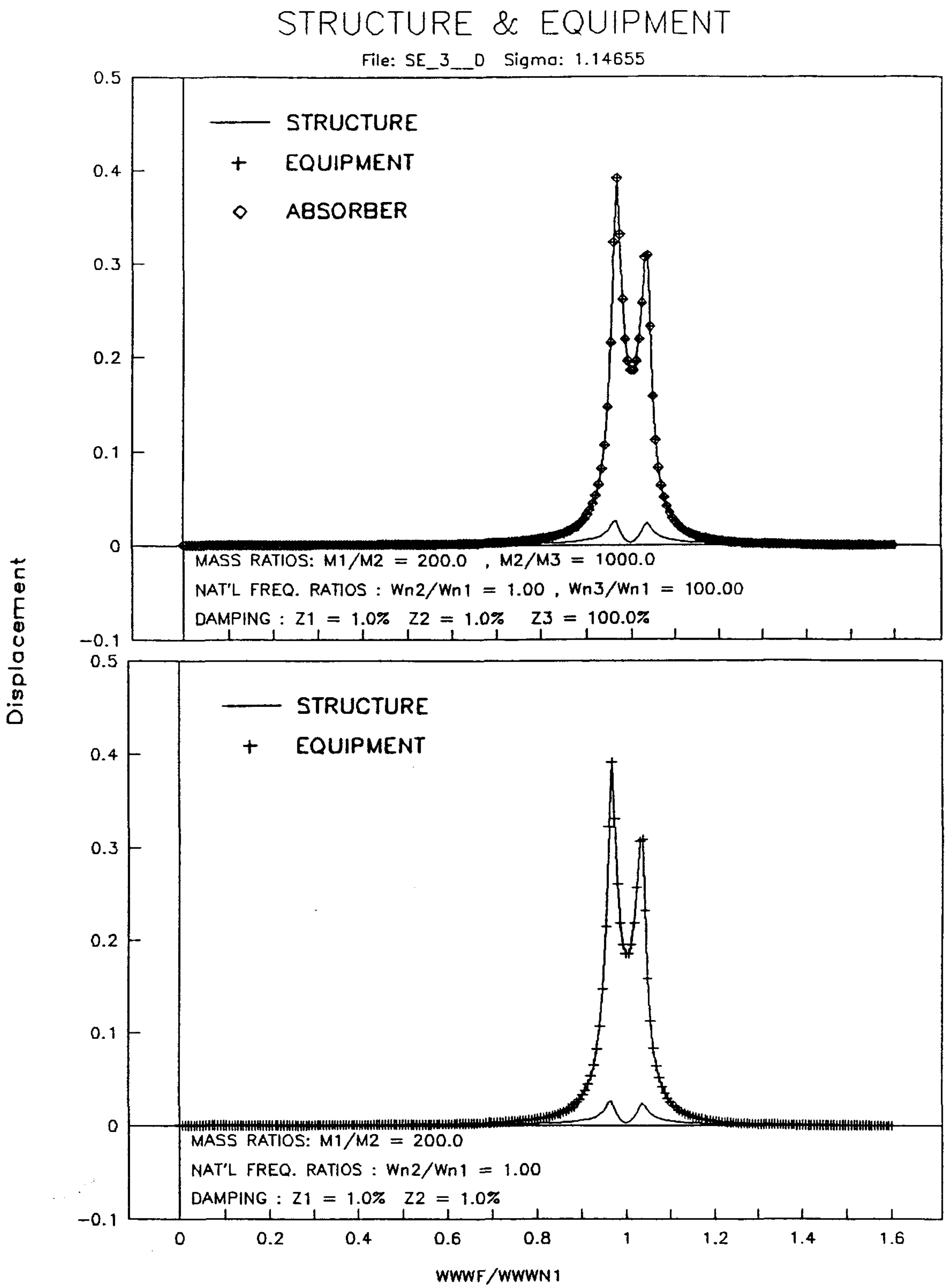


FIGURE A.7: Typical output graphs from EX*_MDOF Program for 2 DOF System (a) with third mass (absorber) shown, (b) removed by macro.

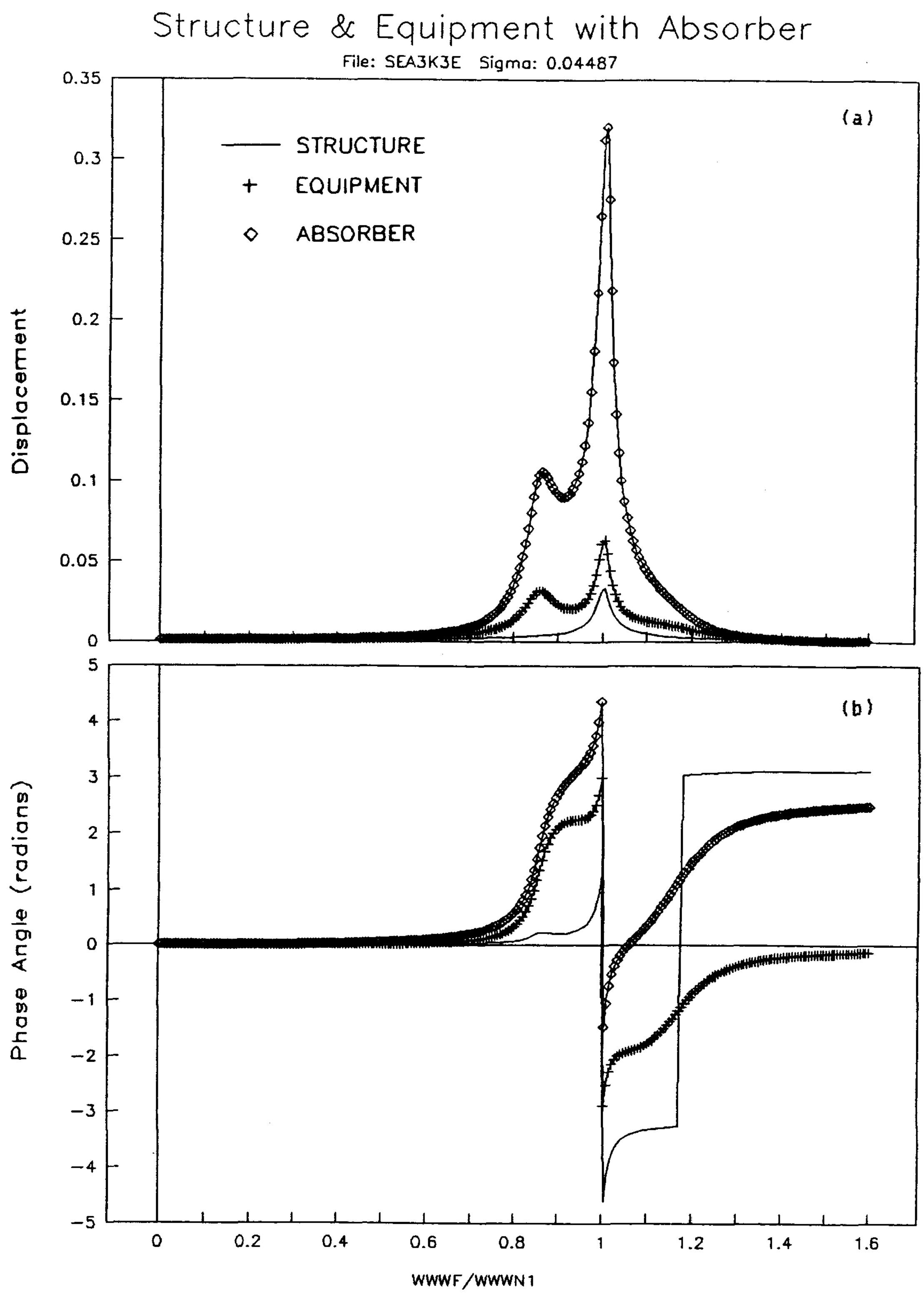


FIGURE A.8: Typical output graphs from EX*_MDOF Program with Parameter Summary Removed: (a) Displacement Transfer Function (b) Phase Relationship

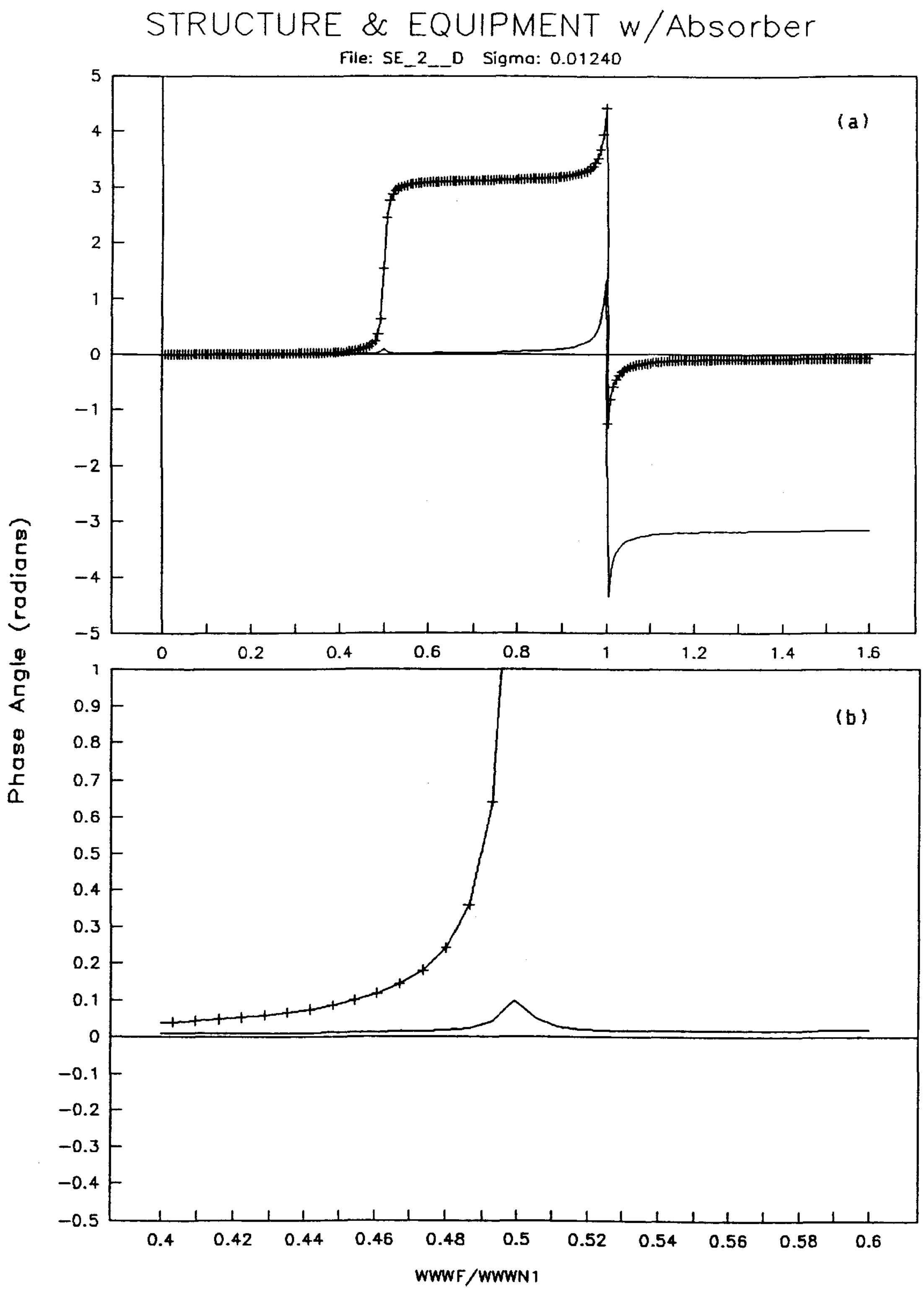


FIGURE A.9: Typical phase angle output graph from EX*_MDOF Program for 2DOF System (a) showing full extent of graph (b) zooming in on a portion of the graph

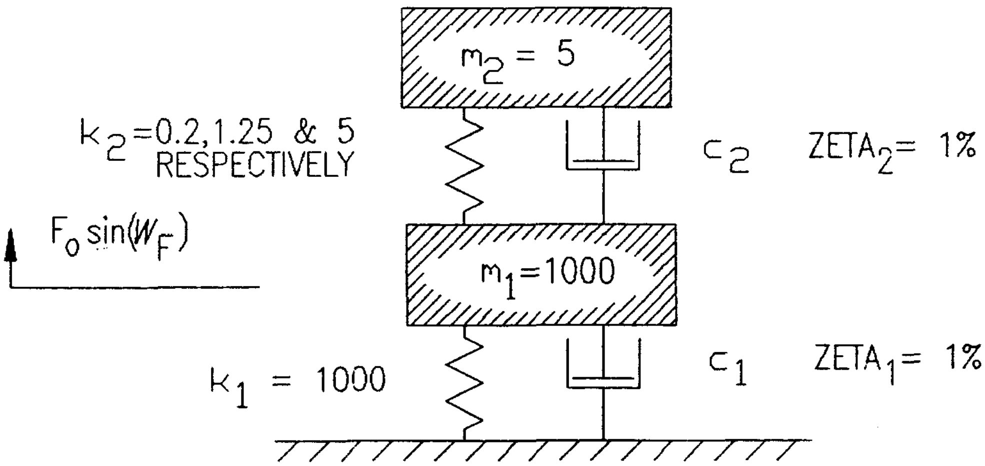


Figure A.10 (a) - Model of 2 DOF System without Absorber for example problem

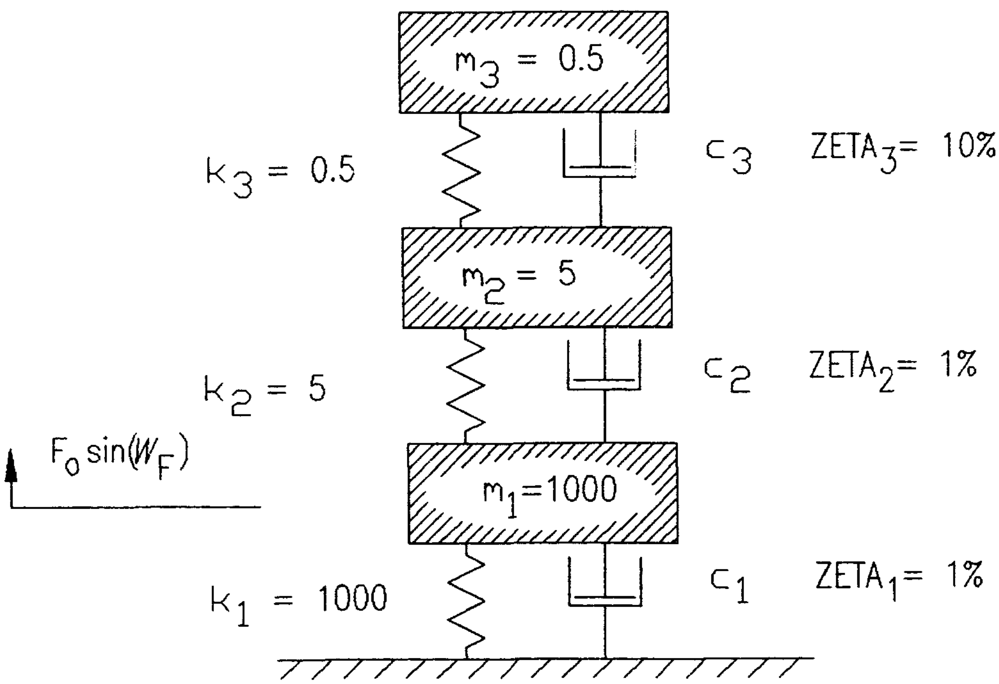


Figure A.10 (b) - Model of 3 DOF System for example problem

Appendix A.1 - Listing of Program EX*_MDOF, Sheet 1 with equations shown.

EX*_MDOF / Sheet 1 / Page 1

ROW #	DESCRIPTION	NAME	CALC	UNITS	SOURCE	EQUATION
6	Parameters of the Forcing Function:					
7	Force amplitude	FOOH	1	F		
8	Forcing Frequency	WWWF	1	R/T	input	
9						
10	Parameters of the supporting structure:					
11	Mass	MMM1	1000	M	input	
12	Spring constant	KKK1	1000	F/L	input	
13	Percentage of damping	ZETA1	0.01		input	
14	Resultant calculated values:					
15	Critical damping	CRIT1	2000			2*@SQRT(I12*I11)
16	Actual damping	CCC1	20	M/T		+I15*I13
17	Natural Frequency	WWWN1	1	R/T		@SQRT(I12/I11)
18						
19	Desired mass ratio of MASS 1 / MASS 2	MRAT1:2	200		input	
20	Resultant Required value of Mass 2	MMM2	5	M		+I11/I19
21						
22	Desired Ratio of Natural Freq. 2:1	WRAT2:1	1		input	
23	Resultant Nat. Frequency of Mass 2	WWWN2	1	R/T		+I17*I22
24	and Spring Constant of Mass 2	KKK2	5	F/L		+I20*I23^2
25	Percentage of damping for mass 2	ZETA2	0.01		input	
26	Resultant calculated values:					
27	Critical damping	CRIT2	10			2*@SQRT(I24*I20)
28	Actual damping	CCC2	0.1	F/L		+I27*I25
29						
30	Desired mass ratio of MASS 2 / MASS 3	MRAT2:3	10000		input	
31	Resultant Required value of Mass 3	MMM3	0.0005	M		+I20/I30
32						
33	Desired Ratio of Natural Freq. 3:1	WRAT3:1	100		input	
34	Resultant Nat. Frequency of Mass 3	WWWN3	0.01	R/T		+I17*I33
35	and Spring Constant of Mass 3	KKK3	1.0E+08	F/L		+I31*I34^2
36						
37	Percentage of damping for mass 3	ZETA3	100.0%		input	
38	Resultant calculated values:					
39	Critical damping	CRIT3	0.0001			2*@SQRT(I35*I31)
40	Actual damping	CCC3	0.0001	M/T		+I39*I37
41						
42						
43	Natural Frequency values for combined Masses					
44	Masses 1 and 2 held together	WWWN12	0.9975	R/T		@SQRT(I12/(I11+I20))
45	Masses 2 and 3 held together	WWWN23	0.9995	R/T		@SQRT(I24/(I20+I31))
46	Masses 1 , 2 and 3 held together	WWWN123	0.9975	R/T		@SQRT(I12/(I11+I20+I31))

Pages 2 and 3 of this Appendix list the values associated with the filename matrix code created for an investigation undertaken using these EXACT programs. For this investigation the following system parameters are held constant:

MMM1 = 1000
KKK1 = 1000
ZETA1 = 1.0%
ZETA2 = 1.0%
MRAT2_3 = 10

Example: The first mass is a structure (with a mass ratio of MMM1:MMM2 = 200) and the natural frequency ratio of 2:1 = 1.0. The ratio of the natural frequency of 3:1 = 0.975 (an off peak frequency). The critical damping is 60%. This is the first run.

The filename made up of :

Position	1	2	3	4	5	6	7	8
Code	S	E	A	3	J	5	_	

or : SEA3J5_

Position	Description						
1	First Mass Description	T	S				
		Truck	Structure				
2	Second Mass Description	_	E				
		None	Equipment				
3	Third Mass Description	_	A				
		None	Absorber				
4	Ratio of Natural Frequency of Mass 2 : Mass 1						
	1	2	3	4	5		
	0.2	0.5	1	2	5		
5	Ratio of Natural Frequency of Mass 3 : Mass 1						
	_	1, 2, 3, etc	A, B, C, etc				
	No Absorber	At peaks	Off peaks				
	See chart on next page						
6	Percent damping of absorber						
	_	1	2	3	4	5	6
	No Absorber	0.1%	1.0%	10%	30%	60%	100
7	Revision of the same parameters (scale)						
	_ : First	A : Second	B : Third	etc.			
8	For Plots Only						
	D: Displacement	P: Phase Angle					

Listing Identifying Code Symbols for Natural Frequency Ratio 3:1

System	Frequency Ratio	Code	System	Frequency Ratio	Code
No Absorber			Off Peaks		
SE_*__*	0.01	_	SEA3***	0.5	C
TE_*__*	0.01			0.6	E
				0.7	F
				0.8	G
				0.9	H
At Displacement Peaks				0.95	I
				0.975	J
				1	K
				1.025	L
SEA2***		1		1.05	M
		2		1.1	N
				1.2	O
SEA3***	0.96	1		1.3	P
	1.04	2		1.4	Q
				1.5	R
SEA4***		1			
		2			
			TEA3***	0.5	C
				0.6	E
				0.7	F
				0.9	G
TEA2***	0.5	1		0.95	I
	1.1	2		1	K
				1.05	M
TEA3***	0.83	1		1.1	O
	1.16	2		1.2	R
				1.3	S
TEA4***	0.93	1		1.4	T
	2.25	2		1.5	U

EX*_MDOF

PROGRAM LISTING

Parameters of the Forcing Function:			
Force amplitude	FOOH	1	
Forcing Frequency	WWWF	**1**	input
Parameters of the supporting structure:			
Mass	MMM1	**1000**	input
Spring constant	KKK1	**1000**	input
Percentage of damping	ZETA1	**1.0%**	input
Resultant calculated values:			
Critical damping	CRIT1	2000	
Actual damping	CCC1	20	
Natural Frequency	WWWN1	1	
Desired mass ratio of MASS 1 / MASS 2	MRAT1:2	**10**	input
Resultant Required value of Mass 2	MMM2	100	
Desired Ratio of Natural Freq. 2:1	WRAT2:1	**1**	input
Resultant Nat. Frequency of Mass 2	WWWN2	1.0000	
and Spring Constant of Mass 2	KKK2	100	
Percentage of damping for mass 2	ZETA2	**1.0%**	input
Resultant calculated values:			
Critical damping	CRIT2	200	
Actual damping	CCC2	2	
Desired mass ratio of MASS 2 / MASS 3	MRAT2:3	**10**	input
Resultant Required value of Mass 3	MMM3	10	
Desired Ratio of Natural Freq. 3:1	WRAT3:1	**0.4**	input
Resultant Nat. Frequency of Mass 3	WWWN3	0.4000	
and Spring Constant of Mass 3	KKK3	1.6000	
Percentage of damping for mass 3	ZETA3	**30.0%**	input
Resultant calculated values:			
Critical damping	CRIT3	8.000	
Actual damping	CCC3	2.400	
Natural Frequency values for combined Masses			
Masses 1 and 2 held together	WWWN12	0.9535	
Masses 2 and 3 held together	WWWN23	0.9535	
Masses 1 , 2 and 3 held together	WWWN123	0.9492	

```
                                    LINE NAME                              NOMORE

STACKED INPUT LOCATION
----------------------------------------------------

The input stack is actually input in a range called
STACK in file EX_STACK.  Macro will look there
for input data.  Do not enter data here.

                          STACK1------v
Name of spreadsheet file  PLOTFILE  SE_3__D SEA3C3D  .... SEA3P3D  999
Values of                 MMM1         1000    1000  ....    1000
                          KKK1         1000    1000  ....    1000
                          ZETA1        1.0%    1.0%  ....    1.0%
                          MRAT12        200     200  ....     200
                          WRAT12          1       1  ....       1
                          ZETA2        1.0%    1.0%  ....    1.0%
                          MRAT23       1000      10  ....      10
                          WRAT13      0.001     0.5  ....     1.3
                          ZETA3      100.0%   10.0%  ....   10.0%
Main title of graph plot  PLOTITLE STRUCTURESTRUCTUR .... STRUCTURE & EQ
What is the base mass     BASE     STRUCTURESTRUCTUR .... STRUCTURE
X-Axis start point        MANSTART        0       0  ....       0
X-Axis last point         MANEND          3       3  ....       3
Is there an absorber      ABSORBER       no     yes  ....     yes
Retention status                   ===============================
    save amplitude plot   AMP_PLOT      yes     yes  ....     yes
    save phase angle plot PH_PLOT        no      no  ....      no
    save file database                  yes     yes  ....     yes
```

Equations

Components of EEE

-MMM1*MMM2*MMM3*WWWF^6	-1E+06
+WWWF^4*MMM1*MMM3*(KKK3+KKK2)	1016000
+MMM3*WWWF^4*(CCC1+CCC2)*(CCC3+CCC2)	968
(KKK1+KKK2)*WWWF^4*MMM2*MMM3	1100000
-(KKK1+KKK2)*(KKK3+KKK2)*MMM3*WWWF^2	-1E+06
+WWWF^4*(CCC3+CCC2)*CCC3*MMM1	10560
+CCC3*(CCC1+CCC2)*WWWF^4*MMM2	5280
-(CCC1+CCC2)*(KKK3+KKK2)*WWWF^2*CCC3	-5364.4
-(KKK1+KKK2)*(CCC3+CCC2)*CCC3*WWWF^2	-11616
+KKK3*WWWF^4*MMM1*MMM2	160000
-WWWF^2*MMM1*(KKK3+KKK2)*KKK3	-162560
-(CCC1+CCC2)*(CCC3+CCC2)*WWWF^2*KKK3	-154.88
-KKK3*(KKK1+KKK2)*WWWF^2*MMM2	-176000
(KKK1+KKK2)*(KKK3+KKK2)*KKK3	178816
-MMM3*CCC2^2*WWWF^4	-40
+MMM3*KKK2^2*WWWF^2	100000
2*(KKK2*CCC2*CCC3*WWWF^2)	960
+CCC2^2*WWWF^2*KKK3	6.4
-KKK2^2*KKK3	-16000
+KKK3^2*WWWF^2*MMM1	2560
-CCC3^2*WWWF^4*MMM1	-5760
2*(KKK3*CCC3*(CCC1+CCC2)*WWWF^2)	168.96
-KKK3^2*(KKK1+KKK2)	-2816
(KKK1+KKK2)*CCC3^2*WWWF^2	6336
EEE	1E+04

Components of GGG

-MMM3*KKK2*WWWF^2	-1000
-CCC2*CCC3*WWWF^2	-4.8
+KKK3*KKK2	160
SUBTOTAL	-844.8
+K165*FOOH	-844.8

Components of AAA

+MMM2*MMM3*WWWF^4	1000
-WWWF^2*KKK3*MMM2	-160
-CCC3*(CCC3+CCC2)*WWWF^2	-10.56
-(KKK3+KKK2)*MMM3*WWWF^2	-1016
+KKK3*(KKK3+KKK2)	162.56
-KKK3^2	-2.56
+CCC3^2*WWWF^2	5.76
SUBTOTAL	-20.8
+K90*FOOH	-20.8

Components of FFF

+WWWF^5*MMM3*MMM1*(CCC3+CCC2)	44000
(CCC1+CCC2)*WWWF^5*MMM2*MMM3	22000
-(CCC1+CCC2)*(KKK3+KKK2)*WWWF^3*MMM3	-22352
-(KKK1+KKK2)*(CCC3+CCC2)*WWWF^3*MMM3	-48400
+CCC3*WWWF^5*MMM1*MMM2	240000
-WWWF^3*MMM1*(KKK3+KKK2)*CCC3	-243840
-(CCC1+CCC2)*(CCC3+CCC2)*CCC3*WWWF^3	-232.32
-(KKK1+KKK2)*CCC3*WWWF^3*MMM2	-264000
(KKK1+KKK2)*(KKK3+KKK2)*CCC3*WWWF	268224
-MMM1*KKK3*WWWF^3*(CCC3+CCC2)	-7040
-(CCC1+CCC2)*WWWF^3*MMM2*KKK3	-3520
(CCC1+CCC2)*WWWF*(KKK3+KKK2)*KKK3	3576.32
+KKK3*(KKK1+KKK2)*(CCC3+CCC2)*WWWF	7744
2*(MMM3*CCC2*KKK2*WWWF^3)	4000
+CCC2^2*CCC3*WWWF^3	9.6
-KKK2^2*CCC3*WWWF	-24000
-2*(CCC2*KKK2*KKK3*WWWF)	-640
2*(WWWF^3*KKK3*CCC3*MMM1)	7680
-KKK3^2*(CCC1+CCC2)*WWWF	-56.32
+CCC3^2*WWWF^3*(CCC1+CCC2)	126.72
-2*((KKK1+KKK2)*KKK3*CCC3*WWWF)	-8448
FFF	-25168

Components of HHH

-CCC2*WWWF^3*MMM3	-20
+KKK2*CCC3*WWWF	240
+KKK3*CCC2*WWWF	3.2
SUBTOTAL	223.2
+K174*FOOH	223.2

Components of JJJ

+KKK2*KKK3	160
-CCC2*CCC3*WWWF^2	-4.8
SUBTOTAL	155.2
+K182*FOOH	155.2

Components of LLL

+KKK2*CCC3*WWWF	240
+KKK3*CCC2*WWWF	3.2
SUBTOTAL	243.2
+K190*FOOH	243.2

Components of BBB

-MMM2*CCC3*WWWF^3		-240
-(CCC3+CCC2)*MMM3*WWWF^3		-44
+KKK3*(CCC3+CCC2)*WWWF		7.04
(KKK3+KKK2)*CCC3*WWWF		243.84
-2*(KKK3*CCC3*WWWF)		-7.68
	SUBTOTAL	-40.8
+K101*FOOH		-40.8

Gather Terms

+EEE^2+FFF^2	8E+09
@SQRT((AAA*EEE+BBB*FFF)^2+(BBB*EEE-AAA*FFF)^2)	4004600
@SQRT((GGG*EEE+HHH*FFF)^2+(HHH*EEE-GGG*FFF)^2)	8E+07
@SQRT((JJJ*EEE+LLL*FFF)^2+(LLL*EEE-JJJ*FFF)^2)	3E+07
@ATAN2(BBB,AAA)	-2.6701
@ATAN2(HHH,GGG)	-1.3124
@ATAN2(LLL,JJJ)	0.56800
@ATAN2(FFF,EEE)	1.86274

Values of Displacement

XXX1	0.00052
XXX2	0.00999
XXX3	0.00329

Phase Angles

ANG1	-4.5328
ANG2	-3.1752
ANG3	-1.2947

```
\X        {windowson}
          {panelon}
\0        {menubranch LOOP}
```

Menu for performing all standard program features

```
LOOP ────┬──RUN
         │  Input new variables as stack or singly; update graph settings
         │  {menubranch MINPUT}                                  [Page 3]
         │
         ├──SAVE
         │  Save the plots and/or file under system name
         │  {SAVER}                                              [Page 8]
         │  {menubranch LOOP}
         │
         ├──BROWSE
         │  Move around the Spreadsheet
         │  {menubranch BROWSE}
         │
         ├──VIEW
         │  Look at the graph
         │  {VIEWER}                                             [Page 9]
         │  {menubranch LOOP}
         │
         └──QUIT
            Exit the macro loop at your present location.
            {quit}

BROWSE───┬──INPUTS
         │  Move to the spreadsheet data input section
         │  {goto}INPUT~{menubranch LOOP}
         │
         ├──EQUATION
         │  Move to the equations for the transfer function
         │  {goto}EQUATION~{menubranch LOOP}
         │
         ├──MACROS
         │  Move to the macros
         │  {menubranch MENU3}                                   [Page 2]
         │
         ├──TABLE
         │  Move to the output table
         │  {goto}TABLE~{menubranch LOOP}
         │
         └──STACK
            Move to the input stacks:
            {goto}STACK~{menubranch LOOP}
```

```
MENU3──┬─MENUS
       │ Top of the user defined menus
       │ {goto}\0~
       │ {left}
       │ {menubranch LOOP}                               [Page 1]
       │
       ├─LABELS
       │ To the Graph label macro
       │ {goto}LABELS~
       │ {left}
       │ {menubranch LOOP}                               [Page 1]
       │
       ├─TITLES
       │ To the Graph titles section
       │ {goto}TITLES~
       │ {left}
       │ {menubranch LOOP}                               [Page 1]
       │
       ├─SPECTRUM
       │ To were the range of frequencies is set
       │ {goto}SPECTRUM~
       │ {left}
       │ {menubranch LOOP}                               [Page 1]
       │
       ├─ZOOM
       │ Macro to zoom in of a section of the graph
       │ {goto}ZOOM
       │ {left}
       │ {menubranch LOOP}                               [Page 1]
       │
       ├─VIEWER
       │ Macro to set which graph to view.
       │ {goto}VIEWER~
       │ {left}
       │ {menubranch LOOP}                               [Page 1]
       │
       └─MULTI
         Macro to step through a stack of parameters
         {goto}MULTI~
         {left}
         {menubranch LOOP}                               [Page 1]
```

```
Menu for performing some input functions
===============================================
MINPUT──┬──SINGLE
        │  Manually change the input parameters of the model.
        │  /rvNOPE~ARRAYON~
        │  {menubranch OPTION4}
        │
        ├──MULTI
        │  Calculate stack of input setups and record results
        │  {menubranch MULTI}                                 [Page 12]
        │
        └──ABORT
           Go back to the main menu.
           {menubranch LOOP}                                  [Page 1]



OPTION4──┬──CHANGE
         │  Revise the input variables before updating the database
         │  {MANMODS}                                         [Page 6]
STEP8    │  {SPECTRUM}                                        [Page 7]
         │  {DATABASE}                                        [Page 8]
STEP9    │  {LABELS}                                          [Page 4]
         │  {TITLES}                                          [Page 4]
         │  {menubranch LOOP}                                 [Page 1]
         │
         └──RETAIN
            Keep the same input variables
            {menubranch OPTION5}



OPTION5──┬──UPDATE
         │  Update the database as well as the graph
         │  {branch STEP8}
         │
         └──RETAIN
            Keep the database, just update the graph
            {branch STEP9}
```

Subroutine to Change the Data Labels

```
=========================================================================
LABELS    {goto}DLABEL~MASS RATIOS: M1/M2 =
          10.0                          < @string(MRAT1:2,2)
           , M2/M3 =
          10.0                          < @string(MRAT2:3,2)
          ~{goto}ELABEL~NAT'L FREQ. RATIOS : Wn2/Wn1 =
          1.00                          < @string(WRAT2:1,2)
           , Wn3/Wn1 =
          0.40                          < @string(WRAT3:1,2)
          ~{goto}FLABEL~DAMPING : Z1 =
          1.0                           < @string(ZETA1*100,1)
          %  Z2 =
          1.0                           < @string(ZETA2*100,1)
          %  Z3 =
          30.0                          < @string(ZETA3*100,1)
          %~

DLABEL    MASS RATIOS: M1/M2 = 10.0 , M2/M3 = 10.0
ELABEL    NAT'L FREQ. RATIOS : Wn2/Wn1 = 1.00 , Wn3/Wn1 = 0.40
FLABEL    DAMPING : Z1 = 1.0%  Z2 = 1.0%  Z3 = 30.0%
```

Subroutine to Modify Graph Titles

```
=========================================================================

TITLES    {if ARRAYON=YES}{branch STEP1}
          {menubranch TITLE1}

TITLE1──┬─RETAIN
        │ Keep the same main title on the plot graph
        │ {menubranch TITLE2}                                  [Page 5]
        │
        └─CHANGE
          Change the title on the plot graph.
          {getlabel "Type in the new plot title:",PLOTITLE}
          {menubranch TITLE2}                                  [Page 5]
```

```
TITLE2──┬──RETAIN
        │  Keep the same spreadsheet file name
        │  {menubranch LEGENDS}
        │
        └──CHANGE
           Change the spreadsheet file name.
           {getlabel "Type in plot file name:",FILENAME}
           {menubranch LEGENDS}


LEGENDS──┬──TRUCK
         │  Base is a truck
         │  /rvTRUCK~LEGENDA~
         │  {branch STEP1}
         │
         └──STRUCTURE
            Base is a structure
            /rvSTRUCTURE~LEGENDA~
            {branch STEP1}

STEP1      /gotfFAKE{esc}
PLOTITLE   TRUCK & EQUIPMENT W/ABSORBER
           ~tsFAKE{esc}
           File:
           {FILENAME}                                      [Page 8]
             Sigma:
           839.6              < @string(SIGMA,5)
           ~laFAKE{esc}
LEGENDA    TRUCK
           ~qq
           {if ARRAYON=YES}{return}
           {menubranch ABSORB}


ABSORB───┬──ABSORBER
         │  There is an absorber
         │  {RETAIN}                                       [Page 6]
         │
         └──NO_ABSORB
            There is not an absorber
            {DITCH}                                        [Page 6]

TRUCK       TRUCK
STRUCTURE   STRUCTURE
```

Subroutine to ditch indication of Absorber on graph and set display mode for ranges A and B

```
=====================================================================
DITCH    /golcFAKE{esc}~
         fcnbbalqqq
         {goto}DLABEL~{edit}{bs 14}~
         {goto}ELABEL~{edit}{bs 16}~
         {goto}FLABEL~{edit}{bs 10}~
```

Subroutine to retain/return indication of Absorber on graph and set display mode for ranges A and B

```
=====================================================================
RETAIN   /golcFAKE{esc}ABSORBER~
         fcbbbalqqq
```

Subroutine to manually step through Input Data modifications

```
=====================================
MANMODS  {goto}INPUT~
         {goto}WWWF~{?}~
         {goto}MMM1~{?}~
         {goto}KKK1{?}~
         {goto}ZETA1~{?}~
         {calc}
         {goto}MRAT1:2~{?}~
         {pgdn}
         {goto}WRAT2:1~{?}~
         {goto}ZETA2~{?}~
         {calc}
         {goto}MRAT2:3~{?}~
         {goto}WRAT3:1~{?}~
         {goto}ZETA3~{?}~
         {calc}
         {pgdn}
```

Subroutines to set the spectrum of frequencies

```
==========================================================================
SPECTRUM  {menubranch RANGE}


RANGE─────AUTO
        │ Range is 1.6 times maximum natural frequency
        │ /dfWWWFRNGE~
        │ 0
        │ ~
        │ 0.0064            < @string(AUTOSTEP,4)
        │ ~
        │ 3.2000            < @string(2*AUTOEND,4)
        │ ~
        │ /rvAUTOSTEP~FREQSTEP~
        │
        └─MANUAL
          Set the frequency range increment manually
          {getnumber "Type in lower X axis position:",MANSTART
          {getnumber "Type in upper X axis position:",MANEND}~
          {MANADJUST}


MANADJUST {calc}
          /dfWWWFRNGE~
          0.0000            <  @string(MANSTART,4)
          ~
          0.0064            <  @string(MANSTEP,4)
          ~
          3.2000            <  @string(MANEND*2,4)
          ~
          /rvMANSTEP~FREQSTEP~


POINTS         250          <  Desired number of data points
MANSTART         0          <  manually or stack input min & max freq.
MANEND         1.6          <
MANSTEP     0.0064          <  (MANEND-MANSTART)/POINTS
AUTOEND        1.6          <  @max(WWWN1,WWWN2,WWWN3)*1.6
AUTOSTEP    0.0064          <  AUTOEND/POINTS
FREQSTEP    0.0064          <  Register of step size being used
```

```
Subroutine to save either the plot or the complete file
=======================================
SAVER       {menubranch WHICH}

WHICH────┬─ PLOT
         │  Save the graph plot as presently configured
         │  /gs
         │  {FILENAME}
PLOTTYPE │  P
         │  ~q
         │
         └─ FILE
            Save the complete file
            /fs
            {FILENAME}
            ~


Subroutine for the filename
=======================================
FILENAME  TEA3E4D


Subroutine to calculate the Database
=======================================================================
DATABASE  /dt1OUT_TABLE~WWWF~
          /cSIGMABIT~SIGRANGE~
          /rvSIGRANGE~SIGRANGE~
          {calc}

SIGMABIT          0          <  0.5*(L523+L524)*$FREQSTEP
```

```
Subroutine to set and view the database plots
=====================================
VIEWER    {windowsoff}
          {menubranch OPTION1}


OPTION1─┬─PH_ANGLES
        │ Set up to view the phase angles
        │ /rvPPPPP~PLOTTYPE~
        │ /rvPHASEANG~YAXIS~
        │ {ANG_PLOT}                                  [Page 11]
        │ /rvMINANGLE~MINYAXIS~
        │ /rvMAXANGLE~MAXYAXIS~
        │ {menubranch OPTION6}
        │
        └─DISPLACE
          Set up to view the absolute displacements
          /rvDDDDD~PLOTTYPE~
          /rvDISPLACE~YAXIS~
          {DISP_PLT}                                  [Page 11]
          /rvMINDISP~MINYAXIS~
          /rvMAXDISP~MAXYAXIS~
          {menubranch OPTION6}


OPTION6─┬─DISPLAY
        │ Display the summary of input parameters on the graph
        │ {INPT_PLT}                                  [Page 11]
        │ {menubranch OPTION2}                        [Page 10]
        │
        └─REMOVE
          Remove the input parameter display from the graph
          /grdefqq
          {menubranch OPTION2}                        [Page 10]
```

```
OPTION2─┬─FULL
        │ View the full graph (all data points)
        │ /gosxaqsyaqqq
STEP4   │ {TITLEY}                                            [Page 11]
        │ {calc}
        │ /gvq
        │ {windowson}
        │
        └─ZOOM
          Modify the X and Y coordinates to zoom in or out
          {menubranch OPTION3}


OPTION3─┬─ AS_BEFORE
        │  Use the previously manually set zoomed in scale
        │  /gosxmqsymqqq
        │  {branch STEP4}
        │
        └─ NEW
           Set up new limits on the scale
           {ZOOM}                                             [Page 11]


                              Data base values
                              ---------------------------
MINANGLE    -4.9451           < @min(phase angles)
MAXANGLE     3.4875           < @max(phase angles)
MINDISP      0.0001           < @min(displacements)
MAXDISP      0.0530           < @max(displacements)
MAXYAXIS     0.0530
MINYAXIS     0.0001
FULLSCALE    0.0529           < @abs(MAXYAXIS-MINYAXIS)
PPPPP       P
DDDDD       D
PHASEANG    Phase Angle (radians)
DISPLACE    Displacement
```

Subroutine to zoom in on an area of interest

```
ZOOM     {getlabel "Note maximums of both graph scales",JUNK}~
       /gosxaqsyaqqvq
         {getnumber "Desired low limit of X scale?",XMINSCALE}~
         {getnumber "Desired up limit of X scale?",XMAXSCALE}~
         {getnumber "Desired low limit of Y scale?",YMINSCALE}~
         {getnumber "Desired up limit of Y scale?",YMAXSCALE}~
         {calc}
         /gosxml
         2.800000000000000          < @string(XMINSCALE,15)
         ~u
         3.000000000000000          < @string(XMAXSCALE,15)
         ~qsymu
         0.010000000000000          < @string(YMAXSCALE,15)
         ~l
         0.000000000000000          < @string(YMINSCALE,15)
         ~qqvq

XMAXSCALE        3         < maximum x scale
XMINSCALE      2.8         < minimum x scale
YMAXSCALE     0.01         < maximum y scale
YMINSCALE        0         < minimum y scale
JUNK                       <Cell for redundant macro input
```

Subroutines to set the graph ranges

```
=======================================================================
DISP_PLT  /gxWRANGE~aX1RANGE~bX2RANGE~cX3RANGE~q

ANG_PLOT  /gxWRANGE~aAG1RANGE~bAG2RANGE~cAG3RANGE~q

INPT_PLT  /gdDRANGE~eERANGE~fFRANGE~
          oddDLABEL~reELABEL~rfFLABEL~rqqq
```

Subroutine to set the Y-Axis title

```
=======================================================================
TITLEY    /gotyFAKE{esc}
YAXIS     Displacement
          ~qq
```

Subroutine to iterate through a stack of input variables

```
==========================================================
MULTI     {windowsoff}{paneloff}
          /rvYES~ARRAYON~
          /gosxaqsyaqqq       < Set graph scales to automatic
          {INPT_PLT}          < set input display parameters   [Page 11]
          {goto}STACK1~                 <  Erases old stacked input
          /reENDFLAG~                   <
          /re{end}{right}{end}{down}~   <
          /fccnSTACK~                   < imports new stack input
          EXACT\EX_STACK~               < location of stack input
          {end}{right 2}
          /cNOMORE~~                    < mark end of stack
          /rncENDFLAG~{bs}~
          {goto}STACK1~
          {windowson}
          {menubranch CHECK}

CHECK---+--QUIT
        |  Quit to allow checking of input stack in other program
        |  {quit}
        |
        +--CONTINUE
           Carry on with the macro
LOOPD      /rncMARKER~{bs}{up}{right}~
           {windowson}{windowsoff}      < updates position in stack
           {READ_IN}                                          [Page 13]
           {calc}
           {MANADJUST}                                        [Page 7]
           /rvMANSTEP~FREQSTEP~
           {DATABASE}                                         [Page 8]
           /rncMARK~{bs}~         < mark position in stack for later return
           {LABELS}                                           [Page 4]
           {TITLES}                                           [Page 4]
           {goto}MARK~
           {if MARK=NOPE}{DITCH}      <Determine if absorber  [Page 6]
           {if MARK=YES}{RETAIN}                              [Page 6]
           {goto}MARK~{down 2}
           {if @cellpointer("contents")=NOPE}{branch SKIP2}   [Page 13]
           /rvMINDISP~MINYAXIS~     v-< Set up to save displacement plot
           /rvMAXDISP~MAXYAXIS~
           {calc}
           /rvDISPLACE~YAXIS~
           {TITLEY}                                           [Page 11]
```

(macro is continued on next page)

(macro continued from previous page)

```
        {DISP_PLT}                                          [Page 11]
        /gs{FILENAME}A~q                                    [Page 8]
SKIP2   {down}
        {if @cellpointer("contents")=NOPE}{branch SKIP3}
        /rvMINANGLE~MINYAXIS~      v-< Set up to save phase angle plot
        /rvMAXANGLE~MAXYAXIS~
        {calc}
        /rvPHASEANG~YAXIS~
        {TITLEY}                                            [Page 11]
        {ANG_PLOT}                                          [Page 11]
        /gs{FILENAME}P~q                                    [Page 8]
SKIP3   {down}
        {if @cellpointer("contents")=NOPE}{branch SKIP4}
        /fs{FILENAME}~          < save the spreadsheet file [Page 8]
SKIP4   {goto}MARKER~{down}
        {if @cellpointer("contents")=NOMORE}{branch STEP7}
        {branch LOOPD}                                      [Page 12]

STEP7   /rvNOPE~ARRAYON~
        /fsEX*_MDOF~r              < CHANGE IF FILE REVISION
        {windowson}{panelon}                STATUS CHANGED

NOMORE  999
YES     yes
NOPE    no
ARRAYON no
```

Subroutine to read in new information from stack

```
READ_IN /rv~FILENAME~{down}
        /rv~MMM1~{down}
        /rv~KKK1~{down}
        /rv~ZETA1~{down}
        /rv~MRAT1:2~{down}
        /rv~WRAT2:1~{down}
        /rv~ZETA2~{down}
        /rv~MRAT2:3~{down}
        /rv~WRAT3:1~{down}
        /rv~ZETA3~{down}
        /rv~PLOTITLE~{down}
        /rv~LEGENDA~{down}
        /rv~MANSTART~{down}
        /rv~MANEND~{down}
```

OUT_TABLE

WWWFRNGE	WRANGE	X1RANGE	X2RANGE	X3RANGE	AG1RANGE	AG2RANGE	AG3RANGE	
WWWF	WF/WN1	XXX1	XXX2	XXX3	ANG1	ANG2	ANG3	XXX2^2/F
1	1	0.000	0.010	0.003	-4.53	-3.17	-1.29	0.01560
0	0	0.0010	0.0010	0.0010	0.0000	0.0000	0.0000	0.0001
0.0064	0.0064	0.0010	0.0010	0.0010	0.0001	0.0001	0.0001	0.0002
0.0128	0.0128	0.0010	0.0010	0.0010	0.0003	0.0003	0.0003	0.00016
0.0192	0.0192	0.0010	0.0010	0.0010	0.0004	0.0004	0.0005	0.00016
0.0256	0.0256	0.0010	0.0010	0.0010	0.0005	0.0005	0.0007	0.00016
0.032	0.032	0.0010	0.0010	0.0010	0.0006	0.0006	0.0009	0.00016
0.0384	0.0384	0.0010	0.0010	0.0010	0.0008	0.0008	0.0013	0.00016
0.0448	0.0448	0.0010	0.0010	0.0010	0.0009	0.0009	0.0017	0.00016
0.0512	0.0512	0.0010	0.0010	0.0010	0.0010	0.0010	0.0023	0.00016
0.0576	0.0576	0.0010	0.0010	0.0010	0.0012	0.0012	0.0030	0.00016
0.064	0.064	0.0010	0.0010	0.0010	0.0013	0.0013	0.0038	0.00016
0.0704	0.0704	0.0010	0.0010	0.0010	0.0014	0.0014	0.0048	0.00016
0.0768	0.0768	0.0010	0.0010	0.0011	0.0015	0.0016	0.0059	0.00016
0.0832	0.0832	0.0010	0.0010	0.0011	0.0017	0.0017	0.0072	0.00016
0.0896	0.0896	0.0010	0.0010	0.0011	0.0018	0.0018	0.0088	0.00016
0.096	0.096	0.0010	0.0010	0.0011	0.0019	0.0020	0.0106	0.00016
0.1024	0.1024	0.0010	0.0010	0.0011	0.0021	0.0021	0.0126	0.00016
0.1088	0.1088	0.0010	0.0010	0.0011	0.0022	0.0023	0.0149	0.00016
0.1152	0.1152	0.0010	0.0010	0.0011	0.0023	0.0024	0.0175	0.00017
0.1216	0.1216	0.0010	0.0010	0.0011	0.0025	0.0025	0.0205	0.00017
0.128	0.128	0.0010	0.0010	0.0012	0.0026	0.0027	0.0237	0.00017
.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.
1.4912	1.4912	0.0010	0.0008	0.0001	3.1009	-0.1283	1.6912	0.00010
1.4976	1.4976	0.0009	0.0008	0.0001	3.1017	-0.1269	1.6918	0.00009
1.504	1.504	0.0009	0.0007	0.0001	3.1025	-0.1256	1.6924	0.00008
1.5104	1.5104	0.0009	0.0007	0.0001	3.1032	-0.1243	1.6929	0.00008
1.5168	1.5168	0.0009	0.0007	0.0001	3.1040	-0.1231	1.6934	0.00007
.	.	.	.	.	.	.	.	.

WWWFRNGE	X2RANGE		DRANGE	ERANGE	FRANGE	SIGRANGE
Output Table						
			0.04	0.12	0.2	
WWWF	XXX2	XXX2^2/F	DDD	EEE	FFF	SIGMA
1	0.0100	0.01560				0.034390
0	0.0010	0.00016	-2.0E-03	-6.3E-03	-1.0E-02	
0.0064	0.0010	0.00016				1.00E-06
0.0128	0.0010	0.00016			-1.3E-02	1.00E-06
0.0192	0.0010	0.00016				1.00E-06
0.0256	0.0010	0.00016				1.00E-06
0.032	0.0010	0.00016				1.00E-06
0.0384	0.0010	0.00016				1.01E-06
0.0448	0.0010	0.00016				1.01E-06
0.0512	0.0010	0.00016				1.01E-06
0.0576	0.0010	0.00016				1.01E-06
0.064	0.0010	0.00016				1.02E-06
0.0704	0.0010	0.00016				1.02E-06
0.0768	0.0010	0.00016				1.02E-06
0.0832	0.0010	0.00016				1.03E-06
0.0896	0.0010	0.00016				1.03E-06
0.096	0.0010	0.00016				1.04E-06
0.1024	0.0010	0.00016				1.04E-06
0.1088	0.0010	0.00016				1.05E-06
0.1152	0.0010	0.00017				1.06E-06
0.1216	0.0010	0.00017				1.06E-06
0.128	0.0010	0.00017				1.07E-06
.	.	.	.	.	.	.
.	.	.	.	.	.	.
1.4912	0.0008	0.00010				6.46E-07
1.4976	0.0008	0.00009				6.02E-07
1.504	0.0007	0.00008				5.62E-07
1.5104	0.0007	0.00008				5.25E-07
1.5168	0.0007	0.00007				4.90E-07
.	.	.				.

EX_STACK

PROGRAM LISTING

```
\0        {menubranch MENU0}          <   \X


MENU0─┬──EDIT
      │  Change the stack
      │  {menubranch MENU2}                          [Page 2]
      │
      ├─ NAME
      │  Select the range named STACK
      │  {goto}COMMENT2~{?}
      │  /rncSTACK~{?}~
      │  {menubranch MENU0}
      │
      ├─ BROWSE
      │  Move through the file
      │  {menubranch MENU1}
      │
      ├─ SAVE
      │  Save the file as EX_STACK
      │  /fsEX_STACK~r
      │  {menubranch MENU0}
      │
      └─ QUIT
         Quit the macro
         {quit}


MENU1─┬─ MACRO
      │  Move to the Macro section
      │  {goto}\X~{left}
      │  {menubranch MENU0}
      │
      ├─ STACKS
      │  Move to were the input stacks are located
      │  {goto}STACKS~
      │  {menubranch MENU0}
      │
      └─ COMMENTS
         Move to the comments section
         {menubranch MENU3}                          [Page 2]
```

```
MENU2──┬─INPUTS
       │ Change the input stacks
       │ {goto}COMMENT1~{?}
       │ {goto}STACKS~
       │
       └─FILENAME
         Edit the filenames
         {goto}COMMENT3~{?}
         {goto}\F~{left}{right}{down}


MENU3──┬─ONE
       │ Comment re. Editing Input
       │ {goto}COMMENT1~
       │ {menubranch MENU0}                                  [Page 1]
       │
       ├─TWO
       │ Comment re. naming STACK
       │ {goto}COMMENT2~
       │ {menubranch MENU0}                                  [Page 1]
       │
       └─THREE
         Comment re. naming STACK
         {goto}COMMENT3~
         {menubranch MENU0}                                  [Page 1]


Macro for editing file names
~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~

         SEA3B3S      999     < sample file for checking \F macro

LOOP     {edit}   <  \F
         {bs}D    < This line is edited to delete and add characters
         ~{right}
         {if @cellpointer("contents")=NOMORE}{menubranch MENU0} [Page 1]
         {branch LOOP}

NOMORE    999         < cell to indicate completion of edit macro.
```

COMMENT 1

The input values for different runs are entered in columns to the right of the column of titles listed in a row. Although you can added or delete columns the number and description of the rows must remain as is. For a full description of what each row means see the user's manual. Make change to any input values as with a typical spreadsheet. After you press ENTER the macro will move the cursor to the stack area and quit. To restart the macro, press {alt}X. To revise the Filenames it may be easier to use the basic macro already started.

Hit enter to move to the input stack.

COMMENT 2

The range name STACK is imported by the other programs EX*_MDOF and EX_COMPL. The macro initiates the naming of this range. If you wish to revise the range do so in the normal spreadsheet manner and then press ENTER to accept.

Press ENTER to continue.

If in the course of making input revisions the range name STACK is no longer assigned to any range the cursor will remain on this comment.

To get to the appropriate sheet type {bs}{tab}{end}{down}{pgdn}

COMMENT 3

Because as this research program has been set up the filenames usually differ by only one or two characters it is possible to easily modify the names by using a macro.

The method for doing this is described in the User's manual. By pressing ENTER, this macro will move to the appropriate line in the filename edit macro. After making the appropriate change, restart the macro and move to the stack to begin the editing.

Press ENTER to continue.

Range name : STACK

Stack input					
PLOTFILE	SE_1__D	SE_2__D	...	TEA221D	TEA3W3D
MMM1	1000	1000	...	1000	1000
KKK1	1000	1000	...	1000	1000
ZETA1	1.0%	1.0%	...	1.0%	1.0%
MRAT1:2	200	200	...	10	10
WRAT2:1	0.2	0.5	...	0.5	1
ZETA2	1.0%	1.0%	...	1.0%	1.0%
MRAT2:3	1000	1000	...	10	10
WRAT3:1	0.01	0.01	...	1.1	1.7
ZETA3	100.0%	100.0%	...	0.1%	10.0%
PLOTITLE	STRUCTURE	STRUCTURE	...	TRUCK & E	TRUCK & EQUIPMENT
BASE	STRUCTURE	STRUCTURE	...	TRUCK	TRUCK
MANSTART	0	0	...	0	0
MANEND	3	3	...	1.6	1.6
ABSORBER	no	no	...	yes	yes
	=========	=========	...	=========	=========
AMP_PLOT	yes	yes	...	yes	yes
PH_PLOT	no	yes	...	yes	no
FILESAVE	yes	no	...	yes	no

EX_COMPL

PROGRAM LISTING

```
Start up macro
============================================
\0       {menubranch MENU1}         < \X


Menu for performing functions
=====================================================
MENU1─┬──COMPILE
      │  Compile data
      │  {branch COMPILE}                                  [Page 3]
      │
      ├──SETUP
      │  Import files to be compiled
      │  {goto}COMMENT2~{?}
      │  {goto}STACK~
      │  {quit}
      │
      ├──BROWSE
      │  Move about the spreadsheet within the macro
      │  {menubranch MENU2}
      │
      └──QUIT
         Quit the macro
         {quit}


Menu for moving about the spreadsheet
============================================
MENU2─┬──MACROS
      │  Go to the macro section
      │  {menubranch MENU3}                                [Page 2]
      │
      ├──COMMENTS
      │  Go to the message section
      │  {goto}COMMENT1~
      │  {menubranch MENU1}
      │
      └──STACK
         Go to the input stack
         {goto}STACK~
         {menubranch MENU1}
```

Menu for moving about the spreadsheet
==

```
MENU3──┬──MENUS
       │  Go to the menu macros
       │  {goto}\0~{left}
       │  {menubranch MENU1}                              [Page 1]
       │
       ├──COMPILE
       │  Go to the top of the Main macro
       │  {goto}COMPILE~
       │  {left}{up 3}
       │  {menubranch MENU1}                              [Page 1]
       │
       ├──EVEREST
       │  Go to Subroutine to find peaks
       │  {goto}EVEREST~{left}
       │  {menubranch MENU1}                              [Page 1]
       │
       ├──RECORD
       │  Go to the subroutine to Record peaks
       │  {goto}RECORD~{left}
       │  {menubranch MENU1}                              [Page 1]
       │
       └──IMPORT
          Where ranges are imported
          {goto}TOPRANGE~{left}{up 2}
          {menubranch MENU1}                              [Page 1]
```

Main Compile Program Macro
```
===========================================

COMPILE  {goto}COMMENT1~{?}
         {goto}STACK~{?}
         {windowsoff}{paneloff}
         /rncMARK1~{bs}~
LOOP2    /rv~FILENAME~          < copy file name into COMBINE subroutine
         {windowson}{windowsoff}
         {goto}TOPRANGE~{down}        < move cursor to import area
         /fccnX2RANGE~{COMBINE}     < import X2 displacement values
         {right}
         /fccnWRANGE~{COMBINE}      < import associated frequencies
         {left}
         {EVEREST}                                              [Page 4]
         /reFULLRANGE~
         {goto}MARK1~{end}{down 2} < go to end of this files variables
         /cPEAKS~~                    < record peaks found
         {end}{down 2}
         /cWWW~~                < record associated frequencies
         {end}{down 2}
         @max(PEAKS)~/rv~~            < record maximum peak
         {down}
         /fccnSIGMA~{COMBINE}  < Import equation for SIGMA
         /rv~~                        < convert to a value
         {goto}MARK1~{right}   < go to next file to compile
         {if @cellpointer("contents")=NOMORE}{branch SAVE}
         /rncMARK1~{bs}~              < move marker
         {branch LOOP2}
```

Macro to save file at completion of compiling
```
===========================================
SAVE     {windowson}{panelon}
         /fsEX_COMPL~r
```

Subroutine with name of file to import from
```
===========================================
COMBINE  EXACT\
FILENAME SEA412D
         ~
```

Subroutine to determine peaks of displacement curve

```
===========================================
EVEREST  /rvRESET~NUMBER~           < reset or zero all previous values
        /rvZERO~PEAKS~
         /rvZERO~WWW~
         {calc}
         /rv~LAG~                   < note first displacement
         {down}
         /rv~POINT~                 < note second displacement
         {down}
LOOP1    {SHIFT}                        < Subroutine SHIFT
         {if NUMBER>MAXPEAKS}{return}   < stop if all peaks found
         {down}
         {if @cellpointer("contents")=NOMORE}{return}  < stop if no more
         {branch LOOP1}                                     data points

SHIFT    /rv~LEAD~                  < note third displacement
         {if POINT>LAG}{if POINT>LEAD}{RECORD} <if centre point larger
         {if NUMBER>MAXPEAKS}{return}        than either side a peak
         /rvPOINT~LAG~  < move points        has been found
         /rvLEAD~POINT~        ahead

LAG        0.0001 <registers
POINT      0.0002 <
LEAD       0.0003 <
```

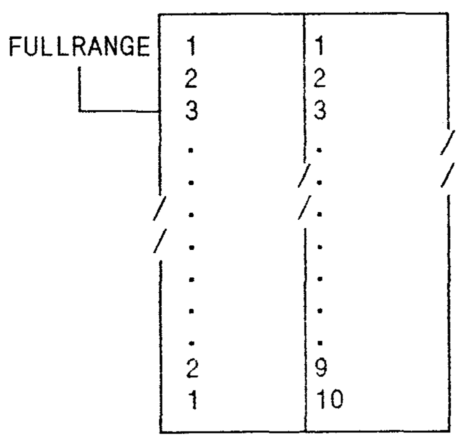
Subroutine to record values of the peaks and frequency

```
===========================================
RECORD   /rvPOINT~                  < copy peak value into appropriate
         PEAK                           < peak register
         3        < @string(NUMBER,0)   <
         ~                              <
         /rncMARK2~{bs}~      < mark position in data stack
         {right}{up}
         /rv~WWW                      < copy associated frequency
         3        < @string(NUMBER,0) <     into approp. freq. register
         ~                            <
         {goto}NUMBER~{down}
         +{up}+1~                       < increment # of peaks found
         /rv~{up}~
         {calc}
         {goto}MARK2~               < return to data stack
```

```
Registers for values used or created in the program
============================================
MAXPEAKS          3
WWW1          0.996 < WWW
WWW2           1.98 <
WWW3              0 <
NUMBER            3
PLUS_ONE          4 < NUMBER + 1
RESET             1
PEAK1        0.0658 < PEAKS
PEAK2        0.0053 <
PEAK3             0 <
ZERO              0
NOMORE              < range for comparing to end of stack

============================================
```

```
AREA WHERE THE DISPLACEMENT DATA IS ENTERED
vvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvv
TOPRANGE    XRANGE    WRANGE
```



COMMENT 1

After you press ENTER move the curser to the first column of file data you want to retrieve. Then press ENTER again. All

the files that are to the right of the cursor will be compiled until the cursor senses a blank cell.

After compiling all the files this program saves itself so that the data will be retained in case of a power outage.

Press ENTER to continue.

COMMENT 2

The files to be compiled can be set up in various ways. The most common is to import the same "STACK" from file "EX_STACK" that was used to create them originally. The macro will move you to the Stack sheet and then quit. You can either import the stack or set it up in any way you want. If you import the stack all the data below ZETA3 must be manually erased since this program uses that space.

Press ENTER to continue.

To restart the macro press {alt}X.

STACK1

Stack input file and compiled output.

```
          Start
          VVVVVVVVV
PLOTFILE >>SE_5__D  SE_4__D    ...  SEA412D  SEA413D  SEA414D
MMM1     >>   1000     1000    ...     1000     1000     1000
KKK1     >>   1000     1000    ...     1000     1000     1000
ZETA1    >>   1.0%     1.0%    ...     1.0%     1.0%     1.0%
MRAT12   >>    200      200    ...      200      200      200
WRAT21   >>      5        2    ...        2        2        2
ZETA2    >>   1.0%     1.0%    ...     1.0%     1.0%     1.0%
MRAT23   >>   1000     1000    ...       10       10       10
WRAT31   >>   0.01     0.01    ...      0.5      0.5      0.5
ZETA3    >> 100.0%   100.0%    ...     1.0%    10.0%    30.0%
PEAK1    >> 0.0518   0.0665    ...   0.0016   0.0653   0.0648
PEAK2    >>      0   0.0162    ...   0.0657   0.0124   0.0089
PEAK3    >>      0        0    ...   0.0154        0        0
WWW1     >>  0.996    0.996    ...    0.492    0.996    0.996
WWW2     >>      0    2.004    ...    0.996    2.016    2.004
WWW3     >>      0        0    ...    2.016        0        0
PEAKMAX  >>0.051756 0.066520   ...  0.065671 0.065279 0.064840
SIGMA    >>0.007153 0.013062   ...  0.012726 0.012401 0.012059
```

Appendix B

USER MANUAL

FOR

SPREADSHEET PROGRAM SERIES "INTEGRAT"

SPREADSHEET SOLUTION
FOR A THREE DEGREE-OF-FREEDOM
SYSTEM WITH AN IMPACT DAMPER

This APPENDIX is written to be a stand alone manual describing the use of the INTEGRAT programs. Throughout this document it is referred to as the "Manual" as opposed to Appendix B. Referenced Sections, Figures or Appendices are contained within this manual except when identified otherwise e.g in the thesis. Stand alone versions of this manual will contain all referenced material as Appendices.

Table of Contents

List of Figures

1 INTRODUCTION

This series of programs was written to generate numerical integration solutions for a three degree of freedom mass/spring/damper system with an impact damper attached to the third mass. There is cyclic excitation of the base mass. A schematic representation of the model is given in Figure B.1. A more complete description of the model and the development of the equations is given in Chapter 3.0 in the thesis.

The complete program consists of four different spreadsheets. The main program, RK*_MDOF[1], as presently configured, performs the numerical integration. The numerical integration is controlled by a macro. The macro allows the solution of single set of parameters or generates solutions for multiple "stacks" of parameters, saving the output to disk for later analysis. The macro also facilitates moving the cursor around in the spreadsheet.

The other three programs compliment the main program. The stacks of input parameters which may be used by the main program RK*_MDOF are contained in a separate file called RK_STACK. These parameters are imported into the main file at the start of a multiple run. The third spreadsheet, called RK_COMPL is used after completing a number of case runs. It collects the output data from selected runs and combines it with the applicable input parameters to create a database for comparison. The fourth program, RK_GRAPH, facilitates setting up

---

1 The asterik within the program name RK*_MDOF is replaced with a number which indicates the revision status of the program. For example, revision 5 is given as RK5_MDOF.

graphs of the output data from any selected run.

The programs are written in LOTUS 123[2] Revision 2.0. They are fully compatible with Revisions 2.1 and 2.2. Although the programs are largely menu driven, a basic knowledge of spreadsheet programming is necessary to use these programs. It is not necessary to understand spreadsheet macro programming (hereafter called macros) to utilize these programs. Descriptions of what each program is meant to do and the results of each menu selection are included in this manual. However, a good knowledge of macros is required to fully understand the exact operation of the macros listed. A brief description of what macros do and how they are written is given in Appendix C of this thesis. For further information on spreadsheet program, the user is refer to the references [LOTUS 1985].

---

2 Trademark LOTUS Development Corporation, Cambridge, Mass. USA

2 INSTALLATION AND GENERAL OPERATING PROCEDURES

There are four files included in this program: RK*_MDOF, RK_STACK, RK_COMPL and RK_GRAPH. Each has the extension .wk1 indicating that they are LOTUS 123 worksheet files.

2.1 Hardware Requirements:

2.1.1 These programs will operate on any computer capable of running LOTUS 123.

2.1.2 The computer should be equipped with a hard disk drive and one 5.25" low density floppy disk drive.

2.1.3 An automatic feed printer is required for the program output results.

2.2 Software Required:

2.2.1 A copy of LOTUS 123 Revision 2.0, 2.1 or 2.2 must be installed on the computer hard drive.

2.3 Installation Procedure:

2.3.1 Copy all four programs onto the hard drive in a directory called INTEGRAT.

2.3.2 Within the directory INTEGRAT make the following subdirectories: RK_MITT, RK_BIN and RK_CHIVE.

2.3.3 Start LOTUS 123.

2.3.4 Make the LOTUS default directory that which contains the directory INTEGRAT. e.g. If the directory tree is C:\DATA\LOTUS\VIBRATE\INTEGRAT, the default directory should be C:\DATA\LOTUS\VIBRATE

2.3.5 Ensure that there is adequate spare capacity on the computer hard drive to store any files which will be generated. Depending on the length of the simulation, the complexity of the model movement and the number of data points retained, file sizes of 200,000 bytes can be expected.

2.4 General Operating Procedures:

2.4.1 To use any program, retrieve as with any LOTUS file.

2.4.2 Each program begins with an auto start menu macro. To select from the menu either type in the first letter or move the cursor over and press ENTER.

2.4.3 If it is necessary to quit the macros the start-up menu can be recalled by pressing {alt}X.

2.4.4 Programs are set up with manual recalculation (The program will only recalculate equations when the CALC button (F9) is pressed). Do not change to automatic recalculation. This will slow down operation considerably and may, in some cases, lead to improper operation of the macros.

2.4.5 Data files are saved in directory RK_MITT.

e.g. C:\DATA\LOTUS\VIBRATE\INTEGRAT\RK_MITT

2.4.6 Prior to starting a multiple run of parameters move all data files in directory RK_MITT into directroy RK_BIN. Otherwise, if file names have been inadvertantly duplicated, the program will generate an error message and not continue.

2.4.7 Graph files , created by RK_GRAPH, remove data files from directory RK_BIN and save then to directory RK_CHIVE.

3 PROGRAM DESCRIPTIONS

Listings of the four programs are included at the end of the manual. These are printouts of each of the four complete spreadsheets programs. Each page is identified with a header containing three components:

PROGRAM \ SHEET \ PAGE

The program will be one of either RK*_MDOF, RK_STACK, RK_COMPL or RK_GRAPH. The sheet number refers to a section of the program as generally described in Appendix C of the thesis. An outline of the sheet locations for each of the programs is given in Figures B.2 through B.5. Each program includes a set of menus (called BROWSE) for moving about the spreadsheet.

To facilitate presentation and understanding, the sheets have been modified from what would be seen when examining the spreadsheet program file:

i. Each sheet has been split into pages.

ii. Where spreadsheet menus are used, they have been expanded as described in Appendix C of the thesis so that they are readable.

iii. Some of the sheets do not support the normal presentation of range names. These have had range names added. These additional range names have been highlighted in **bold** and the ranges are either boxed or set within lines.

iv. Where subroutines or menus are called that are not on the same page, the listing page containing the subroutine or menu is given to the right.

v. In some cases, to suit presentation of related macros, the code has been grouped together onto a single line. Normally, as described in Appendix C of the thesis, each action is put onto a separate line to facilitate editing. As long as there are no spaces between the different commands, the macro executes them in the same manner.

The remainder of this section describes the contents and output of each of the programs. Beside the heading for each program and sheet is the User Manual page number where the sheet begins. It is highlighted in bold print. Detailed descriptions of the macro operation are given in Section 4.

3.1 Program RK*_MDOF **[Page 242]**

See Figure B.2 for the layout of this spreadsheet. This program, as presently configured, performs the numerical integration.

3.1.1 Sheet 1: Input Parameters **[Page 243]**

Input parameters are what describe the model and how the program will treat the data that is generated. This sheet is laid out in the standard calculation format described in Appendix B of the thesis. It has been laid out to reflect relationship of parameters chosen for this particular investigation. The user can modify those parameters identified as inputs. Another printout of this sheet, displaying the formulas which generate the numeric values, is given in Appendix B.1.

3.1.1.1 System Parameters

The system parameters describe the model. The user directly specifies numerical values for the base mass (MMM1) and spring (KKK1). The second, third and fourth mass, spring constants and damping are then determined based on satisfying mass and frequency ratios specified by the user. The last two system parameters directly specified by the user, are the clearance or gap and the coefficient of restitution of the impact between the walls and the impact damper. The remaining parameters are a function of the input parameters and determined by calculation. Refer to Appendix B.1 for the equations used.

3.1.1.2 Program Parameters

In addition to defining the system, several of the program control parameters which are frequently varied are defined in this section. The number of integration time steps per minimum time period is called STEPS. The program selects the highest frequency from the three mass/spring natural frequencies and the forcing frequency, and divides the resultant time period into STEPS. A time step of 1/20 of the shortest period usually gives accurate results with a Runge-Kunta integration method, which is the method used.

To reduce the potential size of the file, the position and velocity data from every time step is not necessarily saved. LIMIT2 is the maximum number of time step iterations that will be taken between storing data in the output table. It is called the maximum because certain events such as impacts can or chatter can also call for storing data. This will be explained in Section 4. Note that regardless of how often the position data is stored, the accuracy of the integration (as defined by STEPS) is the same.

The maximum number of forcing frequency cycles to be run or input is called CYCLES. The next five parameters control whether the program will continue generating data until the maximum number of CYCLES is reached. The program monitors the maximum displacements of each of the three lower masses (XXX1, XXX2 and XXX3). The usual objective of the program is to determine the steady state displacement amplitudes of the system masses. If the standard deviation of the absolute displacement of mass 2 (XXX2) is within a percentage, RANGE, of the absolute displacement, the program considers steady state to have been achieved and execution stops. If there are more than MAXCHAT impacts between MMM4 and one side of its container, the program either switches to a CARRY subroutine (if OK_CHAT is set to "yes") or stops (if it is set to "no"). If MAXCHAT is set too large (approximately greater than 20) the program may stop execution of the simulation due to too small a timestep. The concept of CARRYING is described in Chapter 3.0 of the thesis. If the CARRY subroutine is called more than MAXCARRY times the execution of program, for the current set of input parameters is terminated. The user may wish to allow occasional carrying of the impact damper, but stop any simulation where there is continual carrying (excessive chatter). When the CARRY subroutine is running, the user can choose to record each position data point or only the first and the last points. Selecting to record each point is only required if the user is specifically interested in the precise shape of the displacement curve.

The INITIAL conditions are the position and velocity of each of the masses at the start time specified. Usually, all these values are assumed to be zero except when the run is a continuation of a prior run.

3.1.1.3 Runge_Kunta Grid Point Calculation

The Runge-Kunta integration method is self starting. The position and velocity of the three coupled masses (MMM1, MMM2 and MMM3) are entered into several first order differential equations to give the position and velocities of the masses after the specified time step. The first order differential equations are generated by reducing the second order differential equations used to solve the closed form solution of the three mass system. The method is as described in [Rao 1986]. The second order differential equations and the equivalent first order differential equations are given in Appendix D of the thesis.

The equations of motion give the position of the four masses. By monitoring the position of the fourth mass (MMM4) relative to its containment walls, mounted on the third mass, it is possible to determine when MMM4 is outside its containment. Since this is not physically possible, a bisection iteration routine is used to determine the moment of impact of MMM4 with the walls of MMM3. There is then a momentum exchange between MMM3 and MMM4 which changes their velocity. The resultant velocities are generated by the equations located in cells VVR3 and VVR4.

3.1.2 Sheet 2: Input Parameter Stack [Page 247]

This sheet holds the stacks of input parameters created by the user and stored in program EX_STACK. They match the user input described for Sheet 1. Each column is also given a file name, consisting of a maximum of seven characters. This file name should be exclusive to the stack of input parameters which it heads. The system of filenames used in the investigation undertaken in this thesis is given in Appendix F of the thesis. The output of the program is saved in files which contain the file name plus one additional character. This is further explained in conjunction with program RK*_MDOF macro operation (Section 4.2).

3.1.3 Sheet 3: Macros [Page 248]

In addition to controlling the integration routine, the macros in this spreadsheet facilitate the following operations:

i. Movement around the spreadsheet

ii. Varying input data to generate an output table

iii. Presentation of the output as graphs

Page 1 contains the start-up menu macro that is displayed each time the program is retrieved. It is automatically called up when the program is started or can be recalled by pressing {alt}X. For purposes of presentation, the menu macro is staggered as described in Appendix B of the thesis. All menus contained within this program listing are staggered in a similar manner.

Pages 2, 3 and 4 of this sheet contain menu macros for moving about the spreadsheet. (These are explained in Appendix C of the thesis.) Starting at Page 5 the main macro begins. The flow of this macro and the user interface is explained in detail in Section 4.2. The macro extracts the results of each model run to separate spreadsheet files. The screen message (Sheet 4) is saved to a file with the suffix S. The output table (Sheet 5) is saved to a file with the suffix T. Both files are stored in the directory RK_MITT.

3.1.4 Sheet 4: Messages & Comments [Page 267]

When the integration program is being executed, the user can monitor the status of the simulation by observing the screen, which contains a summary of the model parameters and the ongoing spreadsheet status. Page 1 contains two versions of this screen message, only one of which is actually in the program. The upper message is as it would appear at the start of a new run. The system and program parameters are recorded, but the various running averages or totals have either been set to zero or are not yet applicable (@NA). The lower message is typical of one at the end of a run. The various cells for averages and running totals have data in them and the total elapsed time of the simulation is recorded. At any time prior to the end of the run, this message screen is updated each time data is copied to the output table. Until the run is completed, the elapsed time and reason for termination are not given.

Page 2 contains the template of the message screen with the various cell range names printed in. This facilitates cross referencing to the macro. Screen area space constrains did not allow formatting the message screen as a typical spreadsheet.

Page 3 contains Comments displayed to the user when certain subroutines within the macro are selected. This facilitates use of the program without referring to this User Manual.

3.1.5 Sheet 5: Output Table [Page 270]

The output data of the Runge-Kunta integration routine is stored in this table. Within the program, it is actually the input data (Sheet 1, Page 3) which is copied into the table. This is after the output data has been copied into the input position and any other manipulations of data are completed. The sheet is nine columns wide as shown, but the length increases as data is stored. If the length of the simulation (CYCLE) is very long, and the program does not terminate due to having reached steady state or for some other reason, the simulation will continue until the random access memory of the computer overflows. The program will then stop functioning entirely.

3.2 Program RK_STACK [Page 271]

The purpose of this program is to hold stacks of input parameters that describe models to be simulated by the program RK*_MDOF. The stacks are also used as a basis for the compiled model input and output database. See Figure B.3 for the layout of this spreadsheet.

3.2.1 Sheet 1: Macros [Page 272]

The macro for this program is used primarily to move about the spreadsheet. The user views a comment with information about the operation to be performed and is then moved to that section of the spreadsheet. There is also a short macro which makes modification of the filenames faster. This is modified by the user as required to add and delete letters to the list of filenames. A full description of macro operation and user interface is given in Section 4.3.

3.2.2 Sheet 2: Comments [Page 274]

These comments are highlighted during operation of the macro. This program is simply a list of input parameters and is normally manipulated like any other spreadsheet, outside of the control macro (manually). These comments ensure that the user retains the layout of the spreadsheet so that it can be read by the other programs, RK*_MDOF and RK_COMPL.

3.2.3 Sheet 3: Stack [Page 275]

The layout of this sheet conforms to the layout of the input stack sheets in programs RK*_MDOF and RK_COMPL. The section of the sheet given the range name STACK is imported and used by the other two programs. It is simpler and faster to develop the stack of input parameters in this smaller spreadsheet. This allows operation of the other two programs to be almost fully contained within the macros. This program is primarily manipulated outside the macro as a typical spreadsheet.

3.3 Program RK_COMPL [Page 276]

The purpose of this spreadsheet is to compile the output of various model runs into a single database. As presently configured, the output is all the data displayed in the message screen at the termination of the run. This output is listed along with the model input parameters under the descriptive filename. See Figure B.4 for the layout of this spreadsheet.

3.3.1 Sheet 1: Macros [Page 277]

The first two pages of these macros are used to either move about the program or select the operation to be performed. The two main operations performed are preparing the stack of files to be imported (SETUP), or compiling the data from each file (COMPILE). The main macro to compile data begins on Page 3. It extracts information from the S suffix files generated by RK*_MDOF and collects it in a manner that allows comparison of the different parameters. In most cases, the original data file can be deleted since the information is either contained in this compiled format or in a graph file. This macro operation and user interface is described in detail in Section 4.4.

3.3.2 Sheet 2: Comments [Page 281]

As with program RK_STACK, these comments are highlighted during operation of the macro. The comments advise the user of the next step to take so that the program functions properly.

3.3.3 Sheet 3: Import Zone [Page 282]

This sheet of the program is where the data to be compiled is imported by the macro. Program RK*_MDOF saves the message screen as a data file at the end of each run. This program's macro imports that file and moves the cursor about, copying data to the output stack.

3.3.4 Sheet 4: Output/Input Stack [Page 283]

Page 1 of this sheet contains the model data prepared within program RK_STACK and used by program RK*_MDOF. The data files of interest are also imported into this program by the macro. The macro then appends the data extracted from the IMPORTZONE (Sheet 3) to the bottom of the appropriate column. The end result is a complete summary of the results of each run. This data can then be manipulated as any standard spreadsheet database. This is left to the user.

3.4 Program RK_GRAPH [Page 285]

Within Program RK*_MDOF there is a subroutine which facilitates setting up graphs to examine the output data after a single run. When multiple runs are undertaken, the data from each run is removed and stored as a separate file with the suffix T. Access to the subroutine is not available, since only the data points are stored in the new file. This program simply facilitates the generation of plots from an existing database. Its usefulness is primarily because of the repetitive nature of graphs generated as a result of investigations using the RK*_MDOF program. See Figure B.5 for the layout of this spreadsheet.

3.4.1 Sheet 1: Macros [Page 286]

Page 1 contains the start-up menu that is displayed each time the program is retrieved. It is automatically called up when the program is started or can be called up by pressing {alt}X. Pages 2 and 3 contain the macros for moving about the spreadsheet. Starting on Page 4, the main macro begins. Its operation and user interface is described in detail in Section 4.5.

3.4.2 Sheet 2: Comments [Page 292]

As with program RK_STACK these comments are highlighted during operation of the macro. These comments advise the user of the next step to take, so that the program functions properly. Also contained within Sheet 2 are several standard graph titles from which the user can choose. The user can input an original title if desired.

3.4.3 Sheet 3: Import Table [Page 293]

This sheet is where the selected output data file generated by RK*_MDOF is imported. The complete contents of the file are copied into this program. The upper, left corner is positioned on the range IMPORTZONE.

4 MACRO OPERATION

For all programs, when the file is retrieved, an auto start macro[3] displays a menu, hereafter called a start-up menu. The basic operations for this series of programs are menu driven. In some cases, it is necessary to perform routine spreadsheet manipulations outside of the macro. Operations outside of the macro are identified as being "manual".

In any start-up menu, the BROWSE selection moves the user around the spreadsheet. The method is described in Appendix C of the thesis. The QUIT selection exits the macro and returns operation to the keyboard. This is primarily used in conjunction with BROWSE. No further explanation of either of these selections is given here.

When reading this section, it is recommended that the appropriate program be installed and running. If not possible, refer to the program listings in this manual for details of what each operation is specifically being performed. In the program listings, each time a subroutine or menu is called which is not on the same page, the listing page reference is given to the right.

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3 In LOTUS 123, any macro named \0 is automatically called when the spreadsheet file is retrieved.

4.1 Program RK*_MDOF

Start-up Menu:

RUN SAVE_DATA GRAPH CONDENSE BROWSE QUIT

4.1.1 RUN/ONE

Selecting RUN displays the following menu:

MULTI ONE STEP ABORT

If for some reason the user does not wish to continue, ABORT will return to the main menu. This is a standard command that is repeated in different menus. The MULTI and STEP selections are explained as separate subsections.

ONE is selected if the user wishes to simulate the system motion for a single set of input parameters. This function utilizes the majority of the main macro subroutines and options and will be explained first. The input parameters used are those in the program spreadsheet at the time that ONE is selected. Upon selecting ONE, the user is offered the following choice:

ERASE CONTINUE

Selecting CONTINUE will continue with any integration which was already in progress i.e the database. Flag settings are retained and the first integration step is initiated from the data point contained in the input range. Selecting ERASE, erases the output data table and copies the initial positions and velocities of the masses into the input range. In either case, the length of the run will be the complete number of cycles specified by the program parameters. A run can be terminated for one of five reasons:

i) Mass 2 has achieved Steady State:

The purpose of the impact damper is to control the amplitude of Mass 2. As presently set-up, the program monitors the last 20 peak values of Mass 2. If the standard deviation of these peak values is within a user selected percentage of the average of the peak values, then the program is terminated.

ii) Impact Damper Chattering:

Certain conditions will cause the impact damper to continually hit the same side of its enclosure. This often indicates a less than ideal impact damper configuration. The user can select that this is a failure mode by setting OK_CHAT (chatter is okay) to NO.

iii) Exceeded Maximum Carries:

If chatter is considered acceptable, the program contains a subroutine which allows MMM3 to "carry" MMM4 until the conditions vary so that the two masses separate. A model which occasional "carries" may still provide adequate attenuation of vibration amplitudes. If the model is continually "carrying" it is probably not a good candidate for an impact damper. The user can specify the number of "carries" considered acceptable. If exceeded, the program will terminate.

iv) Program Stopped by Operator:

If the program is stopped by the user pressing {control}{break} no result is recorded by the PROGRAM subroutine and the data is not saved either to disk or to the printer. It may be appropriate to save the output. This is done by selecting SAVE_DATA in the main menu. At that time, this result is copied into the screen message.

v) Ran to Time Limit:

If the program is not terminated for any other reason, it should run for the number of cycles specified. This result is then noted.

At the successful completion of any run, a hard copy of the screen message is printed out. The start-up menu is then displayed.

4.1.2 RUN/MULTI

This selection is the most useful function of the macro. A previously stored stack of input parameters can be executed without the user being in attendance. A flow sheet presenting the decisions that the core of the macro program follows is contained in Figure B.6. Immediately upon selecting MULTI, the program sets a flag STACKON which causes the macro to bypass certain decisions the user would normally make. The macro then erases the existing input parameter stack stored in Sheet 2 (if any exists), and imports the range named STACK from the program RK_STACK. The limit of the stack is marked to flag completion. To allow the user to determine if this input data is what was expected, the following menu is presented while the imported stack is on the screen:

QUIT CONTINUE

The user should examine the input data displayed. If there is unexpected data, the user must quit this macro and program to investigate RK_STACK. Assuming that it is as expected, the user selects CONTINUE. Returning to the beginning of the stack, the macro then steps down the first set of inputs, notes the filename and copies values into each of the input parameter cells. It then calls the subroutine PROGRAM. This operates as described in Section 4.2.1.

At the end of the PROGRAM subroutine, control is handed back to the MULTI subroutine because the STACKON flag is set. A subroutine, SAVE_DATA, is called. It extracts the screen message and the output data and saves them into separate files for later compilation and analysis. This subroutine is described in Section 4.2.4. since it is a subsection of the SAVE_DATA menu selection.

The cursor is then moved to the position where the next stack should be located. If the value in this cell is equal to ENDFLAG, then the STACKON flag is reset to NOPE and the start-up menu is displayed. If there is another stack of input parameters, these are read into the spreadsheet and the program continues.

The PRINT subroutine program contains an expression which would catch an unspecified loop in the macro. Before printing the screen message it checks that it has not printed out more than a specified number of screen messages since the MULTI subroutine was originally called. In unattended operation, there is a concern that a program error could result in a loop that continually calls the PRINT subroutine. This could result in a large waste of paper or damage to the printer. The number is presently set at 25, but can be varied (see Section 6). As a consequence, the program will not allow stacks larger than the preset size to be run. This is not a major concern, since there is a significant amount of time required for each run and the elapsed time for a stack is not likely to be more than 24 hours.

4.1.3 RUN/STEPPER

When trouble shooting a particular model or modifications to the program, it can be useful to manually increment the Runge-Kunta integration equations. This selection steps through the integration one step at a time, without checking that the position of MMM4 is within the limits of the enclosure mounted on MMM3. The initial values are copied into the input range and the spreadsheet is calculated. The output is positioned on the screen and the user is asked:

AGAIN **STOP**

AGAIN will swap the output into the input and CALC the spreadsheet again. The menu selection is repeated. Selecting STOP displays the start-up menu.

4.1.4 SAVE_DATA

This selection is used to save the output results from a run which was either initiated by the RUN/ONE command or terminated by the user pressing {control}{break}. The first menu presented to the user is:

BREAK **SINGLE**

Depending on the reason the data was not originally saved, the user presses one or the other option. When BREAK is pressed, the program assumes that the filename as recorded within the program is still acceptable. The result of the run is noted to be " Program Stopped by Operator " and a copy of the screen message is printed. If SINGLE is selected the user is given the option of selecting a new file name:

CONTINUE RENAME

If RENAME is selected the user is prompted to type in a new filename of up to seven letters. Either selection, in both menus, then calls subroutine SAVE_DATA, which saves both the screen message and the output data table. They are saved under the general filename (up to seven letters), with the suffix S added to the screen message filename and the suffix T added to the output table filename. The files are saved into directory RK_MITT. The start-up menu is then displayed.

4.1.5 GRAPH

The graph macro allows the user to quickly set-up graph data ranges from the output table data. All previous graph settings are reset. The graph is set-up with automatic scaling and time is the X-axis. The top of the output table is displayed on the screen and the following menu is presented:

A B C D E F

The user selects one of the ranges, usually A.

After pressing the selection, the user should move the cursor to the top entry of the column to be graphed and press enter again. The complete column is then selected as the range by the macro selecting {end}{down}. The user is prompted for a legend for the range. Legends such as V1, X1, V2, X2 etc. would be appropriate. Upon typing a legend and pressing ENTER the following menu is displayed:

CONTINUE FINISHED

Selecting CONTINUE displays the same menu and the user should select another range. Up to six ranges are possible, but usually only up to three are practical due to crowding of the data points. Selecting FINISHED will cause the macro to display the resultant graph. The graph is exited in the normal spreadsheet manner (press any key), and the start-up menu is displayed. If the user wishes to save the graph for further manipulation or plotting, QUIT is selected on the start-up macro. Further manipulation is as with a typical spreadsheet.

4.1.6 CONDENSE

Normally, it is not necessary to save the file RK*_MDOF after use. The original file is still intact, and since the parameter stacks and output data are saved in other files, nothing is gained. If however, changes are made to the program, it might be necessary to save the new version. After being used, the program often contains the last set of input parameters that were run, as well as the very last output database table. These can increase the size of the file significantly. This selection facilitates removal of this information from the file. Two subroutines are called. CONDENSE deletes all rows below the header in the output table (Sheet 5) and confirms the location of the range FOOTER as the row immediately below the header. DESTACK moves the cursor to STACK1 in Sheet 2. If the contents of this cell indicate that there are stacks, i.e. STACK1 is not equal to NOMORE, then the stacks are erased. The value NOMORE is copied into the STACK1 cell position. The start-up menu is displayed. Saving the program is done manually.

Start-up Menu:

EDIT **NAME** **BROWSE** **QUIT**

4.2.1 EDIT

Selecting EDIT displays the following menu:

INPUTS **FILENAME**

Upon selecting INPUTS, the macro displays Comment 1 which advises the user on how to edit or add to the input variable stack. Editing of the stack is done outside of the macro. The rows must remain the same, but any number of columns can be added. The columns must be beside each other, without any blanks.

If FILENAME is selected, Comment 3 is displayed, which advised the user to refer to this manual for instructions on how to revise the macro \F ({alt}F). In the original research project for which this program was developed, the filenames for the different model parameters have been chosen to facilitate sorting of the parameters. They are chosen based on a matrix which is given in Appendix B.2. There is a great deal of symmetry to the names. The macro \F was developed to speed the revision of file names.

The macro assumes that the cursor is positioned on the first filename to be altered. Furthermore, all other filenames to be altered are in cells to the right and the cell to the right of the last filename contains the value called NOMORE (999). If only some of the existing files are to be altered, a column should be inserted after the last one to be revised and the value NOMORE copied into it. If all the filenames are to be revised, the value NOMORE should be copied into the cell to the right of the last filename. This operation must be done manually.

After reading Comment 3, and pressing ENTER, the macro moves the cursor to the cell named EDIT within the \F macro and quits. The spreadsheet commands to alter any one of the filenames should be entered. The macro already contains the {edit} command and the ENTER (~) required to leave the {edit} mode.

Examples:

i) Changing SAC3W2B to SAC4W2B, SBC3V3B to SBC4V3B, etc.
To delete the 3, the cursor must move to the left four positions. Then delete is pressed and a 4 is entered. This is written as: {left 4}{del}4

ii) Changing SA?3W2B to SAA3W2B then SAB3W2B, SAC3W2B, etc.
This set of parameters has only one different variable. The generic filename, SA?3W2B is copied into each of the filename positions. To delete the ?, the cursor must move to the left five spaces. The new character varies in each filename so the command {?} is used to allow user input. After typing in the correct character, the user presses ENTER and the macro completes the command. The expression is written as: {left 5}{del}{?}. Ensure that the variable in the stack represented by the new character is visible on the screen when running the macro. Use the horizontal windows command if necessary.

4.2.2 NAME

The range named STACK is imported by the other files in this series: RK*_MDOF and RK_COMPL. This selection facilitates naming or checking the contents of this range. Upon selecting NAME, the macro moves to Comment 2 which gives some explanation of how to name the range. Pressing ENTER moves the cursor to the range presently named STACK. If the name exists it will be highlighted in the normal spreadsheet fashion. To move to the four corners continually press the period (.) on the keyboard. If the range does not exist, or that given is not acceptable, it can be altered manually, in the normal spreadsheet fashion. If this range name no longer exists, the cursor remains at the comment. To get to Sheet 3, restart the macro and use the BROWSE commands. The top row must always be the filename and the bottom row the Initial Value for VVV4. The range name must be STACK.

4.3 Program RK_COMPL [Page 277]

Start-up Menu:

COMPILE SETUP BROWSE QUIT

4.3.1 SETUP

Initially, the user sets up the stack of files with their input parameters. To these, the program will add the output data generated by the RK*_MDOF program. To do this, the user selects SETUP which displays a descriptive Comment 2, moves to the stack and quits. Manipulations to the stack are done manually because, although the stack is often imported from the file RK_STACK, this is not always so.

The macro places the cursor in the cell named "START". If there are old data in the stack area this should be removed by using the RANGE\ERASE command and defining the extent of the old data. Prior to doing this be sure that if required, the data has been saved in another file.

If the input parameters stored in program RK_STACK are the ones to be compiled, the spreadsheet commands FILE\COMBINE\COPY\NAME retrieve them. Ensure that the top of the range is in line with the row FILENAME. Ensure that the cell immediately below each initial value VVV4 is empty. There must be a file in the directory RK_BIN for each of the FILENAME's listed. If not, when compiling an error message will be generated and the macro will stop. Sometimes, a large stack of files may have been broken up into smaller batches because of limited time or disk space. Insert a column after the last file that should be compiled. Copy the value in range NOMORE (999) into the cell immediately to the right of the last filename. The COMPILE subroutine will stop when it reaches that column. Any files to the right can be compiled after the next batch is run.

Having set up the input stack the macro is restarted with the command {alt}X. The start-up menu is again displayed.

4.3.2 COMPILE

Selecting COMPILE branches to the compilation macro. The screen displays COMMENT 1, advising the user on where to position the cursor in the stack. The macro will compile from where the cursor is positioned and all files to the right, until it detects a cell containing the value NOMORE. The first file is not necessarily in the START position, if compiling the stack in batches. The macro notes the cell it is on by giving it a range name, MARK1.

First, the macro copies the filename into the range named FILENAME within the COMPILE subroutine. The cursor is then moved to the import zone. The file containing the screen message output of the file in question is imported completely into the import zone. This file is identified by the suffix S appended to the root filename e.g SA13L2_S. From its known position relative to the imported file, the macro moves the cursor around and copies various cell values into the matching position of a range called GATHERED. After all the values are gathered, the cursor is moved back to the top of the stack being compiled and then down to the first empty cell at the bottom. The values from the range GATHERED are copied into this position. The values match up with the labels on the left hand side of the sheet. The cursor moves back to the top of the stack and shifts to the right. If the cell contains the value NOMORE, the program saves itself and stops. Otherwise execution of the COMPILE macro continues with the next file.

After all the file stacks have been compiled the user has a record of the input parameters and the output results. This data should be moved into a new spreadsheet file. Sheets 1 and 2 of the program are not required for the database and can be erased. Further manipulation of the data is left to the user.

4.4 Program RK_GRAPH

[Page 286]

Start-up Menu:

IMPORT GRAPH SAVE CONDENSE BROWSE QUIT

Comment 1 is displayed when the file is initially retrieved. Prior to working with this program it is necessary to know the names of the files to be graphed. The files are those with the suffix T, generated by the RK*_MDOF program. Furthermore, the files must be stored in the directory RK_BIN.

4.4.1 IMPORT

This selection prompts the user for the name of the file to be retrieved into RK_GRAPH. The name is copied into the macro which then copies the entire file into Sheet 3.

4.4.2 GRAPH

The graph subroutine allows the user to quickly set-up graph of the imported output table data. Comment 2 is displayed to advise the user of what will occur. Any prior graph settings are erase. The graph is set-up with automatic scaling. Upon selecting this option, the macro assumes that the X-axis will be Time and moves to where the top of the time data should be. If the position is correct the user presses ENTER. If not correct, the position should be corrected before the user presses ENTER. The remainder of the column, below the cursor, is selected by the macro commands {end}{down}. Then the following menu is presented:

A B C D E F

The user selects one of the ranges, usually A. The macro copies the selected letter into the next portion of the macro where the data range format is set. Control is returned to the user who should move the cursor to the top entry of the column to be graphed and press ENTER again. The complete column is selected as the range by the macro ({end}{down}). The user is then prompted for a legend for this data range. Legends such as V1, X1, V2, X2 etc. would be appropriate. Upon typing a legend and pressing ENTER, the following menu is displayed:

LINES SYMBOLS BOTH

The user selects which type of display is desired for this particular range. The option of neither is not offered; it is assumed that if the range was selected, it is for display. Upon selecting one of the three options, the macro sets the format for that range. The user is then prompted for the next data range by the menu:

CONTINUE FINISHED

Selecting CONTINUE displays the A,B,C,D,E,F menu and the user should select another range. Up to six ranges are possible, but usually only up to three are practical due to crowding of the data points. Selecting FINISHED causes the macro to start the next subroutine for setting the graph titles. The screen presents several options for First Title Choices and the following menu is displayed:

RETAIN AAA BBB CCC DDD EEE FFF OTHER

The user can retain the previous title, select one of six standard titles or type a new one. Selecting OTHER prompts the user for a title of up to 39 characters. Whichever selection is made, it is stored in the cell named RETAIN. The next menu requests the title for the Y-axis:

DISPLACEMENT VELOCITY NONE

Selecting either DISPLACEMENT or VELOCITY causes that label to be copied into the Y-Axis title. Selecting NONE clears any existing title. The macro then types the label TIME into the X-axis title, the label contained in the cell RETAIN into the FIrst graph title and the filename into the second graph title.

Prior to entering any title, the macro types in the label FAKE and then {escape}. To erase any existing titles it is necessary to press {escape}. Otherwise the new title will be appended to any existing title. However, if the title is already blank, pressing {escape} will exit that command. Typing in a label such as FAKE ensures that there always is something in the cell.

The macro will now display the resultant graph. The graph is exited in the normal spreadsheet manner (press any key) and the start-up menu is displayed. If the user wishes to further manipulate this graph or create a plot file, QUIT is selected on the start-up macro. Further manipulation is done manually as with a typical spreadsheet.

4.4.3 SAVE

This option saves this complete program including the imported database into the RK_CHIVE (as in archive) directory. The file is saved with the T suffix replaced with a G. This indicates a graph file. At the same time, the original T file is erased from the RK_BIN directory. Future analysis is now possible by retrieving the new G file. The entire graphing macro is saved along with the database.

4.4.4 CONDENSE

Normally, it is not necessary to save the file RK_GRAPH after it is used. The original file is still intact and nothing is gained. If however, changes are made to the program, it might be necessary to save the new version. When used, the program will contains the last output database table which was imported. This can increase the size of the file significantly. CONDENSE moves to the output table (Sheet 3). All the cells from this point to the bottom right corner of the spreadsheet ({end}{home}) are erased. The start-up menu is again displayed. To save the condensed file as RK_GRAPH, quit the macro and do so manually. Note that the default file name may not be RK_GRAPH so it will have to be changed back.

5 Example Problem

To demonstrate the use of the various programs and the user interface, the programs will be used to generate solutions for three different sets of model parameters. The model will be as described in Figure B.7 (a). Examination of the transfer function allows selection of a value for the impact damper wall spacing, greater than the expected amplitude of MMM3. Therefore MMM4 will not contact them. Figure B.7 (b) is equivalent to that in Figure B.7 (a) as long as the gap d is large enough. Because there is no impact damper in the first examples, the steady state amplitudes of the masses could be found by using closed form solutions (Chapter 2.0 of this thesis). The need to generating these particular charts when the steady state amplitudes are already known are twofold: The amplitudes determined will act as a check of the program results and examination of the graphs will provide further insight into the phase angle relationships of the various masses. The three sets of parameters will be similar in all respects except that they will be at the three resonant frequencies of MMM3: 0.85, 1.0 and 1.175 radians per second.

The order of utilization of the programs is RK_STACK, RK*_MDOF, RK_COMPL and then RK_GRAPH. While reading this section it would be useful to have the various programs available on a computer. The user can then follow the steps as they are presented. The programs should be installed on the computer as described in Section 2. Each user step is identified by a number. As indicated previously, the term "manually' means using standard spreadsheet commands, outside of the macro.

5.1 Program RK_STACK

5.1.1 Manually retrieve program RK_GRAPH

Start-up Menu: **EDIT** **NAME** **BROWSE** **QUIT**

5.1.2 Select EDIT.

Menu: **INPUTS** **FILENAME**

5.1.3 Select INPUTS.

Program displays Comment 1

5.1.4 Read Comment 1, Press ENTER.

Menu: **TITLES** **NO**

5.1.5 Select TITLES.

Cursor is moved to position noted below and titles are set.

```
A    B    C    D    E    F

Stack input
FILENAME
WWWF
MMM1     Mass 1
KKK1     Spring Rate 1
....
```

5.1.6 Type first file name. In this case SA1____.

```
A    B    C    D    E    F

Stack input
FILENAME                    SA1____
WWWF
MMM1     Mass 1
KKK1     Spring Rate 1
....
```

5.1.7 Type model and program parameters. Note selections of program parameters will be based on experience. Only upper and lower portions of file shown here for brevity.

A	B	C	D	E	F
Stack input					
FILENAME		SA1____			
WWWF		0.85			
MMM1	Mass 1	1000			
.. ...	....	...			
.. ...	....	...			
	XXX3	0.000			
	VVV3	0.000			
	XXX4	0.000			
	VVV4	0.000			

5.1.8 Manually copy column as required, in this case twice. Only the top portion of the spreadsheet is shown since that is all that is altered in this example.

A	B	C	D	E	F
Stack input					
FILENAME		SA1____	SA1____	SA1____	
WWWF		0.85	0.85	0.85	
MMM1	Mass 1	1000	1000	1000	
....					

5.1.9 Manually move across columns changing input parameters as required. Although this is a simple example, the macro will be used to alter the filenames.

A	B	C	D	E	F
Stack input					
FILENAME		SA1____	SA1____	SA1____	
WWWF		0.85	1.00	1.175	
MMM1	Mass 1	1000	1000	1000	
....					

5.1.10 Press {alt}X.

Start-up Menu: **EDIT** **NAME** **BROWSE** **QUIT**

5.1.11 Select EDIT.

Menu: **INPUTS** **FILENAME**

5.1.12 Select FILENAME.

Program displays Comment 3.

5.1.13 Read Comment 3, Press ENTER.

Screen display is as below with cursor located as shown:

```
      A          B        C        D       E         F
 LOOP     {edit}           <  \F
                                            < Edited this line
         ~{right}
          {if @cellpointer("contents")=NOMORE}{menubranch MENU0}
          {branch L{menubranch MENU0}
```

5.1.14 Type new code required to change file name. In this case move left five spaces, delete the 1 and wait for user to type the new character.

```
      A          B        C        D       E         F
 LOOP     {edit}           <  \F
          {left 5}{del}{?}                  < Edit this line
         ~{right}
          {if @cellpointer("contents")=NOMORE}{menubranch MENU0}
          {branch L{menubranch MENU0}
```

5.1.15 Press {alt}X.

Start-up Menu: **EDIT** **NAME** **BROWSE** **QUIT**

5.1.16 Select BROWSE.

Menu: **MACROS** **STACKS** **COMMENTS**

5.1.17 Select STACKS.

Start-up Menu: **EDIT** **NAME** **BROWSE** **QUIT**

5.1.18 Select QUIT to leave macro.

5.1.19 Manually move cursor to right of last column filename and type 999 (NOMORE).

```
      A          B                      C      D        E       F
 Stack input
 FILENAME                               SA1___  SA1___  SA1___  999
 WWWF                                   0.85    1.00    1.175
 MMM1     Mass 1                        1000    1000    1000
 ....
```

5.1.20 Manually move cursor to first filename to be altered, in this case the one in column D, above 1.00.

5.1.21 Press {alt}F to envoke name change macro.

Cell contents will be altered to SA____ and macro waits for user input.

5.1.22 Type character to replace the 1, in this case 2.

Cursor moves to next cell right (Column E). Cell contents will be altered to SA____ and the macro waits for user input.

5.1.23 Type character to replace the 1, in this case 3.

Cursor moves to next cell right (Column E) senses 999 and stops \F macro execution and returns to start-up menu. Display now looks like:

```
        A       B                          C       D       E       F

  Stack input
  FILENAME                                SA1____ SA2____ SA3____ 999
  WWWF                                    0.85     1.00   1.175
  MMM1     Mass 1                         1000     1000    1000
  ....
  ....

     Start-up Menu:  EDIT        NAME        BROWSE       QUIT
```

5.1.24 Select NAME.

Program displays Comment 2.

5.1.25 Read Comment 2, Press ENTER.

Cursor will move to limits of the range name STACK as presently defined. Use periods (.) and a cursor arrows to define STACK as shown (within the rectangular box). Press enter to accept.

```
        A       B                          C       D       E       F

  Stack input
  FILENAME                                SA1____ SA2____ SA3____ 999
  WWWF                                    0.85        1   1.175
  MMM1     Mass 1                         1000     1000    1000
  KKK1     Spring Rate 1                  1000     1000    1000
  ZETA1    % Critical Damping             1.0%     1.0%    1.0%
..  ...    ...                            ...      ...     ....
..  ...    ...                            ...      ...     ....
           XXX3                           0.000    0.000   0.000
           VVV3                           0.000    0.000   0.000
           XXX4                           0.000    0.000   0.000
           VVV4                           0.000    0.000   0.000

     Start-up Menu:  EDIT        NAME        BROWSE       QUIT
```

5.1.26 Select SAVE.

Program saved as RK_STACK, replacing existing.

Start-up Menu: EDIT NAME BROWSE QUIT

5.1.27 Select QUIT.

User can either retrieve next file or perform other functions.

5.2 Program RK*_MDOF

5.2.1 Retrieve program RK*_MDOF.

Start-up Menu: RUN SAVE_DATA GRAPH CONDENSE BROWSE QUIT

5.2.2 Select RUN.

Menu: MULTI ONE STEP ABORT

5.2.3 Set printer so that print head is immediately below serations. Ensure that printer is on line.

5.2.4 Select MULTI.

Printer will print message: "PRINTER CHECKS OKAY, CHECK ALIGNMENT OF PAPER". If there are printer problems, the macro will cease and a standard error message will be displayed. Correct and restart macro.

5.2.5 Program imports range STACK from RK_STACK.

Menu: QUIT CONTINUE

5.2.6 Review STACK and determine if as expected. If acceptable, select CONTINUE.

Program displays message which is updated as the integration progresses. The macro will now generate solutions for the three files in STACK unattended. Upon completion, hard copies of each message screen with the final results are printed. A copy of the final message for the last file, SA3____, is given in Figure B.8.

If the user wishes to perform other manipulations with the data from the last run, in this case SA3____, this may be done now. See Section 4.1 for a description of the options.

Inspection of the final message for parameters SA2____ reveals that the program ran to the time limit rather than achieving steady state motion. It is necessary to extend the run time. Rather than start over, the ONE option of the program will be used to continue from the last data point.

Start-up Menu: RUN SAVE_DATA GRAPH CONDENSE BROWSE QUIT

5.2.7 Select BROWSE.

Menu: VARIABLES MACROS TABLE SCREEN PARAMETERS

5.2.8 Select VARIABLES.

Menu: SYSTEM PROGRAM INPUT EQUATION OUTPUT

5.2.9 Select INPUT.

Program moved to the Input Section of the spreadsheet (Sheet 1).

Start-up Menu: RUN SAVE_DATA GRAPH CONDENSE BROWSE QUIT

5.2.10 Select QUIT.

5.2.11 Move to a clear section of the spreadsheet. Manually combine range named LAST from file RK_MITT\SA2____T into spreadsheet.

5.2.12 Manually transpose imported data into INITIAL section of spreadsheet.

Initial conditions for the next run will be the last data point of the previous run.

5.2.13 Press {alt}X.

Start-up Menu: RUN SAVE_DATA GRAPH CONDENSE BROWSE QUIT

5.2.14 Select RUN.

Menu: MULTI ONE STEP ABORT

5.2.15 Select ONE.

Program initates a single run and questions if existing information is to be retained.

Menu: ERASE CONTINUE

5.2.16 Select ERASE.

Screen will display message and user must wait for run to be completed. Upon completion Start-up menu is displayed.

Start-up Menu: **RUN SAVE_DATA GRAPH CONDENSE BROWSE QUIT**

5.2.17 Select SAVE_DATA since output of run has not been saved.

Menu: **BREAK SINGLE**

5.2.18 Select SINGLE.

Menu: **CONTINUE RENAME**

5.2.19 Select RENAME. (Otherwise will be saved under filename SINGLE)

Program prompts for new name.

5.2.20 Type SA2___B. (Must be a different name)

Macro changes name in message screen to SA2___B and prints out hardcopy. Then saves message as SA2___BS and output table as SA2___BT both into RK_MITT.

Start-up Menu: **RUN SAVE_DATA GRAPH CONDENSE BROWSE QUIT**

5.2.21 Select QUIT.

5.2.22 The two databases generated for SA2___* should be manually combined in one file. Manually retrieve SA2____T. Move to below the bottom line remaining in the first column.

5.2.23 Manually combine file SA2___BT into this position.

5.2.24 Manually delete the rows containing the second header and the first duplicated datapoint.

5.2.25 Save the file with a different revision number, in this case SA2___CT.

5.2.26 To save disk space erase the two files SA2____T and SA2___BT.

5.2.27 User can either retrieve another file or perform other functions.

5.3 Program RK_COMPL

5.3.1 Ensure that all files to be compiled (suffix T) have been moved from the RK_MITT directory to the RK_BIN directory.

5.3.2 Retrieve file RK_COMPL.

5.3.3 If data presently contained in the file is to be retained and manipulated separately, the file should first be manually saved under a different filename.

Start-up Menu: **COMPILE** **SETUP** **BROWSE** **QUIT**

5.3.4 Select SETUP.

Program displays Comment 2

5.3.5 Read Comment 2, Press ENTER.

Macro moves cursor to STACK sheet.

```
      A       B         C        D        E        F
  Stack input file
                        Start
                        VVVVVVVVV
  FILENAME
  WWWF
..  ...
```

5.3.6 Manually move cursor to position where STACK data to be imported. Erase data or move if required. In this case will position cursor as shown under START.

5.3.7 Manually combine range named STACK from file RK_STACK.

```
      A       B         C        D        E        F
  Stack input file
                        Start
                        VVVVVVVVV
  FILENAME              SA1____  SA2____  SA3____
  WWWF                     0.85        1    1.175
..  ...                     ...      ...      ...
```

5.3.8 The results of file SA2___B should also be retrieved since it contains data on the completion of the run. This can be done by adding a column with the file name SA2___B. Fill all the cells normally filled with model and system initial conditions with @NA.

```
     A      B         C        D        E        F
 Stack input file
                      Start
                      VVVVVVVVV
 FILENAME             SA1____  SA2____  SA3____  SA2___B
 WWWF                    0.85        1    1.175      @NA
.. ...                   ...      ...      ...       @NA
.. ...                   ...      ...      ...       ...
```

5.3.9 Press {alt}X.

Start-up Menu: **COMPILE** **SETUP** **BROWSE** **QUIT**

5.3.10 Select COMPILE.

Program displays Comment 1

5.3.11 Read Comment 1, Press ENTER.

Screen displays stack.

5.3.12 Manually move cursor to cell to the right of last file to be compiled, in this case SA2___B. Press ENTER.

Macro will copy NOMORE (999) into this cell.

```
     A      B         C        D        E        F        G
 Stack input file
                      Start
                      VVVVVVVVV
 FILENAME             SA1____  SA2____  SA3____  SA2___B   999
 WWWF                    0.85        1    1.175     @NA
.. ...                   ...      ...      ...      ...
```

5.3.13 Manually move cursor to first file to be compiled, in this case SA1____. Press ENTER.

Program will import S files for each file and extract the data. Data will be stored at bottom of each column against the appropriate descriptive title. When macro senses cell containing 999 it stops compiling and saves itself, replacing the existing RK_COMPL file. Start-up menu is then displayed.

Start-up Menu: **COMPILE** **SETUP** **BROWSE** **QUIT**

5.3.14 Select QUIT.

5.3.15 If there is to be no more data compiled as part of this batch save file under a different file name. The new file can be manually condensed to retain only the database. Subsequent manipulation will be totally manual. The results of SA2____ and SA2___B should be manually combined into one column. Retain the appropriate information from each column, e.g inital conditions from SA2____ and final status from SA2___B.

5.3.16 User can either retrieve another file or choose another operation.

5.4 Program RK_GRAPH

As an example of the use of this file, a graph will be made of the motion of MMM2 in file SA2___C (combined results of SA2____ and SA2___B).

5.4.1 Retrieve Program RK_GRAPH.

Program displays Comment 1.

Start-up Menu: **IMPORT GRAPH SAVE CONDENSE BROWSE QUIT**

5.4.2 Select IMPORT.

Panel displays prompt: "Type file to retrieve from RK_BIN :"

5.4.3 Type SA2___CT, press ENTER.

Program import file into import zone.

Start-up Menu: **IMPORT GRAPH SAVE CONDENSE BROWSE QUIT**

5.4.4 Select GRAPH.

Program displays Comment 2.

5.4.5 Read Comment 2, press ENTER.

A B C D E F G H I

Output Table

Time	MASS 1 X	MASS 1 V	MASS 2 X	MASS 2 V	MASS 3 X	MASS 3 V	MASS 4 X	MASS 4 V
0.00	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
1.88	0.0008	0.0009	0.0002	0.0004	0.0000	0.0001	0.0000	0.0000
...	...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...	...
567.37	0.0235	0.0397	-0.0080	0.0048	-0.2422	-0.3902	0.0000	0.0000
569.26	0.0304	-0.0346	0.0070	0.0061	-0.2963	0.3509	0.0000	0.0000

Cursor is postioned on the 0.00 at the top of the Time column. This should be the X-axis.

5.4.6 Press ENTER.

Menu: **A B C D E F**

5.4.7 Select A.

5.4.8 Move cursor to top number in XXX2 column. Press ENTER. Program makes this column the A range.

5.4.9 Program prompts for legend. In this case type X2, press ENTER.

Menu: **LINES** **SYMBOLS** **BOTH**

5.4.10 Select choice of display, in this case LINES.

Menu: **CONTINUE** **FINISHED**

5.4.11 Select FINISHED.

```
      A         B                C

  FIRST TITLE CHOICES
  ==========================================
  RETAIN  Displacement of Mass 2
  AAA     Displacement of Mass 1
  BBB     Displacement of Mass 2
  CCC     Displacement of Mass 3
  DDD     Velocity of Mass 2
  EEE     Velocity of Mass 3
  FFF     Velocity of Mass 4
  ==========================================
```

Menu: **RETAIN** **AAA** **BBB** **CCC** **DDD** **EEE** **FFF** **OTHER**

5.4.12 Select BBB.

Menu: **DISPLACEMENT** **VELOCITY** **NONE**

5.4.13 Select DISPLACEMENT.

Program will display graph on screen. The plot generated is shown in Figure B.9.

5.4.14 Press any key to return to start-up menu.

Start-up Menu: **IMPORT** **GRAPH** **SAVE** **CONDENSE** **BROWSE** **QUIT**

5.4.15 Select SAVE.

Macro saves complete file under file name SA2___CG in directory RK_CHIVE. Macro also erases existing file RK_BIN\SA2___CT.

Start-up Menu: **IMPORT** **GRAPH** **SAVE** **CONDENSE** **BROWSE** **QUIT**

5.4.16 Select QUIT.

5.4.17 If the user wants to manipulate the graph further, this is done manually. Save graph manually for plotting, if necessary.

6 Program Revisions

The program revisions covered in this section are generally of a minor nature. They assume that the general purpose of the spreadsheet is retained i.e. an investigation of a three degree of freedom spring/mass/damper system with a single external excitation force and an impact damper attached to the third mass. The proper selection of clearance dimensions will effectively remove the impact damper from the system.

The spreadsheet programs are a good basis from which to develop new programs, investigating completely different phenomena. Before attempting this, it is important to be very familiar with how the program works and how to write spreadsheet macros.

6.1 Program RK*_MDOF

The version of this program included with this manual will have a number in place of the asterisk in the title. This indicates the revision status of the program. If multiple copies of the program are in use, it might be difficult to keep track of which program has the latest revisions. In the case of significant revisions, the program should be saved with the next highest number.

6.1.1 Sheet 1 - The Input Parameters:

6.1.1.1 The numeric values of the cells identified as constant {set} can be changed as desired:

i.	Forcing function amplitude	FOOH
ii.	Tolerance on impact sensing	WITHIN
iii.	Tolerance on zero acceleration	STOPPED

6.1.1.2 To add or delete parameters identified as inputs {input}, they must also be added or deleted from the following locations:

Program RK*_MDOF:	READSTK Subroutine	Sheet 3, Page 7
	Stack	Sheet 2, Page 1
	Message Screen	Sheet 4, Page 1
Program RK_STACK:	Stack	Sheet 4, Page 1
Program RK_COMPL:	Stack	Sheet 4, Page 1

The inputs must be added in the same location in each area so that the macros will not get out of synchronization.

6.1.1.3 Cells not identified as either {set} or {input} contain equations, which usually describe mathematical relationships. They are not at the discretion of the user. However, if appropriate due to a change in the problem definition, they can be revised by moving to the cell and typing in a new value or equation.

6.1.1.4 The transfer functions (Sheet 1) are developed to model a particular mass/spring/damper arrangement with external excitation of the base mass. The equations take the input parameters and calculate output values for displacement and velocity of the model. Using the same inputs, with similar outputs, any other set of equations can be substituted for those presently in the program.

6.1.2 Sheet 2 - Stacks

6.1.2.1 The values considered to be variable from run to run, have been included in this stack. For certain investigations, many values will not change. Athough it could be considered inefficient, the present method is to leave these values in the stack and have the macro insert them for each run. If considered necessary the user can remove them from the stack by deleting the row(s). The same changes must be made to the following areas.

Program RK*_MDOF:	READSTK Subroutine	Sheet 3, Page 7
	Message Screen	Sheet 4, Page 1
Program RK_STACK:	Stack	Sheet 3, Page 1
Program RK_COMPL:	Stack	Sheet 4, Page 1

Sheet 1 should also be updated to indicate that certain values are no longer inputs but rather set.

6.1.3 Sheet 3 - Macros Settings

6.1.3.1 The numeric value 999 is used as the flag NOMORE (Page 6) to indicate completion of a task. If this value conflicits with any values used elsewhere in the program, it can be changed to any other numeric value.

6.1.3.2 Accuracy of the average peak value of XXX1, XXX2 and XXX3 is determined by the size of the associated registers of peak values in subroutines STEADYX2, TRACK_X1 and TRACK_X3 (REGS4, REGS7 and REGS6 respectively on Pages 15 and 16) As originally configured, the averages are the absolute values of the last ten peaks. The user can insert or delete rows between the limits given in the spreadsheet and shown in the listing. The minimum number of peaks that can constitute the average is three for XXX1 and XXX3, two for XXX2. The various register range names will automatically adjust to the new configuration.

6.1.3.3 Accuracy of determining the steady state motion of XXX2 is determined by the size of REGS2 in subroutine STEADYX2. As originally configured the size is 20 peaks. The user can insert or delete rows between the limits given in the spreadsheet and shown on in the listing. The minimum number is four if REGS7 is set to two.

6.1.3.4 The macro contains an upper limit on the number of times the screen message will print. This is meant as protection against an accidental infinite computing loop, but effectively limits the number of stacks of parameters that can be run in one batch. The value PRINTMAX (Page 17) is presently set at 25. This can be changed to any numeric value.

6.1.4 Sheet 4 - Screen Message and Comments

6.1.4.1 The screen message can be altered to display anything that the user wants, however, only an experienced spreadsheet user should undertake this. If the message is changed the following areas must also be changed.

i. Program RK*_MDOF: UPDATE Subroutine, Sheet 3, Page 10

ii. Program RK_COMPL: COMPILE Subroutine, Sheet 1, Page 3

Note that while many of the values contained in the message are copied from cells elsewhere in the program, the following values are only contained in the message section:

i. The average and standard deviations of the peak X values in the tracking registers.

ii. The start, finish and elapsed times of the run.

iii. The maximum, minimum values and standard deviation of the range of XXX2 peaks values used to determine steady state.

iv. The total number of impacts (QUEUUP, QUEULOW).

v. The total number of carries (CARRYUP, CARRYDWN).

They should not be erased, although they can be removed to another portion of the spreadsheet. Ensure that the border around the message is retained or the PRINT and SAVE_DATA subroutines will be affected.

6.1.4.2 The comments which provide information to the user can be revised by quitting the macro and typing additional information.

6.1.5 Sheet 5 - Output Table

6.1.5.1 The width and number of decimal points displayed can be altered manually.

6.1.5.2 The values retained are the displacement and velocities of the four masses comprising the system. All other information regarding the system can be generated from this information. However, if desired the information can automatically be added to the output table. The output table is built-up by transposing the INPUT range from Sheet 1. If, for example, it was desired that the acceleration of mass 3 was recorded, the following would be required.

i. Place the equation for mass 3 acceleration in the cell below the last value in the range INPUT (presently VVV4) in Sheet 1.

ii. Increase the extent of range named INPUT to include this cell.

iii. Identify the column to the right of VVV4 in Sheet 5 as the acceleration of mass 3.

iv. Subroutine SAVE_DATA (Sheet 3, Page 13) contains a line which defines the extent of the output range to be saved. Increase the width by changing {right 8} to {right 9}.

6.2 Program RK_STACK

Normally the only reason to change this program is for compatiblity with RK*_MDOF or RK_COMPL.

6.2.1 The comments which provide information to the user can be revised by quitting the macro and typing additional information.

6.3 Program RK_COMPL

This program extracts information from the S files generated by RK*_MDOF. As presently configured, all possible data is compiled. If some data is not required, it can easily be deleted from the compiled database. It is suggested that one file be retained to store all the data and that the original S files be deleted.

6.3.1 To reduce or revise the data extracted from the S file, go to the COMPILE subroutine and follow through the commands. Remove any RANGE\VALUE commands for data not required but ensure that the cursor commands remain. Otherwise, the cursor will be out of position.

6.3.2 The comments which provide information to the user can be revised by quitting the macro and typing additional information.

6.4 Program RK_GRAPH

6.4.1 The first title for the graph can either be typed by the user or selected from the typical titles given to speed up the operation (Sheet 2, Page 2). These can be edited by quitting the macro and typing new titles of less than 39 characters.

6.4.2 The second graph title is automatically set as the filename. The X-Axis is considered to be TIME. If not appropriate for any given run, they can be changed manually. Normally, these are appropriate and changing the macro is not recommended.

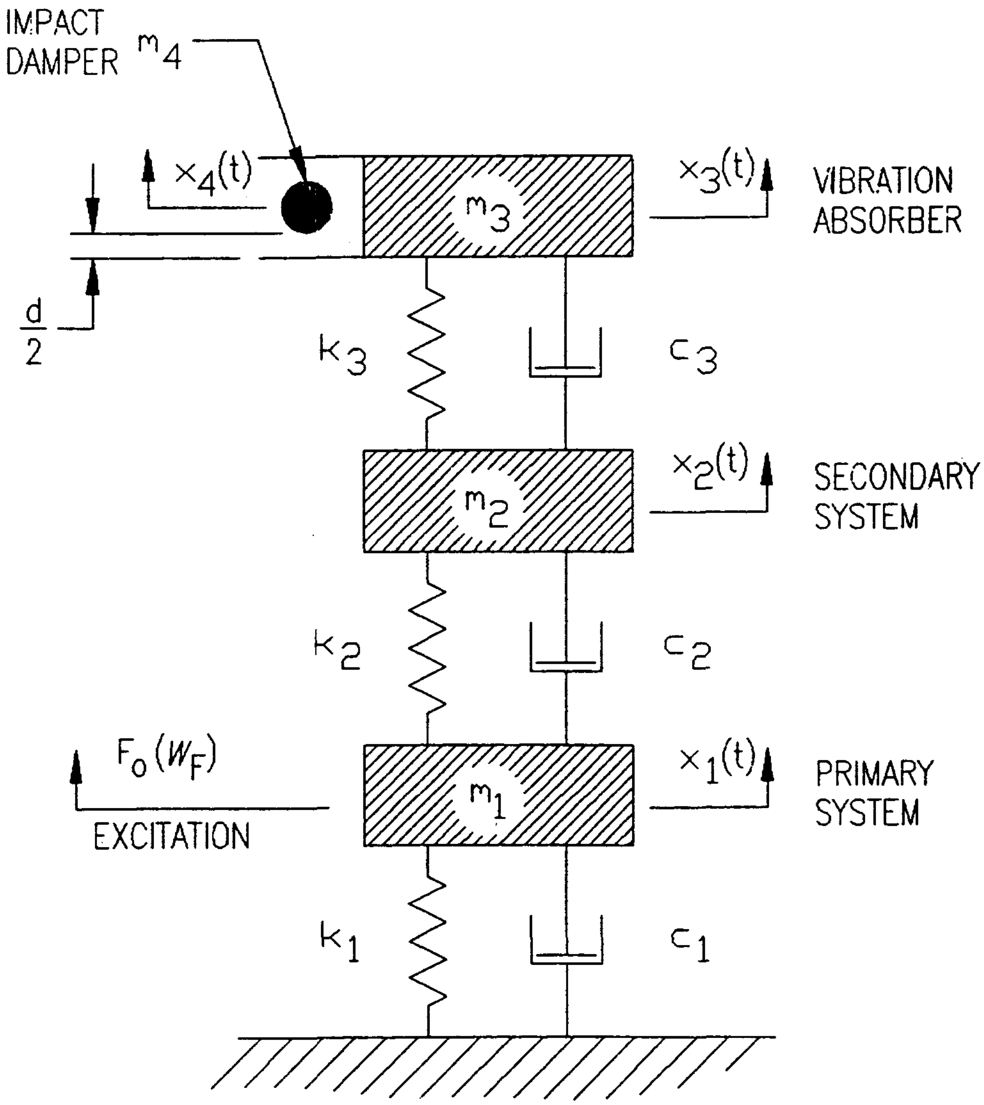


Figure B.1 - Schematic Representation of 3 DOF Systen with impact damper

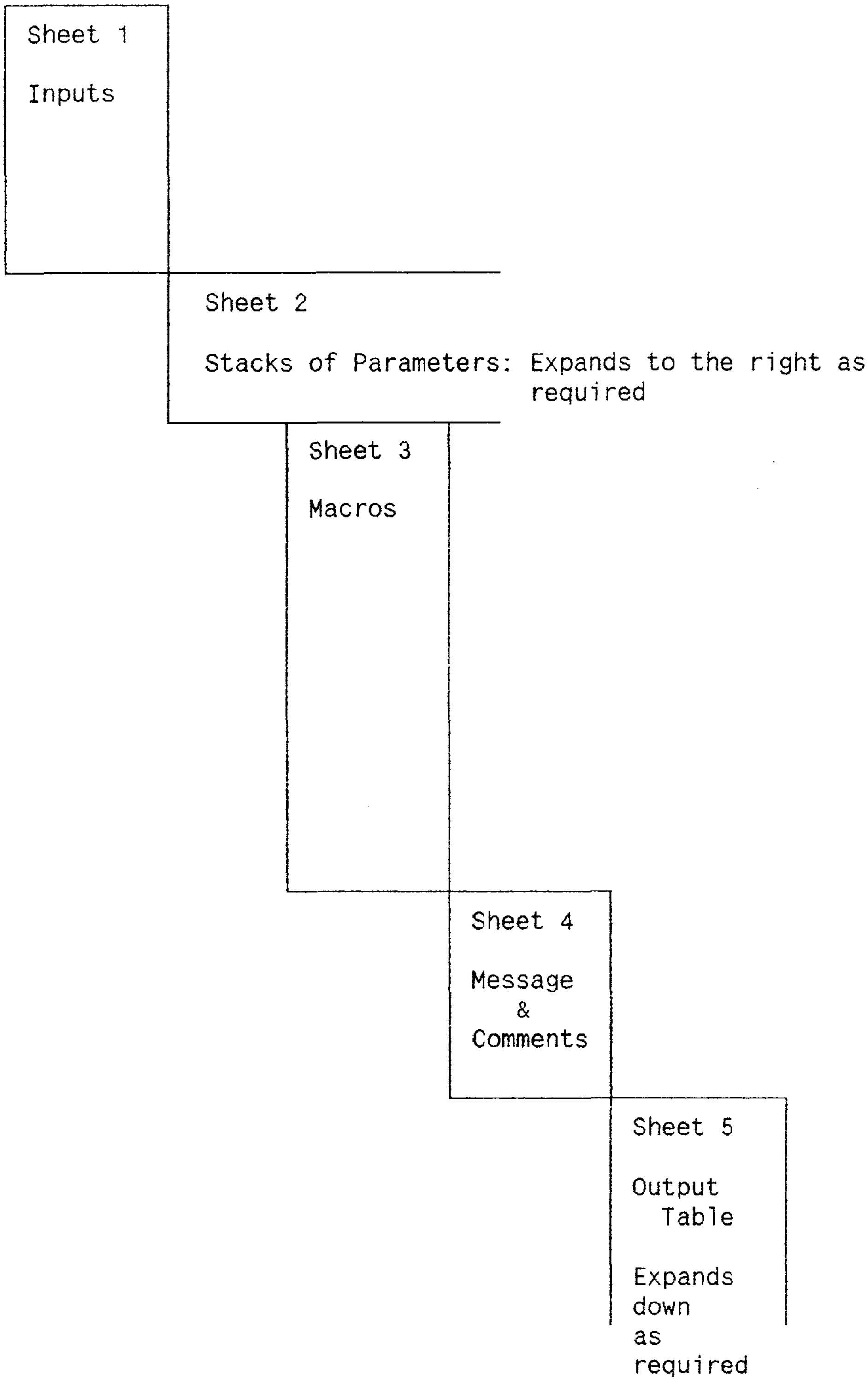


Figure B.2 - Layout of RK*_MDOF Spreadsheet

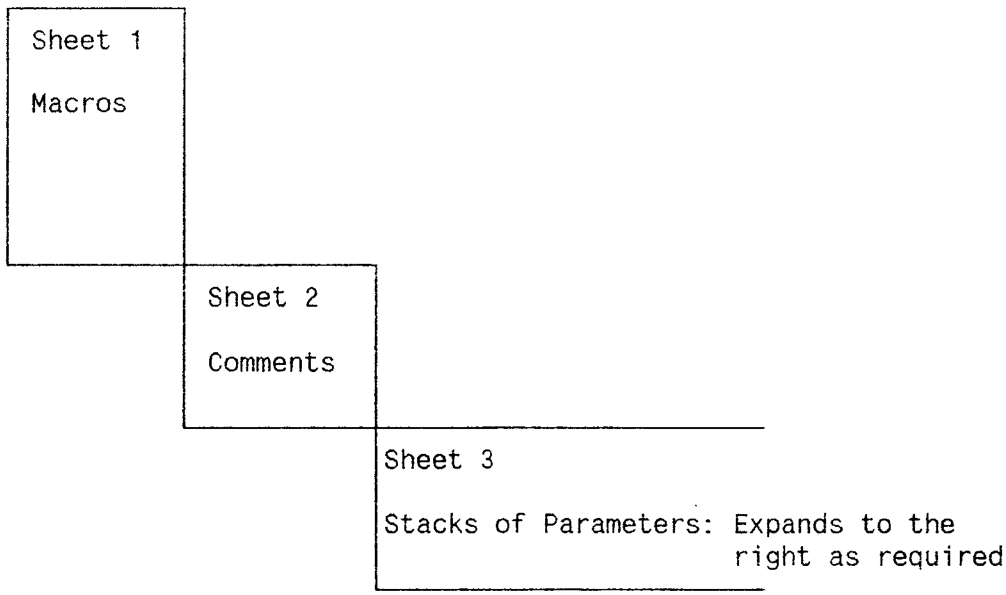


Figure B.3 - Layout of RK*_STACK Spreadsheet

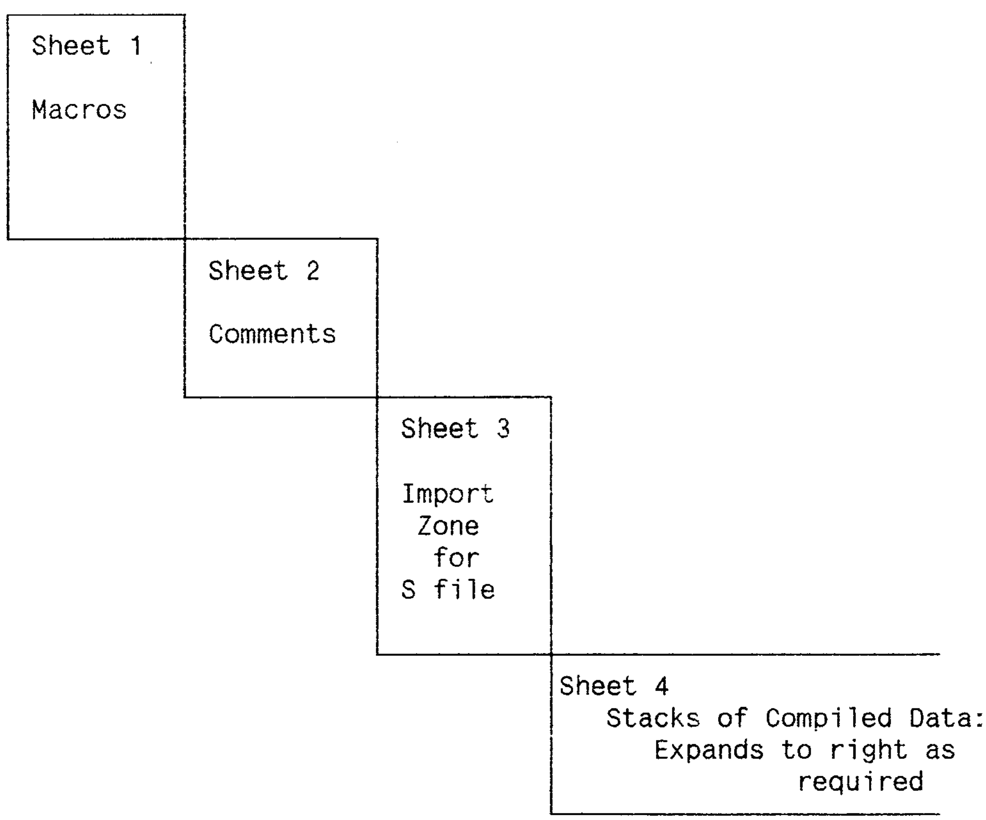


Figure B.4 - Layout of RK*_COMPL Spreadsheet

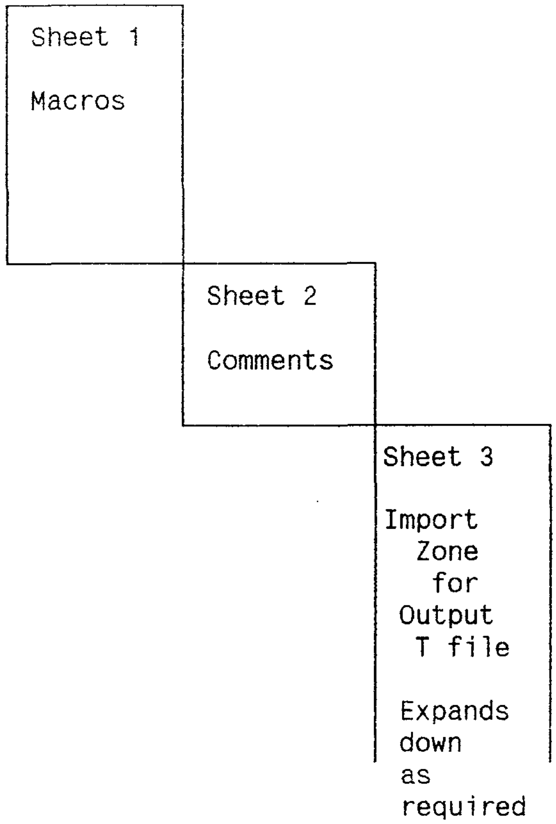


Figure B.5 - Layout of RK*_GRAPH Spreadsheet

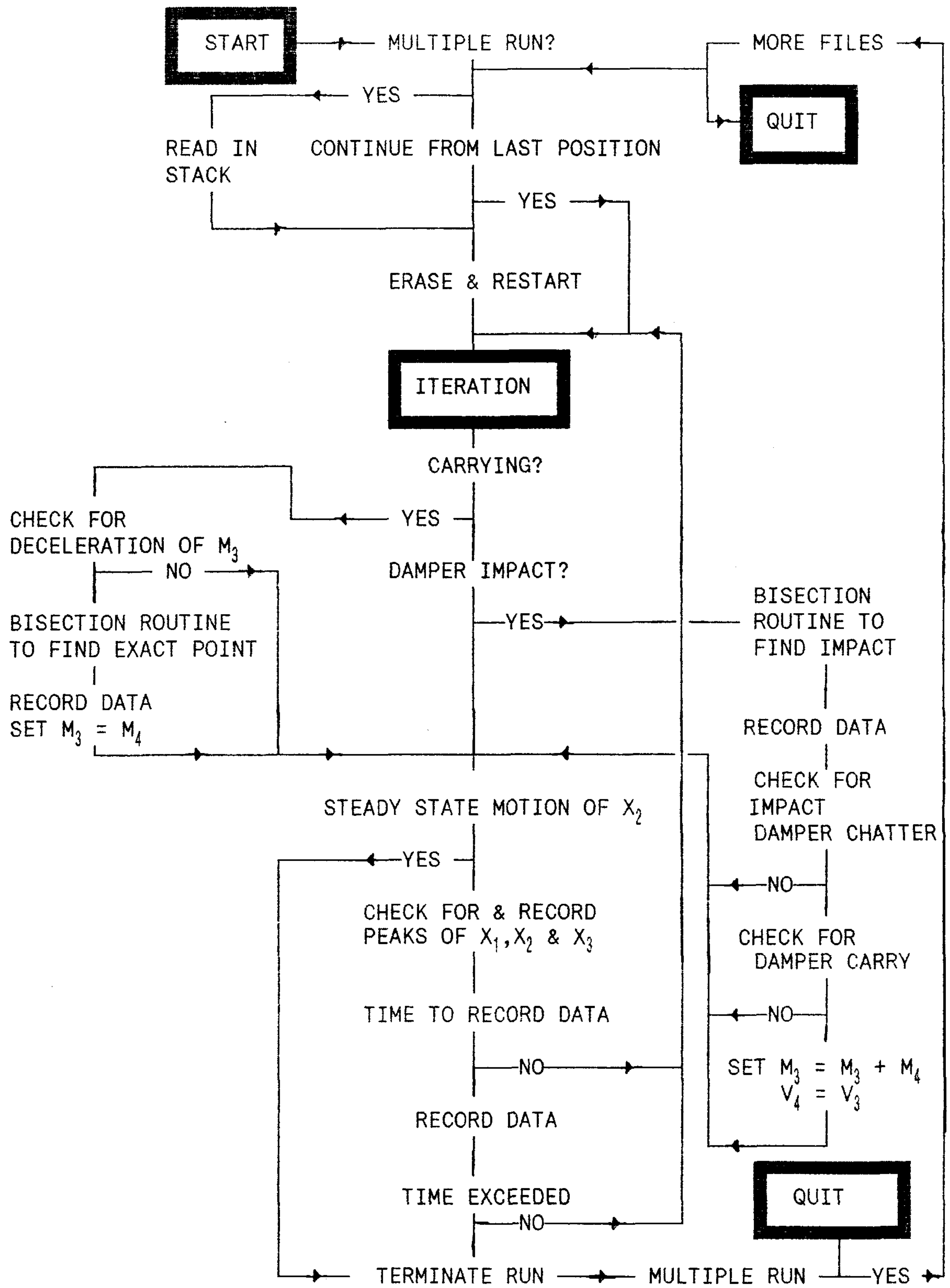


Figure B.6 - Flowsheet of RK*_MDOF for Multiple Stacks of Inputs

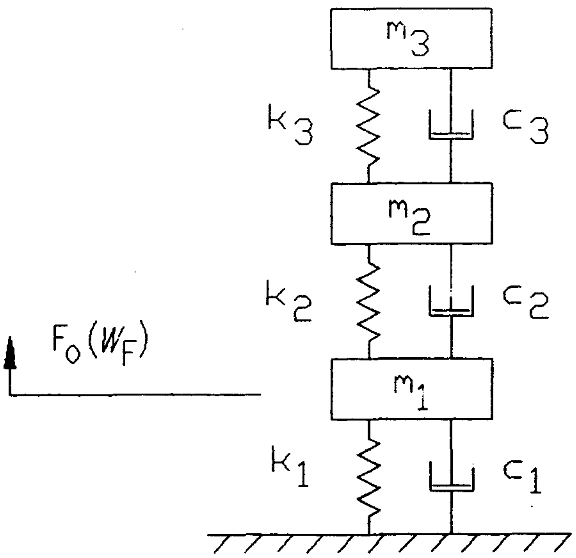


Figure B.7(a) - Model of 3 DOF System without Impact Damper

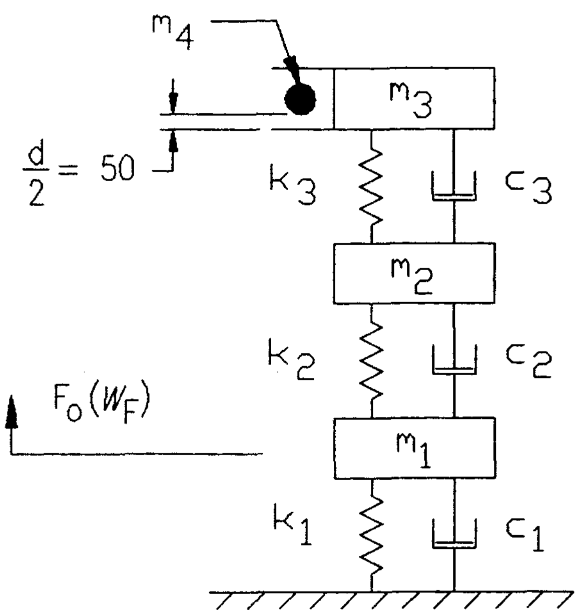


Figure B.7(b) - Model of 3 DOF system with Impact Damper values set so as not to contact walls: D = 100, therefore XXX4 = 0

```
|^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^|
| SA3____ - MASS 2 achieved steady state                       08-May-91  |
|-------------------------------------------------------------------------|
| XXX1  =  0.0027  @  6.2%              FIRSTS | WWWF  =          1.175   |
| XXX2  =  0.0460  @  0.8%    IMPACT        NA | DDD   =            100   |
| XXX3  =  0.1200  @  1.5%    CARRY         NA | EEE   =            0.3   |
|-------------------------------------------------------------------------|
| MMM1  =     1000 | Over Last       20  Peaks | OK_CHAT =          yes   |
| KKK1  =     1000 | X2 Peaks  0.04650 Maximum | ALLPACT =           no   |
| ZETA1 =     1.0% |           0.04497 Minimum | SS Quit =         1.0%   |
| MMM2  =        5 |           0.00046 Std Dev |          Clock Time      |
| KKK2  =        5 |                           |    Start    11:41 PM     |
| ZETA2 =     1.0% | MAXCARRY=       80 total  |    Finish   12:36 AM     |
| MMM3  =      0.5 | MAXCHAT =        8 /side  |  Elapsed       00:55     |
| KKK3  =      0.5 |    FOOH =        1 F      |            Model Time    |
| ZETA3 =     1.0% |  WITHIN = 1.0E-05 L       |    Start         0.0     |
| MMM4  =     0.05 |             Upper  Lower  |     Step     0.26737     |
| WR2:1 =        1 | Impacts :       0      0  |   Expect       401.1     |
| WR3:1 =        1 |   Carry :       0      0  |   Actual       275.4     |
|vvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvv|
```

Figure B.8 - Hard copy of final screen message for example run SA3____

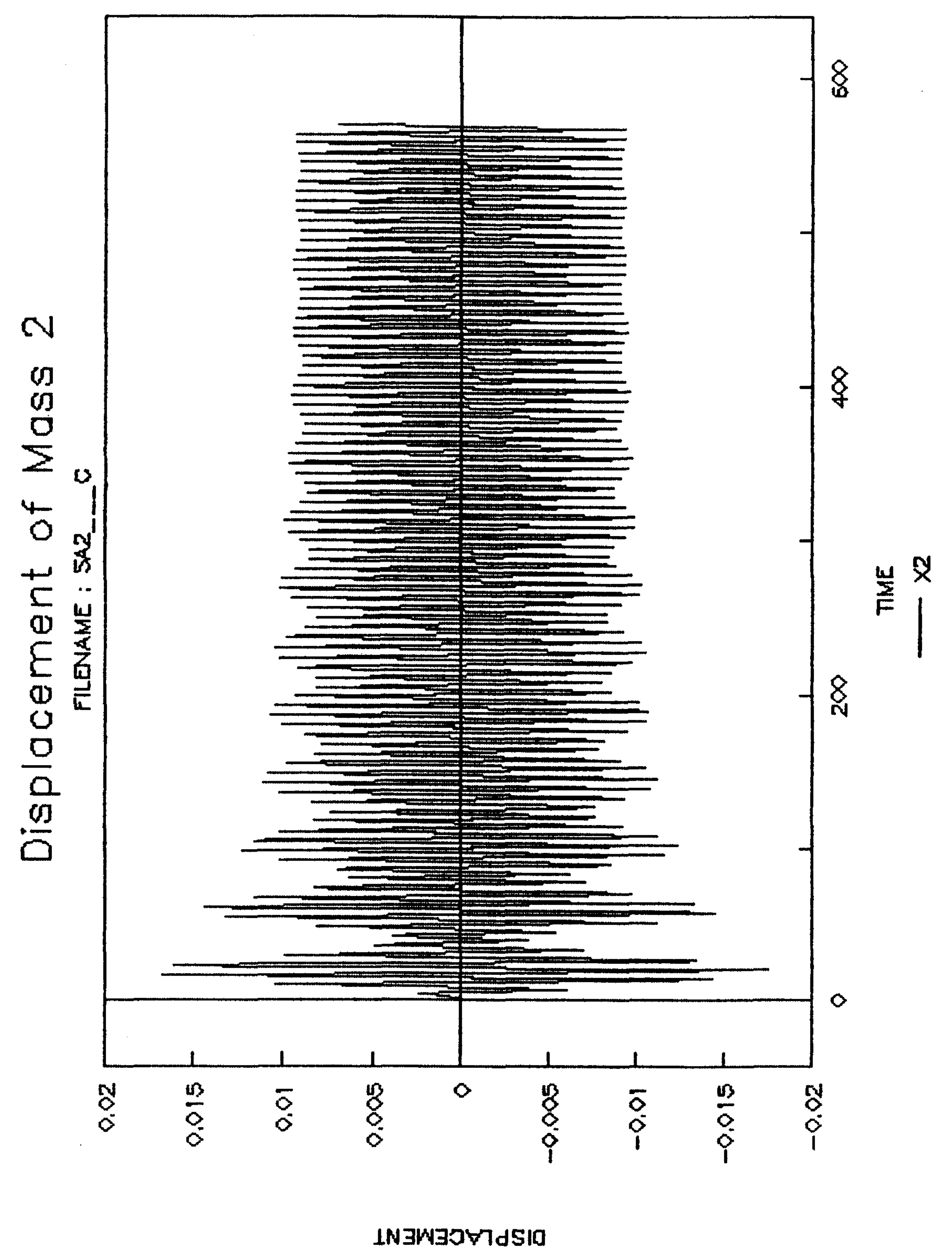


Figure B.9 - Time History Displacement for XXX2 from File SA2___C

Appendix B.1 - Listing of Program RK*_MDOF, Sheet 1 with equations shown.

RK*_MDOF / Sheet 1 / Page 1

ROW	DESCRIPTION	NAME	CALC	UNITS	SOURCE	EQUATION
#						
	System Parameters					
8	Forcing Function Frequency	WWWF	1.14	1/T	(input)	
9	Force Function Amplitude	FOOH	1	F		
10	Period of Forcing function	PERIOD	5.512	T		+(@PI*2)/L8
12	1: Mass	MMM1	1000	M	(input)	
13	Spring Constant	KKK1	1000	F/L	(input)	
14	Natural Frequency	WWWN1	1	1/T		@SQRT(L13/L12)
15	Critical Damping Ratio	ZETA1	1.0%		(input)	
16	Critical Damping	CRIT1	2000			+2*L12*L14
17	Resultant Damping	CCC1	20			+L15*L16
19	2: Desired mass ratio MMM1/MMM2	MRAT1:2	200		(input)	
20	Mass	MMM2	5			+L12/L19
21	Desired Freq. Ratio WWN1/WWN2	WRAT2:1	1		(input)	
22	Natural Frequency	WWWN2	1	1/T		+L14*L21
23	Spring Constant	KKK2	5			+L22^2*L20
24	Critical Damping Ratio	ZETA2	1.0%		(input)	
25	Critical Damping	CRIT2	10			+2*L20*L22
26	Resultant Damping	CCC2	0.1			+L24*L25
28	3: Desired mass ratio MMM2/MMM3	MRAT2:3	10		(input)	
29	Mass	MMM3	0.5	M		+$L$20/$L$28
30	Desired Freq. Ratio WWN1/WWN3	WRAT3:1	1		(input)	
31	Natural Frequency	WWWN3	1	1/T		+L14*L30
32	Spring Constant	KKK3	0.5			+L31^2*L29
33	Critical Damping Ratio	ZETA3	1.0%		(input)	
34	Critical Damping	CRIT3	1			+2*L29*L31
35	Resultant Damping	CCC3	0.01			+L33*L34
37	4: Desired mass ratio MMM3/MMM4	MRAT3:4	10		(input)	
38	Inverse mass ratio MMM4/MMM3	MRAT4:3	0.1			+1/L37
39	Mass of the impact damper	MMM4	0.05	M		+L29/L37
41	MASS of MMM3 and MMM4 combined	M3PLUS4	0.55	M		+L39+L29
42	Effective mass of absorber	M3_USED	0.5	M		
44	Distance between the impact walls	DDD	100	L	(input)	
45	Coefficient of restitution	EEE	0.3		(input)	

Appendix B.1 - Listing of Program RK*_MDOF, Sheet 1 with equations shown.

RK*_MDOF / Sheet 1 / Page 2

ROW #	DESCRIPTION	NAME	CALC	UNITS	SOURCE	EQUATION
	Program Parameters					
49	Steps / minimum period	STEPS	20		{input}	
50	Minimum number of cycles desired	CYCLES	80		{input}	
51	Resultant minimum time of run	RUNTIME	440.9	T		+L50*L10
52	Max of Mass Nat'l Freq & Force Freq		1.14	1/T		@MAX($L$8,$L$14,$L$22,$L$31)
53	Normal Time Step	NORMSTEP	0.2756	T		+2*@PI/L52/L49
54	Time step used for bisection	BISTEP	0.1378	T		+(L136-L83)/2
55	Time Step being used	HHH	0.2756	T		
56	Max # of interations before printing	LIMIT2	10		{input}	
57	Minimum # of lines printed	LIMIT1	160			@INT(+L51/L53/L56)
58	Tolerance on impact position	WITHIN	0.00001	L	{set}	+0.0000001*L44
59	Tolerance on deceleration for carry	STOPPED	1.0E-06	L/T^2	{set}	
60	Tolerance for steady State	RANGE	0.01		{input}	
61	Max. consecutive impacts on one side	MAXCHAT	8		{input}	
62	Ok to let MMM3 carry MMM4	OK_CHAT	yes		{input}	
63	Max. Total Carries on either side	MAXCARRY	80		{input}	
64	Recording every impact, not just start	ALLPACT	no		{input}	
	Initial Conditions					
69	Time	INITIAL	0	T	{input}	
70	Mass 1: Displacement	v	0	L	{input}	
71	Velocity	v	0	L/T	{input}	
72	Mass 2: Displacement	v	0	L	{input}	
73	Velocity	v	0	L/T	{input}	
74	Mass 3: Displacement	v	0	L	{input}	
75	Velocity	v	0	L/T	{input}	
76	Mass 4: Displacement	v	0	L	{input}	
77	Velocity	---	0	L/T	{input}	

Appendix B.1 - Listing of Program RK*_MDOF, Sheet 1 with equations shown.

```
RK*_MDOF / Sheet 1 / Page 3
-------------------------------------------------------------------------------------------------------------
ROW ! DESCRIPTION                    NAME        CALC UNITS SOURCE ! EQUATION
  # ! ---------------------------------------------------------------! ------------------------------------------
    ! Runge-Kutta Grid Points Calculation                            !
    ! ============================                                   !
    ! Input Values                                                   !
    ! ----------                                                     !
 83 ! Time                   INPUT   TTT     25.628782 T             !
 84 ! Mass 1: Displacement     v      XXX1     0.004478 L             !
 85 !         Velocity         v      VVV1     0.003988 L/T           !
 86 ! Mass 2: Displacement     v      XXX2     0.000288 L             !
 87 !         Velocity         v      VVV2     0.015000 L/T           !
 88 ! Mass 3: Displacement     v      XXX3    -0.027163 L             !
 89 !         Velocity         v      VVV3    -0.085733 L/T           !
 90 ! Mass 4: Displacement     v      XXX4     0.000000 L             !
 91 !         Velocity        ---     VVV4     0.000000 L/T           !
    !                                                                !
    ! First approximation                                            !
 94 !   Forcing Function Time input           29.216812 RAD          ! +L83*L8
 95 !   Forcing Function                      -0.809017 F            ! +L9*@SIN(L94)
 96 !   A:   of displacement                   0.001099 L            ! +L55*L85
 97 !        of velocity                      -0.001484 L/T          ! +L55*(+L95-L17*L85-L13*L84-L23*(L84-L86)-
    !                                                                !   L26*(L85-L87))/L12
 98 !   B:   of displacement                   0.004134 L            ! +L55*L87
 99 !        of velocity                       0.000282 L/T          ! -L55*((L35+L26)*L87+(L32+L23)*L86-L32*L88-L35*
    !                                                                !   L89-L23*L84-L26*L85)/L20
100 !   C:   of displacement                  -0.023626 L            ! +L55*L89
101 !        of velocity                       0.008120 L/T          ! -L55*(L35*L89+L32*L88-L32*L86-L35*L87)/L42
    !                                                                !
    ! Second Approximation                                           !
104 !   Forcing Function Time input           29.373891 RAD          ! +(L83+L55/2)*L8
105 !   Forcing Function                      -0.891007 F            ! +L9*@SIN(L104)
106 !   A:   of displacement                   0.000894 L            ! +L55*(L85+L97/2)
107 !        of velocity                      -0.001652 L/T          ! +L55*(+L105-L17*(L85+L97/2)-L13*(L84+L96/2)-
    !                                                                !   L23*((L84+L96/2)-(L86+L98/2))-
    !                                                                !   L26*((L85+L97/2)-(L87+L99/2)))/L12
108 !   B:   of displacement                   0.004172 L            ! +L55*(L87+L99/2)
109 !        of velocity                      -0.000522 L/T          ! -L55*((L35+L26)*(L87+L99/2)+(L32+L23)*
    !                                                                !   (L86+L98/2)-L32*(L88+L100/2)-L35*(L89+L101/2)-
    !                                                                !   L23*(L84+L96/2)-L26*(L85+L97/2))/L$20
110 !   C:   of displacement                  -0.022507 L            ! +L55*(L89+L101/2)
111 !        of velocity                       0.011924 L/T          ! -L55*(L35*(L89+L101/2)+L32*(L88+L100/2)-
    !                                                                !   L32*(L86+L98/2)-L35*(L87+L99/2))/L42
    ! Third Approximation                                            !
114 !   Forcing Function Time input           29.373891 RAD          ! +(L83+L55/2)*L8
115 !   Forcing Function                      -0.891007 F            ! +L9*@SIN(L114)
116 !   A:   of displacement                   0.000871 L            ! +L55*(L85+L107/2)
117 !        of velocity                      -0.001623 L/T          ! +L55*(+L115-L17*(L85+L107/2)-L13*(L84+L106/2)-
    !                                                                !   L23*((L84+L106/2)-(L86+L108/2))-L26*((L85+
    !                                                                !   L107/2)-(L87+L109/2)))/L12
118 !   B:   of displacement                   0.004062 L            ! +L55*(L87+L109/2)
119 !        of velocity                      -0.000537 L/T          ! -L55*((L35+L26)*(L87+L109/2)+(L32+L23)*
    !                                                                !   (L86+L108/2)-L32*(L88+L110/2)-L35*(L89+L111/2)-
    !                                                                !   L23*(L84+L106/2)-L26*(L85+L107/2))/L20
120 !   C:   of displacement                  -0.021983 L            ! +L55*(L89+L111/2)
121 !        of velocity                       0.011762 L/T          ! -L55*(L35*(L89+L111/2)+L32*(L88+L110/2)-
    !                                                                !   L32*(L86+L108/2)-L35*(L87+L109/2))/$L$42
```

Appendix B.1 - Listing of Program RK*_MDOF, Sheet 1 with equations shown.

```
RK*_MDOF / Sheet 1 / Page 4
------------------------------------------------------------------------------------------------------------------------
ROW ! DESCRIPTION                              NAME          CALC UNITS SOURCE ! EQUATION
 #  ! -------------------------------------------------------------------------! ------------------------------------------
    ! Fourth Approximation                                                      !
124 !    Forcing Function Time input                     29.530971 RAD          ! +(L83+L55)*L8
125 !    Forcing Function                                -0.951057 F            ! +L9*@SIN(L124)
126 !    A:    of displacement                            0.000652 L            ! +L55*(L85+L117)
127 !          of velocity                               -0.001750 L/T          ! +L55*(+L125-L17*(L85+L117)-L13*(L84+L116)-L23*
    !                                                                           !   ((L84+L116)-(L86+L118))-L26*((L85+L117)-
    !                                                                           !   (L87+L119)))/L12
128 !    B:    of displacement                            0.003986 L            ! +L55*(L87+L119)
129 !          of velocity                               -0.001314 L/T          ! -L55*((L35+L26)*(L87+L119)+(L32+L23)*(L86+L118)-
    !                                                                           !   L32*(L88+L120)-L35*(L89+L121)-L23*(L84+L116)-
    !                                                                           !   L26*(L85+L117))/L20
130 !    C:    of displacement                           -0.020385 L            ! +L55*(L89+L121)
131 !          of velocity                                0.015230 L/T          ! -L55*(L35*(L89+L121)+L32*(L88+L120)-L32*(L86+
    !                                                                           !   L118)-L35*(L87+L119))/L42
    ! Output Values                                                             !
    ! -----------                                                               !
136 ! Time                                    TSTEP      25.904360 T            ! +L83+L55
137 ! Mass 1: Displacement                    XSTEP1      0.005358 L            ! +L84+(L96+2*L106+2*L116+L126)/6
138 !         Velocity                        VSTEP1      0.002357 L/T          ! +L85+(L97+2*L107+2*L117+L127)/6
139 ! Mass 2: Displacement                    XSTEP2      0.004386 L            ! +L86+(L98+2*L108+2*L118+L128)/6
140 !         Velocity                        VSTEP2      0.014475 L/T          ! +L87+(L99+2*L109+2*L119+L129)/6
141 ! Mass 3: Displacement                    XSTEP3     -0.049328 L            ! +L88+(L100+2*L110+2*L120+L130)/6
142 !         Velocity                        VSTEP3     -0.073946 L/T          ! +L89+(L101+2*L111+2*L121+L131)/6
143 ! Mass 4: Displacement                    XSTEP4      0.000000 L            ! +L55*L91+L90
144 !         Velocity                        VSTEP4      0.000000 L/T          ! +L91
    !                                                                           !
146 ! Acceleration of Mass 3                  ACCSTEP3    0.055483 L/T^2        ! +(L32*(L139-L141)+L35*(L140-L142))/L42
    !                                                                           !
    ! Absolute Positions of Impact Damper & Constraints                         !
    ! ============================                                              !
150 ! Position of lower wall                  LWALL     -50.049328 L            ! +L141-L44/2
151 ! Position of upper wall                  UWALL      49.950672 L            ! +L141+L44/2
152 ! Position of impact damper relative to walls                               !
153 !    Lower wall                           LLIMIT     50.049328 L            ! +L143-L150
154 !    Upper wall                           ULIMIT     49.950672 L            ! +L151-L143
    !                                                                           !
    ! Resultant Velocities (if Impact Occurs)                                   !
    ! ============================                                              !
158 ! Mass 3                                  VVR3      -0.0652071 L/T          ! +(1-L38*L45)/(1+L38)*L142+L38*(1+L45)/(1+L38)*L14
159 ! Mass 4                                  VVR4      -0.0873910 L/T          ! +(1+L45)/(1+L38)*L142+(L38-L45)/(1+L38)*L144
```

Pages 2 and 3 of this Appendix list the values associated with the filename matrix code created for an investigation undertaken using these INTEGRAT programs.

Example: Simulation of a model with

MMM1	=	1000
KKK1	=	1000
ZETA1	=	1.0%
MMM2	=	5
KKK2	=	5
ZETA2	=	1.0%
MMM3	=	0.5
KKK3	=	0.5
ZETA3	=	1.0%

With an impact damper of 30% of the weight of the absorber (MMM3), inside a container with gap of 0.2 units and a coefficient of restitution of 0.6. The forcing frequency is 0.97 radians/second.

The filename is made up of :

Position	1	2 3	4	5	6	7	8
Code	S	A M	6	V	6	_	

or : SAM6V6_

<table>
<tr><th>Position</th><th colspan="7">Description</th></tr>
<tr><td rowspan="3">1</td><td colspan="7">First, Second and Third Spring/Mass/Damper Parameters</td></tr>
<tr><td colspan="7">A, B, C, etc</td></tr>
<tr><td colspan="7">See listing next page</td></tr>
<tr><td rowspan="4">2
3</td><td colspan="7">Forcing Frequency</td></tr>
<tr><td colspan="7">A, B, C, etc See listing next page</td></tr>
<tr><td colspan="2">1, 2, 3, etc</td><td colspan="5">A, B, C, etc</td></tr>
<tr><td colspan="2">on peaks</td><td colspan="5">off peaks (see listing)</td></tr>
<tr><td rowspan="3">4</td><td colspan="7">Coefficient of Restitution , EEE</td></tr>
<tr><td>_</td><td>3</td><td>6</td><td>9</td><td colspan="3">etc</td></tr>
<tr><td>No Damper</td><td>0.3</td><td>0.6</td><td>0.9</td><td colspan="3">etc see listing</td></tr>
<tr><td rowspan="3">5</td><td colspan="7">Width between Damper restrains , DDD</td></tr>
<tr><td>_</td><td colspan="6">A, B, C, etc</td></tr>
<tr><td>No damper</td><td colspan="6">Varies with each case, see listings</td></tr>
<tr><td rowspan="3">6</td><td colspan="7">Mass of impact damper</td></tr>
<tr><td>_</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td></tr>
<tr><td>No Damper</td><td>5%</td><td>10%</td><td>15%</td><td>20%</td><td>25%</td><td>30%</td></tr>
<tr><td rowspan="3">7</td><td colspan="7">Additional runs : same parameters & damper setting</td></tr>
<tr><td>_</td><td colspan="6">A, B, C, etc</td></tr>
<tr><td>First</td><td colspan="6">Additional, usually combine with main</td></tr>
<tr><td rowspan="3">8</td><td colspan="7">Data from the</td></tr>
<tr><td></td><td colspan="2">T</td><td colspan="2">S</td><td colspan="2">G</td></tr>
<tr><td>Complete File</td><td colspan="2">Table</td><td colspan="2">Screen</td><td colspan="2">Graphed</td></tr>
</table>

Listing of values related to FILENAME

Parameters		Forcing Freq.		EEE		DDD		Damper mass	
S		BM	0.800						
		BA	0.810	_	none	M	0.00001	_	none
MMM1	1000	AA	0.820	1	0.1	L	0.001	1	5%
KKK1	1000	BL	0.825	2	0.2				
ZETA1	1.0%	AC	0.830			O	0.05	2	10%
MMM2	5	AD	0.840	3	0.3	Q	0.06	3	15%
KKK2	5	A1	0.850	4	0.4	P	0.07	4	20%
ZETA2	1.0%	AE	0.860	5	0.5	B	0.08	5	25%
MMM3	0.5	AF	0.870	6	0.6	C	0.09	6	30%
KKK3	0.5	AG	0.880	7	0.7	D	0.10		
ZETA3	1.0%	AH	0.890	8	0.8	I	0.15		
		AI	0.900	9	0.9	V	0.20		
		AJ	0.910			J	0.25		
		AK	0.920			W	0.30		
D		AL	0.930			U	0.35		
		AB	0.940			X	0.40		
MMM1	1000	BB	0.950			A	0.45		
KKK1	1000	BC	0.960			Y	0.50		
ZETA1	1.0%	AM	0.970			E	0.55		
MMM2	5	AN	0.980			Z	0.60		
KKK2	5	AO	0.990			F	0.65		
ZETA2	1.0%	A2	1.000			G	0.70		
MMM3	0.5	AP	1.010			H	0.75		
KKK3	0.5	AQ	1.020			K	0.80		
ZETA3	10.0%	AR	1.030			R			
		AS	1.040			S			
		AT	1.050			T			
		AU	1.060			N			
		AV	1.070						
		BD	1.080						
		BE	1.090						
		BF	1.100						
		BG	1.110						
		BH	1.120						
		BJ	1.130						
		BI	1.140						
		BK	1.150						
		AW	1.160						
		AX	1.170						
		A3	1.175						
		AY	1.180						
		AZ	1.190						
		BN	1.200						

RK*_MDOF

PROGRAM LISTING

```
System Parameters
------------------------------
Forcing Function Frequency          WWWF            1 1/T  {input}
Force Function Amplitude            FOOH            1 F    {set}
   Period of Forcing function       PERIOD      6.283 T


1:  Mass                            MMM1         1000 M    {input}
    Spring Constant                 KKK1         1000 F/L  {input}
       Natural Frequency            WWWN1           1 1/T
    Critical Damping Ratio          ZETA1        1.0%      {input}
       Critical Damping             CRIT1        2000
       Resultant Damping            CCC1           20


2:  Desired mass ratio MMM1/MMM2    MRAT1:2       200      {input}
       Mass                         MMM2            5
    Desired Freq. Ratio WWN2/WWN1   WRAT2:1         1      {input}
       Natural Frequency            WWWN2           1 1/T
       Spring Constant              KKK2            5
    Critical Damping Ratio          ZETA2        1.0%      {input}
       Critical Damping             CRIT2          10
       Resultant Damping            CCC2          0.1


3:  Desired mass ratio MMM2/MMM3    MRAT2:3        10      {input}
       Mass                         MMM3          0.5 M
    Desired Freq. Ratio WWN3/WWN1   WRAT3:1         1      {input}
       Natural Frequency            WWWN3           1 1/T
       Spring Constant              KKK3          0.5
    Critical Damping Ratio          ZETA3        1.0%      {input}
       Critical Damping             CRIT3           1
       Resultant Damping            CCC3         0.01


4:  Desired mass ratio MMM3/MMM4    MRAT3:4        10      {input}
       Inverse mass ratio MMM4/MMM3 MRAT4:3       0.1
       Mass of the impact damper    MMM4         0.05 M


MASS of MMM3 and MMM4 combined      M3PLUS4      0.55 M
Effective mass of absorber          M3_USED      0.55 M


Distance between the impact walls   DDD         0.001 L    {input}
Coefficient of restitution          EEE           0.3      {input}
```

Program Parameters

Steps / minimum period	STEPS	20		{input}
Maximum number of cycles desired	CYCLES	75		{input}
Resultant maximum time of run	RUNTIME	471.2	T	
Max of Mass Nat'l Freq & Force Freq		1.000	1/T	
Normal Time Step	NORMSTEP	0.31416	T	
Time step used for bisection	BISTEP	0.15707963	T	
Time Step being used	HHH	0.31416	T	
Max # of iterations before printing	LIMIT2	1		{input}
Minimum # of lines printed	LIMIT1	1500		
Tolerance on impact position	WITHIN	1.0E-10	L	{set}
Tolerance on deceleration for carry	STOPPED	1.0-E07	L/T^2	{set}
Tolerance for steady State	RANGE	1.0%		{input}
Max. consecutive impacts on one side	MAXCHAT	5		{input}
Ok to let MMM3 carry MMM4	OK_CHAT	yes		{input}
Max. Total Carries on either side	MAXCARRY	85		{input}
Recording every impact during Carry	ALLPACT	no		{input}

Initial Conditions

Time		INITIAL>	0.000	T	{input}
Mass 1:	Displacement	>	0.000	L	{input}
	Velocity	>	0.000	L/T	{input}
Mass 2:	Displacement	>	0.000	L	{input}
	Velocity	>	0.000	L/T	{input}
Mass 3:	Displacement	>	0.000	L	{input}
	Velocity	>	0.000	L/T	{input}
Mass 4:	Displacement	>	0.000	L	{input}
	Velocity	>	0.000	L/T	{input}

Runge-Kutta Grid Points Calculation

Input Values

Time	INPUT	> TTT	352.167	T
Mass 1: Displacement		> XXX1	-0.0437537	L
Velocity		> VVV1	0.01464052	L/T
Mass 2: Displacement		> XXX2	-0.0422465	L
Velocity		> VVV2	0.00414986	L/T
Mass 3: Displacement		> XXX3	0.39734697	L
Velocity		> VVV3	-0.1337745	L/T
Mass 4: Displacement		> XXX4	0.39784697	L
Velocity		> VVV4	-0.1337745	L/T

First approximation

Forcing Function Time input	352.167	RAD
Forcing Function	0.30332675	F
A: of displacement	0.005	L
of velocity	0.01375100	L/T
B: of displacement	0.00130371	L
of velocity	0.01331597	L/T
C: of displacement	-0.0420265	L
of velocity	-0.1247597	L/T

Second Approximation

Forcing Function Time input	352.324	RAD
Forcing Function	0.44865660	F
A: of displacement	0.00675945	L
of velocity	0.01302838	L/T
B: of displacement	0.00339538	L
of velocity	0.01311102	L/T
C: of displacement	-0.0616237	L
of velocity	-0.1181779	L/T

Third Approximation

Forcing Function Time input	352.324	RAD
Forcing Function	0.44865660	F
A: of displacement	0.00664594	L
of velocity	0.01269131	L/T
B: of displacement	0.00336319	L
of velocity	0.01278157	L/T
C: of displacement	-0.0605898	L
of velocity	-0.1151001	L/T

Runge-Kutta Grid Points Calculation (continued)

Fourth Approximation		
Forcing Function Time input	352.481	RAD
Forcing Function	0.58293904	F
A: of displacement	0.00858654	L
of velocity	0.01166606	L/T
B: of displacement	0.00531916	L
of velocity	0.01225722	L/T
C: of displacement	-0.0781862	L
of velocity	-0.1057643	L/T

Output Values

Time	OUTPUT >	TSTEP	352.481	T
Mass 1: Displacement	>	XSTEP1	-0.0370876	L
Velocity	>	VSTEP1	0.02744993	L/T
Mass 2: Displacement	>	XSTEP2	-0.0388898	L
Velocity	>	VSTEP2	0.01704293	L/T
Mass 3: Displacement	>	XSTEP3	0.33657364	L
Velocity	>	VSTEP3	-0.2499545	L/T
Mass 4: Displacement	>	XSTEP4	0.35582045	L
Velocity	>	VSTEP4	-0.1337745	L/T
Acceleration of Mass 3		ACCSTEP3	-0.3364759	L/T^2

Absolute Positions of Impact Damper & Constraints

Position of lower wall	LWALL	0.33607364	L
Position of upper wall	UWALL	0.33707364	L
Position of impact damper relative to walls			
Lower wall	LLIMIT	0.01974681	L
Upper wall	ULIMIT	-0.0187468	L

Resultant Velocities (if Impact Occurs)

Mass 3	VVR3	-0.2362242	L/T
Mass 4	VVR4	-0.2710782	L/T

PARAMETER STACKS

This section contains the stack of input and variables the the macro will step through if called.

STACK 1>----v

FILENAME	SA23A2_	SA24A2_	SA23A2_	TAB6A2_	...	SA33A3_	999
WWWF	1	1	1	0.85	...	1	
MMM1	1000	1000	1000	1000	...	1000	
KKK1	1000	1000	1000	1000	...	1000	
ZETA1	10.0%	10.0%	10.0%	1.0%	...	10.0%	
MRAT1:2	200	200	200	10	...	200	
WRAT2:1	1	1	1	1	...	1	
ZETA2	1.0%	1.0%	1.0%	1.0%	...	1.0%	
MRAT2:3	10	10	10	10	...	10	
WRAT3:1	1	1	1	1	...	1	
ZETA3	5.0%	5.0%	5.0%	0.1%	...	5.0%	
MRAT3:4	1	1	1	1	...	1	
DDD	0.1	0.15	0.15	0.1	...	0.25	
EEE	0.3	0.3	0.3	0.6	...	0.3	
STEPS	20	20	20	20	...	20	
CYCLES	60	60	60	60	...	75	
LIMIT2	4	4	4	4	...	5	
RANGE	2.0%	2.0%	2.0%	2.0%	...	1.0%	
MAXCARRY	25	25	25	25	...	25	
ALLPACT	yes	yes	yes	yes	...	yes	
OK_CHAT	yes	yes	no	yes	...	no	
MAXCHAT	6	6	6	6	...	6	
INITIAL	=========	=========	=========	=========	...	=========	
TTT	0.000	0.000	0.000	0.000	...	0.000	
XXX1	0.000	0.000	0.000	0.000	...	0.000	
VVV1	0.000	0.000	0.000	0.000	...	0.000	
XXX2	0.000	0.000	0.000	0.000	...	0.000	
VVV2	0.000	0.000	0.000	0.000	...	0.000	
XXX3	0.000	0.000	0.000	0.000	...	0.000	
VVV3	0.000	0.000	0.000	0.000	...	0.000	
XXX4	0.000	0.000	0.000	0.000	...	0.000	
VVV4	0.000	0.000	1.000	0.000	...	0.000	

```
\0          {goto}MESSAGE~           <Start-up Macro
\X          {panelon}                < If Control Break or quit is used
            {windowson}              to stop the program this macro will
            {indicate}               reset the display if required and
            {menubranch CHOICE}      call up the master menu.
```

MENU MACROS

```
CHOICE  ─┬─ RUN
         │  Run the Program
         │  {menubranch RUN}                                  [Page 5]
         │
         ├─ GRAPH
         │  Set up graph for this particular database and view
         │  {branch SETGRAPH}                                 [Page 18]
         │
         ├─ SAVE_DATA
         │  Saves & prints present database after manual break
         │  {menubranch SAVECHK}                              [Page 19]
         │
         ├─ CONDENSE
         │  Erase existing database to condense file size
         │  {CONDENSE}                                        [Page 7]
         │  {DESTACK}                                         [Page 6]
         │  {windowson}{panelon}
         │  {menubranch CHOICE}
         │
         ├─ BROWSE
         │  Just look around the Spreadsheet
         │  {windowsoff}
         │  {menubranch BROWSE}                               [Page 2]
         │
         └─ QUIT
            Get out of all macros and reset window & panel
            {panelon}{indicate}{windowson}
            {quit}
```

```
BROWSE ──┬─ VARIABLES
         │  SYSTEM   PROGRAM   INPUT   EQUATION   OUTPUT
         │  {menubranch VARIABLE}
         │
         ├─ MACROS
         │  MENUS   STACK   PROGRAM   FACILITIES   CHECKS
         │  {menubranch MACROS}                                [Page 3]
         │
         ├─ TABLE
         │  Output for the graph
         │  {goto}TABLE~{windowson}{menubranch CHOICE}         [Page 1]
         │
         ├─ SCREEN
         │  Message on screen during macros
         │  {goto}MESSAGE~{windowson}{menubranch CHOICE}       [Page 1]
         │
         └─ PARAMETERS
            Where the stack of runs is imported
            {goto}STACK~{windowson}{menubranch CHOICE}         [Page 1]


VARIABLE ┬─ SYSTEM
         │  Where the system being modelled is described.
         │  {goto}SYSTEM~{windowson}{menubranch CHOICE}        [Page 1]
         │
         ├─ PROGRAM
         │  Where the run Parameters are located
         │  {goto}PARAMETR~{windowson}{menubranch CHOICE}      [Page 1]
         │
         ├─ INPUT
         │  Where the Initail conditions are given
         │  {goto}INICOND~{windowson}{menubranch CHOICE}       [Page 1]
         │
         ├─ EQUATION
         │  The Runge-Kunta equations
         │  {goto}RK_EQUATE~{windowson}{menubranch CHOICE}     [Page 1]
         │
         └─ OUTPUT
            The output of this timestep
            {goto}OUTVALUE~{windowson}{menubranch CHOICE}      [Page 1]
```

```
MACROS──┬─ MENUS
        │  Go to the menu section
        │  {goto}MENUS~{branch ADJUST}                        [Page 4]
        │
        ├─ STACK
        │  Go to the section for running a stack ofinputs
        │  {goto}MULTI~{branch ADJUST}                        [Page 4]
        │
        ├─ PROGRAM
        │  PROGRAM   BISECTION   IMPACT   CLEAR   LOOP1
        │  {menubranch MAIN}                                  [Page 4]
        │
        ├─ FACILITIES
        │  GRAPH   STEPPER   UPDATE   PRINT   CONDENSE
        │  {menubranch FACILITY}
        │
        └─ CHECKS
           STEADYX2   TRACK_X1   TRACK_X3   CHATTER
           {menubranch CHECKS}                                [Page 4]


FACILITY─┬─ GRAPH
         │  Routine to facilitate setting up graphs
         │  {goto}SETGRAPH~{branch ADJUST}                    [Page 4]
         │
         ├─ STEPPER
         │  Routine to integrat one step at a time
         │  {goto}STEPPER~{branch ADJUST}                     [Page 4]
         │
         ├─ UPDATE
         │  Routine to update the screen message
         │  {goto}UPDATE~{branch ADJUST}                      [Page 4]
         │
         ├─ PRINT
         │  Routine to print screen and set printer
         │  {goto}PRINT~{branch ADJUST}                       [Page 4]
         │
         └─ CONDENSE
            Subroutine to condense file by erasing database
            {goto}CONDENSE~{branch ADJUST}                    [Page 4]
```

```
MAIN ────┬─PROGRAM
         │  Go to top of section
         │  {goto}PROGRAM~{branch ADJUST}
         │
         ├─ BISECTION
         │  Got to the Bisection Routines
         │  {goto}HITLOW~{branch ADJUST}
         │
         ├─ IMPACT
         │  Go to IMPACT subroutine
         │  {goto}IMPACT~{branch ADJUST}
         │
         ├─ CLEAR
         │  Subroutine to Erase settings at start of new run
         │  {goto}CLEAR~{branch ADJUST}
         │
         └─ LOOP1
            Loop that controls length of run
            {goto}LOOP1~{branch ADJUST}


CHECKS ──┬─ STEADYX2
         │  Go to the steady state checking routine
         │  {goto}STEADYX2~{branch ADJUST}
         │
         ├─ TRACK_X1
         │  Subroutine to track average value of X1
         │  {goto}TRACK_X1~{branch ADJUST}
         │
         ├─ TRACK_X3
         │  Subroutine to track average value of X3
         │  {goto}TRACK_X3~{branch ADJUST}
         │
         └─ CHATTER
            Go to the Chatter check routine
            {goto}Chatter~{branch ADJUST}


Routine to adjust position of cursor after browse
~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~

ADJUST      {left}{up 2}
            {windowson}
            {menubranch CHOICE}
```

```
RUN ───┬── MULTI
       │   Execute the program for a stack of inputs
       │   {branch MULTI}                                    [Page 6]
       │
       ├── ONE
       │   Run the Program for the existing input variables
       │   /rvNOPE~STACKON~
       │   /rvNOFILE~STKFILE~
       │   {branch PROGRAM}                                  [Page 8]
       │
       ├── STEP
       │   Step through program one iteration at a time, No Bisection
       │   {STEPPER}
       │   {menubranch CHOICE}                               [Page 1]
       │
       └── ABORT
           Return to main Menu
           {menubranch CHOICE}                               [Page 1]
```

Subroutine for stepping through the iteration without bisection.
~~~~~~

```
STEPPER    {goto}COMMENT1~{?}
           /rvINITIAL~INPUT~
           /rvNORMSTEP~HHH~
           {goto}OUTVALUE~
LOOP5      {calc}
           {menubranch REPEAT}


REPEAT ──┬── AGAIN
         │   Proceed with the next step
         │   {SWAP}                                          [Page 10]
         │   {menubranch LOOP5}
         │
         └── STOP
             Stop and return to main menu
             {return}
```
~~~~~~

Macro to manipulate stacks of input parameters and record output
~~~~~~

```
MULTI       /rvYES~STACKON~
            {SETPRINT}          < set print options            [Page 17]
            {DESTACK}           < Erases old stack input
            /fccnSTACK~                 < imports new stack input
            INTEGRAT\RK_STACK~          < location of stack input
            {windowson}{windowsoff}{paneloff}
            {end}{right 2}
            /cNOMORE~~
            /rncENDFLAG~{bs}~
            {goto}STACK1~
            /rncMARKER~{bs}{right}~
            {menubranch CHECK}

CHECK ---+----------- QUIT
         |            Quit to allow checking of input in other program
         |            {quit}
         |
         +--- CONTINUE
            Carry on with the macro
LOOP6       {goto}MARKER~
            {READ_STK}             < read in new stack values   [Page 7]
            {PROGRAM}                                           [Page 8]
            {SAVEDATA}                                          [Page 13]
            {goto}MARKER~
            {if @cellpointer("contents")~NOMORE}{branch STEP16}
            {branch LOOP6}

STEP16      /rvNOPE~STACKON~
            {menubranch CHOICE}                                 [Page 1]

NOMORE           999       < range for checking if stack complete
YES         yes
NOPE        no
STACKON     no
NOFILE      Single
```

Subroutine to erase existing stack input
~~~~~~

```
DESTACK     {goto}STACK1~
            {windowsoff}{paneloff}
            {if @cellpointer("contents")~NOMORE}{return}
            /re{end}{down}{end}{right}~
            /cNOMORE~~
            /reENDFLAG~
            {windowson}{panelon}
```

Subroutine to record filename and read stack into spreadsheet
~~~~~~

```
READ_STK     {windowsoff}{paneloff}
             /rv~STKFILE~{down}
             /rv~WWWF~{down}
             /rv~MMM1~{down}
             /rv~KKK1~{down}
             /rv~ZETA1~{down}
             /rv~MRAT1:2~{down}
             /rv~WRAT2:1~{down}
             /rv~ZETA2~{down}
             /rv~MRAT2:3~{down}
             /rv~WRAT3:1~{down}
             /rv~ZETA3~{down}
             /rv~MRAT3:4~{down}
             /rv~DDD~{down}
             /rv~EEE~{down}
             /rv~STEPS~{down}
             /rv~CYCLES~{down}
             /rv~LIMIT2~{down}
             /rv~RANGE~{down}
             /rv~MAXCARRY~{down}
             /rv~ALLPACT~{down}
             /rv~OK_CHAT~{down}
             /rv~MAXCHAT~{down 2}
             /rv{down 8}~INITIAL~
```

Subroutine to delete the existing data base
~~~~~~

```
CONDENSE     {if @cell("row",FOOTER)-@cell("row",HEADER)~1}{return}
             {goto}HEADER~
             {down}
             /wdr{end}{down}~
             /rncFOOTER~{bs}~
```

Macro section that controls the numerical integration.

```
PROGRAM     {paneloff}
            {calc}
            {goto}MESSAGE~
            {windowsoff}
            /rvNOPE~TERMNATE~
            /rvNOPE~FLAG1~
            /rvNOPE~CARRYING~
            /rvNOPE~ON_UPPER~
            /rvNOPE~ON_LOWER~
            /reFINISH~
            /reELAPSED~
            {if STACKON~YES}{branch STEP1} < bypass menu if multi mode
            {menubranch ERASE}


ERASE ----- CONTINUE
        |   Continue calculations from previous database
        |   {branch STEP15}
        |
        |
        --- ERASE
            Erase existing data points and start over
STEP1       {CONDENSE}             < clears output            [Page 7]
            {CLEAR}                < clears old data          [Page 10]
            /rvMMM3~M3_USED~       < ensures MMM3 and MMM4 split
            {UPDATE}               < updates screen           [Page 10]
            {calc}
            {goto}START~@now~/rv~~              < Record clock time
            /rvNORMSTEP~HHH~/rvNORMSTEP~RANGE   < Set and record normal
            {goto}MESSAGE~                                  time step
            {windowson}{windowsoff}
            /rvINITIAL~INPUT~               < Initializes the model
            /rtINPUT~HEADER~                < Record initial conditions
STEP15      {for COUNTER1,1,+LIMIT1,1,LOOP1}                  [Page 9]
            {if TERMNATE~NOPE}/rvRESULT3~RESULT~
            {goto}FINISH~@now~/rv~~            < record clock time
            {goto}ELAPSED~+FINISH-START~       < record elapsed time
            {PRINT}                                           [Page 17]
            {panelon}{windowson}{indicate}
            {if STACKON~YES}{return}
            {menubranch CHOICE}                               [Page 1]


COUNTER1     387.000                    < FOR LOOP1 register
TERMNATE    yes          < flag to signal program to termination
```

FOR statement subroutine executed for LIMIT1 iterations

```
LOOP1       {if CARRYING~NOPE}{panelon}{indicate FREE}{paneloff}
            {for COUNTER2,1,+LIMIT2,1,LOOP2}
            {if TERMNATE~YES}{forbreak}
            {goto}MESSAGE~
            {windowson}{windowsoff}           < Updates Message Screen
            {RECORD}

COUNTER2      1.000                           < FOR loop register
```

Subroutine to record values in the output table.

```
RECORD      {if ALLPACT~YES}{branch STEP13}             < allow all
            {if LASTBANG<>THISBANG}{branch STEP13}      < allow first
            {if HHH<NORMSTEP/2}{return}                 < disallow close
STEP13      {goto}FOOTER~
            /wir~         < makes room
            /rtINPUT~~    < transposes input values into the table
```

FOR statement subroutine executed for LIMIT2 iterations

```
LOOP2       {calc}
            {if CARRYING~YES}{SPLITCHK}
            {if FLAG1~NOPE}{if CARRYING~NOPE}{HITCHECK}
            {STEADYX2}                                       [Page 15]
            {TRACK_X1}                                       [Page 16]
            {TRACK_X3}                                       [Page 16]
            {if TERMNATE~YES}{forbreak}
            {if FLAG1~YES}{branch STEP17}
            {SWAP}                                           [Page 10]

STEP17      /rvNOPE~FLAG1~                    < reset the flag
            {branch LOOP2}
```

Subroutine to check for impacts

```
HITCHECK    {if LLIMIT<0}{HITLOW}                            [Page 11]
            {if ULIMIT<0}{HITUP}                             [Page 11]
```

Subroutine to check if Masses 3 and 4 should separate

```
SPLITCHK    {if ON_UPPER~YES}{if XSTEP3<0}──┐
             ┌──────────────────────────────┘
             └──{if VSTEP3<0}{if ACCSTEP3>0}{SPLT_TOP}       [Page 14]
            {if ON_LOWER~YES}{if XSTEP3>0}──┐
             ┌──────────────────────────────┘
             └──{if VSTEP3>0}{ifACCSTEP3<0}{SPLT_BTM}        [Page 14]
```

Subroutine copies output values into input cells, ready for next step

```
SWAP      /rvOUTPUT~INPUT~
          {if CARRYING~YES}/rvVVV3~VVV4~
          {if ON_UPPER~YES}/rvUWALL~XXX4~
          {if ON_LOWER~YES}/rvLWALL~XXX4~
```

Subroutine containing macro cells to be erased at start of new run

```
CLEAR     /cNOT_APP~REGS2~
          /cNOT_APP~REGS4~
          /cNOT_APP~REGS6~
          /reX1LAST~/reX1BEFORE~
          /reX2LAST~/reX2BEFORE~
          /reX3LAST~/reX3BEFORE~
          /reCLOW~/reCUP~
          /reSDOWN~/reSUP~
          /reQUEUCHAT~

NOT_APP        NA                 < @na
```

Subroutine to update screen message at start of new run

```
UPDATE    /rvFOOH~RANGEG~
          /rvWWWF~RANGEE~
          /rvMAXCHAT~RANGEC~/rvMAXCARRY~RANGEV~
          /rvALLPACT~RANGEW~/rvOK_CHAT~RANGEX~
          {goto}RANGEY~@n(INITIAL)~/rv~~
          {goto}RANGEJ~+RANGEY+RUNTIME~/rv~~
          /rvRANGE~RANGEF~
          /rvX2PEAKS~RANGEAC~
          /rvWITHIN~RANGEH~
          {goto}RANGEK~
          /rvMMM1~~{down}/rvKKK1~~{down}/rvZETA1~~{down}
          /rvMMM2~~{down}/rvKKK2~~{down}/rvZETA2~~{down}
          /rvMMM3~~{down}/rvKKK3~~{down}/rvZETA3~~{down}
          /rvMMM4~~{down}
          /rvWRAT2:1~~{down}
          /rvWRAT3:1~~
          /rvNOT_APP~RANGEB~/rvNOT_APP~RANGED~
          /rvDDD~RANGEZ~/rvEEE~RANGEAB~
          /rvZERO~QUEUUP~/rvZERO~QUEULOW~
          /rvZERO~CARRYUP~/rvZERO~CARRYDWN~
          /rvSTKFILE~RANGEA~
          /reRESULT~
```

Bisection Subroutine if impact damper strikes the lower limit.
~~~~~~

```
HITLOW    {panelon}{indicate LOW}{paneloff}{beep}
          {goto}CLOW~                       <Increment the impact count
          +1+QUEULOW~                       <
          /rvCLOW~QUEULOW~
          /rvLOWER~THISCHAT~                < for chatter check
LOOP3     {if @abs(LLIMIT)<WITHIN}{IMPACT}{return}
          /rvBISTEP~HHH~                    < reduce time step by half
          {calc}
          {if LLIMIT<0}{branch LOOP3}       < past impact,retain input
          {SWAP}                                               [Page 10]
          {branch LOOP3}

CLOW          121                           < Low Impact Counter
```

Bisection Subroutine if impact damper strikes the upper limit.
~~~~~~

```
HITUP     {panelon}{indicate UP}{paneloff}{beep}
          {goto}CUP~                        <Increment the impact count
          +1+QUEUUP~                        <
          /rvCUP~QUEUUP~
          /rvUPPER~THISCHAT~                < for chatter check
LOOP4     {if @abs(ULIMIT)<WITHIN}{IMPACT}{return}
          /rvBISTEP~HHH~                    < reduce time step by half
          {calc}
          {if ULIMIT<0}{branch LOOP4}       < past impact, retain input
          {SWAP}                                               [Page 10]
          {branch LOOP4}

CUP           126                           < Up Impact Counter
```

Subroutine for energy transfer & reset normal timestep
~~~~~~

```
IMPACT    {panelon}{indicate BANG}{paneloff}{beep}
          /rvYES~FLAG1~  < set flag indicating there was an impact
          {if QUEUUP+QUEULOW<1.1}/rvTSTEP~RANGEB~   <Note first impact
          {SWAP}{RECORD}                             [Page 10][Page 9]
          /rvVVR3~VVV3~  < There is an energy transfer between
          /rvVVR4~VVV4~    masses 3 and 4 which change velocity
          {RECORD}{CHATTER}                          [Page 9][Page 12]
          {if TERMNATE~YES}{return}
          /rvNORMSTEP~HHH~
          {goto}MESSAGE~
          {windowson}{windowsoff}

FLAG1     no             < flag to tell that impact has been found
```
~~~~~~

Subroutine to check for chatter of damper against one wall

```
CHATTER     {if LASTBANG~THISBANG}{branch STEP12}    <Impact same side ?
            /rvRESET~CCHAT~
            /rvCCHAT~QUEUCHAT~
            /rvTHISBANG~LASTBANG~
            {panelon}{indicate FREE}{paneloff}

STEP12      {goto}CCHAT~             < increase same side impact queue
            +1+QUEUCHAT~             <
            /rvCCHAT~QUEUCHAT~       <
            {if CCHAT<MAXCHAT}{return} < check if more than max allowed
            {if OK_CHAT~NOPE}{branch STEP14}
            {SETCARRY}                                          [Page 13]

STEP14      /rvYES~TERMNATE~         < flag termination
            /rvRESULT1~RESULT~       < record reason

STEP11      {panelon}{indicate FREE}{paneloff}
            {return}

RESET            1                   <
ZERO             0                   <

LASTBANG      upper                  < record of last impact location
THISBANG      upper                  < record of this impact location
CCHAT            1                   < impact chatter counter
QUEUCHAT         1                   < queue of impacts on latest side

UPPER         upper                  < tags for impact side
LOWER         lower                  <
```

```
Subroutine to bind impact damper against wall of absorber
~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~

SETCARRY     {if CARRYUP+CARRYDWN>MAXCARRY}{branch STEP18}
             {if CARRYUP+CARRYDWN<1.1}/rvTSTEP~RANGED~ < note first carry
             /rvM3PLUS4~M3_USED~
             /rvVVV3~VVV4~
             /rvRESET~CCHAT~
             /rvCCHAT~QUEUCHAT~
             /rvYES~CARRYING~
             {if THISBANG~UPPER}/rvYES~ON_UPPER~
             {if THISBANG~LOWER}/rvYES~ON_LOWER~
             {panelon}{indicate CARRY}{paneloff}

STEP18       /rvYES~TERMNATE~
             /rvRESULT4~RESULT~

CARRYING     yes
ON_UPPER     yes
ON_LOWER     no


Subroutine to save message and database as files
~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~

SAVEDATA     {goto}TABLE~
             /fxv
             {FILENAME}
             T~
             .{down 3}{end}{down}{right 8}~  < extents of output table
             {goto}MESSAGE~
             /fxv
             {FILENAME}
             S~
             .{end}{right}{end}{down}~

FILENAME     INTEGRAT\RK_MITT\
STKFILE      Single
```

Bisection Subroutine looking for start of Mass 3 Negative Acceleration

```
SPLT_TOP     {panelon}{indicate SPLITTING}{paneloff}{beep}
             {goto}SUP~               < increment carry counter
             +1+CARRYUP~              <
             /rvSUP~CARRYUP~          <
LOOP7        {if @abs(ACCSTEP3)<STOPPED}{SPLIT}{return}
             /rvBISTEP~HHH~
             {calc}
             {if ACCSTEP3>0}{branch LOOP7}
             {SWAP}                                          [Page 10..]
             {branch LOOP7}

SUP                25
```

Bisection Subroutine looking for start of Mass 3 Positive Acceleration

```
SPLT_BTM     {panelon}{indicate SPLITTING}{paneloff}{beep}
             {goto}SDOWN~
             +1+CARRYDWN~
             /rvSDOWN~CARRYDWN~
LOOP8        {if @abs(ACCSTEP3)<STOPPED}{SPLIT}{return}
             /rvBISTEP~HHH~
             {calc}
             {if ACCSTEP3<0}{branch LOOP8}
             {SWAP}                                          [Page 10]
             {branch LOOP8}

SDOWN              25
```

Subroutine to release impact damper from wall of absorber

```
SPLIT        /rvMMM3~M3_USED~
             {SWAP}                                          [Page 10]
             {RECORD}                                        [Page 9]
             /rvNOPE~CARRYING~
             /rvNOPE~ON_UPPER~
             /rvNOPE~ON_LOWER~
             /rvNORMSTEP~HHH~
             {panelon}{indicate FREE}{paneloff}
             /rvYES~FLAG1~
```

Subroutine storing latest peak values of X2, looks for steady state

```
~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~

STEADYX2    {if X2NOW>X2LAST}{branch STEP8}
            {if X2NOW<X2LAST}{if X2LAST<X2BEFORE}{branch STEP8}
            {if X2LAST~X2BEFORE}{branch STEP8}
            {if REG1~0}{branch STEP7}
            {if @std(REGS2)/@avg(REGS2)<RANGE}{branch STEP2}
STEP7       /rvREGS1~REGS2~
            /rvX2LAST~REG5~
            {RECORD}                                         [Page 9]
STEP8       /rvX2LAST~X2BEFORE~
            /rvX2NOW~X2LAST~


STEP2       /rvYES~TERMNATE~
            /rvRESULT2~RESULT~


X2NOW        0.03889      < @abs(XSTEP2) at this iteration
X2LAST       0.04225      < @abs(XSTEP2) at prior iteration
X2BEFORE     0.04145      < @abs(XSTEP2) at iteration two previous


REG1         0.04121      REGS2
             0.04156 REGS1 <          Insert/delete lines below here
             0.04189 <     <
             0.04212 <     <
             0.04222 <     <
             0.04217 <     <
             0.04202 <     <
             0.04184 <     <
             0.04170 <     <
             0.04165 <     <
             0.04172 <     <          REGS7  < Do not Delete this line
             0.04190 <     <          <
             0.04215 <     <          <
             0.04241 <     <          <
             0.04261 <     <          <
             0.04271 <     <          <
             0.04270 <     <          <
             0.04260 <     <          <
             0.04245 <     <          <   Insert/delete lines above here
REG5         0.04232 <     <          <


X2PEAKS          20       < @count(REGS2); number of peak values of X2
```

```
Subroutine to track maximum values of X1
~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~

TRACK_X1     {if X1NOW>X1LAST}{branch STEP10}
             {if X1NOW<X1LAST}{if X1LAST<X1BEFORE}{branch STEP10}
             {if X1LAST~X1BEFORE}{branch STEP10}
             /rvREGS3~REGS4~/rvX1LAST~REG18~
STEP10       /rvX1LAST~X1BEFORE~
             /rvX1NOW~X1LAST~

X1NOW         0.03709        < @abs(XSTEP1) at this iteration
X1LAST        0.03709        < @abs(XSTEP1) at prior iteration
X1BEFORE      0.04375        < @abs(XSTEP1) at iteration two previous

              0.04568        REGS4
              0.04574 REGS3  <        Insert/delete lines below here
              0.04580 <      <
              0.04586 <      <
              0.04591 <      <
              0.04596 <      <
              0.04601 <      <
              0.04605 <      <
              0.04609 <      <
REG18         0.04614 <      <        Insert/delete lines above here


Subroutine to track maximum values of X3
~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~

TRACK_X3     {if X3NOW>X3LAST}{branch STEP9}
             {if X3NOW<X3LAST}{if X3LAST<X3BEFORE}{branch STEP9}
             {if X3LAST~X3BEFORE}{branch STEP9}
             /rvREGS5~REGS6~/rvX3LAST~REG23~
STEP9        /rvX3LAST~X3BEFORE~
             /rvX3NOW~X3LAST~

X3NOW         0.33657        < @abs(XSTEP3) at this iteration
X3LAST        0.33657        < @abs(XSTEP3) at prior iteration
X3BEFORE      0.39735        < @abs(XSTEP3) at iteration two previous

              0.41426        REGS6
              0.41373 REGS5  <        Insert/delete lines below here
              0.41333 <      <
              0.41330 <      <
              0.41377 <      <
              0.41472 <      <
              0.41599 <      <
              0.41734 <      <
              0.41849 <      <
REG23         0.41925 <      <        Insert/delete lines above here
```

```
Subroutine to print the results of this model run for the record.
~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~

PRINT        {if PRINTED>PRINTMAX}{BAILOUT}   < check not in a loop
             {goto}CPRINT~                    < increment print count
             +1+PRINTED~                      <
             /rvCPRINT~PRINTED~               <
             /pprMESSAGE~gq                   < print screen message


CPRINT             8
PRINTED            8
PRINTMAX          25                 < upset maximum runs expected


BAILOUT      /pprTOOMUCH~gq          < quit if unexpected number of files
             {panelon}{windowson}{indicate}
             {quit}

TOOMUCH      Maximum number of print calls exceeded! LOOP?



Subroutine to ensure proper printer settings for multi run
~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~

SETPRINT     /ppoof                  < formatted output
             mt0~mb0~ml4~mr76~       < set margins
             sFAKE{esc}~             < default setup
             hFAKE{esc}~             < no header
             fFAKE{esc}~             < no footer
             p66~q                   < page length of 66 lines
             cbaq                    < no borders, align
            /reCPRINT~               < clear print monitoring registers
            /rePRINTED~              <
            /pprTRIAL_PRT~gpq

TRIAL_PRT   This message is a printer check.  It      < This whole
            indicates the top of the page.  If it     < section called
            is not positioned properly, adjust the    < TRIAL_PRT
            paper without resetting the printer or    <
            stopping the program.                     <
```

This macro facilitates setting up the initial graph data ranges
~~~~~~

```
SETGRAPH     {goto}COMMENT2~{?}
             {windowsoff}{goto}HEADER~
             /grgtx
             x.{end}{down}~q
             {goto}TABLE~
             {windowson}{menubranch RANGES}


RANGES ──┬─ A
         │  Move cursor to top of A-Range, hit ENTER
         │  /ga{?}.{end}{down}~ola{?}~qq
         │  {menubranch MORE}
         │
         ├─ B
         │  Move cursor to top of B-Range, hit ENTER
         │  /gb{?}.{end}{down}~olb{?}~qq
         │  {menubranch MORE}
         │
         ├─ C
         │  Move cursor to top of C-Range, hit ENTER
         │  /gc{?}.{end}{down}~olc{?}~qq
         │  {menubranch MORE}
         │
         ├─ D
         │  Move cursor to top of D-Range, hit ENTER
         │  /gd{?}.{end}{down}~old{?}~qq
         │  {menubranch MORE}
         │
         ├─ E
         │  Move cursor to top of E-Range, hit ENTER
         │  /ge{?}.{end}{down}~ole{?}~qq
         │  {menubranch MORE}
         │
         └─ F
            Move cursor to top of F-Range, hit ENTER
            /gf{?}.{end}{down}~olf{?}~qq
            {menubranch MORE}


MORE ────┬─ CONTINUE
         │  Select more of the data ranges
         │  {menubranch RANGES}
         │
         └─ FINISHED
            Finished selecting ranges, View
            /gvq
            {menubranch CHOICE}
```
~~~~~~

Subroutine for Saving output results

```
~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
SAVECHK --┬-- RENAME
          |   Do not save under file name : Single , Select new name
          |   {getlabel "Type in new 7 character filename : ",STKFILE}
          |   /rvSTKFILE~RANGEA~
          |   {menubranch REASON}
          |
          |
          └-- CONTINUE
              Save the information under the file name : Single
              {menubranch REASON}


REASON ---┬-- SINGLE
          |   This was a single run that went to completion
          |   {branch STEP19}
          |
          |
          └-- BREAK
              Run terminated by the operator
              /rvRESULT5~RESULT~
STEP19        {calc}
              {SAVEDATA}                                  [Page 13]
              {PRINT}                                     [Page 17]
              {menubranch CHOICE}
```

Typical MESSAGE at the end of a run, as printed and saved

```
MESSAGE
|^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^|
| Single  - MASS 2 achieved steady state                      13-Mar-91 |
|-----------------------------------------------------------------------|
| XXX1  =  0.0459  @  0.3%               FIRSTS | WWWF  =             1 |
| XXX2  =  0.0424  @  0.8%   IMPACT       25.5  | DDD   =         0.001 |
| XXX3  =  0.4154  @  0.5%   CARRY        35.9  | EEE   =           0.3 |
|-----------------------------------------------------------------------|
| MMM1  =     1000 | Over Last       20  Peaks  | OK_CHAT =         yes |
| KKK1  =     1000 | X2 Peaks   0.04271 Maximum | ALLPACT =          no |
| ZETA1 =     1.0% |            0.04121 Minimum | SS Quit =        1.0% |
| MMM2  =        5 |            0.00040 Std Dev |          Clock Time   |
| KKK2  =        5 |                            |     Start  06:44 AM   |
| ZETA2 =     1.0% | MAXCARRY=       85 total   |    Finish  09:29 AM   |
| MMM3  =      0.5 | MAXCHAT =        5 /side   |   Elapsed     02:44   |
| KKK3  =      0.5 |   FOOH =         1 F       |          Model Time   |
| ZETA3 =     1.0% |  WITHIN = 1.0E-10 L        |     Start     200.7   |
| MMM4  =     0.05 |             Upper  Lower   |      Step   0.31416   |
| WR2:1 =        1 | Impacts :     125    120   |    Expect     672.0   |
| WR3:1 =        1 |   Carry :      24     24   |    Actual     352.2   |
|vvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvv|
```

Typical MESSAGE at start of run before any iterations

```
MESSAGE
|^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^|
| Single                                                      09-Apr-91 |
|-----------------------------------------------------------------------|
| XXX1  =       NA  @   NA               FIRSTS | WWWF  =             1 |
| XXX2  =       NA  @   NA   IMPACT          NA | DDD   =           0.1 |
| XXX3  =       NA  @   NA   CARRY           NA | EEE   =           0.3 |
|-----------------------------------------------------------------------|
| MMM1  =     1000 | Over Last       20  Peaks  | OK_CHAT =         yes |
| KKK1  =     1000 | X2 Peaks        NA Maximum | ALLPACT =          no |
| ZETA1 =     1.0% |                 NA Minimum | SS Quit =        1.0% |
| MMM2  =        5 |                 NA Std Dev |          Clock Time   |
| KKK2  =        5 |                            |     Start  09:08 PM   |
| ZETA2 =     1.0% | MAXCARRY=       85 total   |    Finish             |
| MMM3  =      0.5 | MAXCHAT =        5 /side   |   Elapsed             |
| KKK3  =      0.5 |   FOOH =         1 F       |          Model Time   |
| ZETA3 =     1.0% |  WITHIN = 1.0E-08 L        |     Start       0.0   |
| MMM4  =     0.05 |             Upper  Lower   |      Step   0.31416   |
| WR2:1 =        1 | Impacts :       0      0   |    Expect     471.2   |
| WR3:1 =        1 |   Carry :       0      0   |    Actual       0.0   |
|vvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvv|
```

Listed here is a template of the MESSAGE names

```
---------------------------------------------------------------------------
 P_RANGE                                                                   |
|^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^|
|                                                                          |
| +RANGEA +RESULT                                          @NOW            |
|--------------------------------------------------------------------------|
| XXX1  = +X1_AVG  @ @std(REGS4)/X1_AVG         | WWWF   =     RANGEE      |
| XXX2  = +X2_AVG  @ @std(REGS7)/X2_AVG RANGEB  | DDD    =     RANGEZ      |
| XXX3  = +X3_AVG  @ @std(REGS6)/X3_AVG RANGED  | EEE    =     RANGEAB     |
|--------------------------------------------------------------------------|
| MMM1  = RANGEK     Over Last  RANGEF  Peaks    OK_CHAT =     RANGEX      |
| KKK1  =            X2 Peaks @max(REGS2) MaximumALLPACT =     RANGEW      |
| ZETA1 =                     @min(REGS2) MinimumSS Quit =     RANGEF      |
| MMM2  =                     @std(REGS2) Std Dev.        Clock Time       |
| KKK2  =                                         Start        START       |
| ZETA2 =            MAXCARRY=  RANGEV total      Finish       FINISH      |
| MMM3  =            MAXCHAT =  RANGEC per side  Elapsed       ELAPSED     |
| KKK3  =            FOOH =     RANGEG F                  Model Time       |
| ZETA3 =             WITHIN =  RANGEH L          Start        RANGEY      |
| MMM4  =                        Upper  Lower     Step         RANGEI      |
| WR2:1 =            Impacts :QUEUUP   QUEULOW    Expect       RANGEJ      |
| WR3:1 =              Carry :CARRYUP  CARRYDDWN  Actual       +TTT        |
|vvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvv|
  Ranges X1_AVG, X2_AVG & X3_AVG are also called range MAXIMUMS            |
```

These are the possible end results of this program.

RESULT1 - Impact damper chattering
RESULT2 - MASS 2 achieved steady state
RESULT3 - Ran to time limit
RESULT4 - Exceeded maximum carries
RESULT5 - Program stopped by operator

COMMENT1

```
+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
+                                                                       +
+                                                                       +
+         COMMENT 1                                                     +
+                                                                       +
+         Using the macro STEPPER subroutine                            +
+                                                                       +
+                                                                       +
+         The macro will step through the iteration program             +
+         each time you press ENTER.  The screen will show the          +
+         output results.  There is no bisection routine                +
+         invoked if the limits of the walls are exceeded.              +
+                                                                       +
+                                                                       +
+                                                                       +
+                                                                       +
+                                                                       +
+                                                                       +
+                                                                       +
+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
```

COMMENT2

```
+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
+                                                                       +
+                                                                       +
+         COMMENT 2                                                     +
+                                                                       +
+         Using the SETGRAPH macro subroutine                           +
+                                                                       +
+         The graph set-up macro will quickly allow you to              +
+         set up the data ranges you wish to look at.  After            +
+         selecting which range you want to set up, the macro           +
+         will wait for you move to the top of that range.              +
+         Once you press ENTER, that complete column is                 +
+         entered as the range.                                         +
+                                                                       +
+                                                                       +
+                                                                       +
+                                                                       +
+                                                                       +
+                                                                       +
+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
```

TABLE

Output Table

HEADER

Time	MASS 1		MASS 2		MASS 3		MASS 4	
	X	V	X	V	X	V	X	V
0.00	0.000	0.000	0.000	0.000	0.0000	0.00000	0.0000	0.00000
0.31	0.0000	0.0000	0.00000	0.00000	0.0000	0.00000	0.0000	0.00000
0.63	0.0000	0.0001	0.00000	0.00000	0.0000	0.00000	0.0000	0.00000
0.94	0.0001	0.0003	0.00000	0.00003	0.0000	0.00000	0.0000	0.00000
1.26	0.0002	0.0005	0.00002	0.00009	0.0000	0.00001	0.0000	0.00000
1.57	0.0004	0.0007	0.00006	0.00020	0.0000	0.00002	0.0000	0.00000
.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.
14.77	0.0042	0.0053	-0.0101	0.01054	-0.0404	-0.02757	0.0000	0.00000
15.08	0.0057	0.0038	-0.0063	0.01355	-0.0474	-0.01609	0.0000	0.00000
15.64	0.0069	0.0003	0.00208	0.01564	-0.0490	0.01123	-0.0019	-0.00591
15.96	0.0067	-0.001	0.00689	0.01470	-0.0429	0.02718	-0.0037	-0.00591
16.27	0.0058	-0.003	0.01117	0.01228	-0.0320	0.04180	-0.0056	-0.00591
.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.
17.21	0.0000	-0.007	0.01690	-0.0011	0.0205	0.06207	-0.0111	-0.00591
17.49	-0.002	-0.007	0.01594	-0.0056	0.0372	0.05828	-0.0128	-0.00591
17.49	-0.002	-0.007	0.01594	-0.0056	0.0372	0.05070	-0.0128	0.06995
17.49	-0.002	-0.007	0.01594	-0.0056	0.0372	0.05070	-0.0128	0.06995
.	.	.	.	.	.	.	.	.
19.17	-0.007	0.0027	-0.0081	-0.0161	0.0552	-0.04166	0.1052	0.06995
19.17	-0.007	0.0027	-0.0081	-0.0161	0.0552	-0.02847	0.1052	-0.06195
19.49	-0.006	0.0051	-0.0127	-0.0130	0.0432	-0.04722	0.0857	-0.06195
.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.
20.43	0.0006	0.0087	-0.0181	0.00268	-0.0189	-0.07539	0.0273	-0.06195
20.74	0.0033	0.0083	-0.0163	0.00832	-0.0420	-0.07074	0.0078	-0.06195
21.07	0.0058	0.0070	-0.0128	0.01332	-0.0629	-0.05682	-0.0155	-0.07195
.	.	.	.	.	.	.	.	.
22.50	0.0080	-0.004	0.01164	0.01465	-0.0683	0.05631	-0.1183	-0.07195
22.50	0.0080	-0.004	0.01164	0.01465	-0.0683	0.04116	-0.1183	0.07964
22.81	0.0061	-0.007	0.01558	0.01016	-0.0516	0.06423	-0.0932	0.07964
23.13	0.0036	-0.008	0.01791	0.00454	-0.0285	0.08185	-0.0682	0.07964
23.44	0.0006	-0.009	0.01838	-0.0015	-0.0010	0.09177	-0.0432	0.07964
23.44	0.0006	-0.009	0.01838	-0.0015	-0.0010	0.09177	-0.0432	0.07964
23.76	-0.002	-0.009	0.01692	-0.0075	0.0282	0.09248	-0.0182	0.07964

FOOTER

RK_STACK

PROGRAM LISTING

```
\X              /wtc
\0              {menubranch MENU0}

MENU0 ───┬──── EDIT
         │     Change the stack
         │     {menubranch MENU2}
         │
         ├──── NAME
         │     Select the range named STACK
         │     {goto}COMMENT2~{?}/rncSTACK~{?}~
         │
         ├──── BROWSE
         │     Move through the file
         │     /wtc
         │     {menubranch MENU1}
         │
         ├──── SAVE
         │     Save the file as RK_STACK
         │     /fsRK_STACK~r
         │     {menubranch MENU0}
         │
         └──── QUIT
               Quit the macro ( Restart {alt}X )
               {quit}

MENU1────┬──── MACRO
         │     Move to the Macro section
         │     {goto}\X~{left}
         │     {menubranch MENU0}
         │
         ├────  STACKS
         │     Move to were the input stacks are located
         │     {goto}STACKS~
         │     {menubranch MENU0}
         │
         └──── COMMENTS
               Move to the comments section
               {menubranch MENU3}                          [Page 2]

MENU2────┬──── INPUTS
         │     Change the input stacks
         │     {goto}COMMENT1~{?}
         │     {goto}STACKS~
         │     {right 2}{down 2}
         │     {menubranch SCR_TTL}                        [Page 2]
         │
         └──── FILENAME
               Edit the filenames
               {goto}COMMENT3~{?}
               {goto}EDITED~
```

```
SCR_TTL ──┬── YES
          │   Set up screen with horizontal & vertical titles
          │   /wtb~
          │
          └── NO
              Do not set up titles


MENU3 ──┬──── ONE
        │     Comment re. Editing Input
        │     {goto}COMMENT1~
        │     {menubranch MENU0}                         [Page 1]
        │
        ├──── TWO
        │     Comment re. naming STACK
        │     {goto}COMMENT2~
        │     {menubranch MENU0}                         [Page 1]
        │
        └──── THREE
              Comment re. naming STACK
              {goto}COMMENT3~
              {menubranch MENU0}                         [Page 1]
```

Macro for revising file names
~~~~~~

```
              SA1___C     999     < test spot for setting up \F macro

LOOP          {edit}              < also called \F
EDITED        {left 5}{del}{?}    < edit this line
              ~{right}
              {if @cellpointer("contents")=NOMORE}{menubranch MENU0}─┐
              {branch LOOP}                                   [Page 1]

NOMORE              999 < Cell to indicate completion of edit macro.
```
~~~~~~

COMMENT 1

The input values for different runs are entered in columns to the right of the a column of titles listed in a row. Although you can added or delete columns the number and description of the rows must remain as is. For a full description of what each row means see the user's manual. Make change to any input values as with a typical spreadsheet. After you hit enter the macro will move the cursor to the stack area and quit. To restart the macro hit {alt}X. To revise the Filenames it may be easier to use the basic macro already started.

Press ENTER to move to the input stack.

COMMENT 2

The range name STACK is imported by the other programs RK*_MDOF and RK_COMPL. The macro initiates the naming of this range. If you wish to revise the range do so in the normal spreadsheet manner and then hit enter to accept.

Press ENTER to continue.

If in the course of making input revisions the range name STACK is no longer assigned to any range the cursor will remain on this comment.

To get to the appropriate sheet type {bs}{tab}{end}{down}{pgdn}

Press ALT{X} to restart macro

COMMENT 3

Because as this research program has been set up the filenames usually differ by only one or two characters it is possible to easily modify the names by using a macro.

The method for doing this is described in the User's manual. By pressing ENTER, this macro will move to the appropriate line in the filename edit macro. After making the appropriate change, restart the macro and move to the stack to begin the editing.

Press ENTER to continue.

Stack input

FILENAME		SAC3W2B	SA13E2B	..	SA13G2B 999
WWWF		0.83	0.85	..	0.85
MMM1	Mass 1	1000	1000	..	1000
KKK1	Spring Rate 1	1000	1000	..	1000
ZETA1	% Critical Damping	1.0%	1.0%	..	1.0%
MRAT1:2	Mass Ratio 1:2	200	200	..	200
WRAT2:1	Freq Ratio 2:1	1	1	..	1
ZETA2	% Critical Damping	1.0%	1.0%	..	1.0%
MRAT2:3	Mass Ratio 2:3	10	10	..	10
WRAT3:1	Freq Ratio 3:2	1	1	..	1
ZETA3	% Critical Damping	1.0%	1.0%	..	1.0%
MRAT3:4	Mass Ratio 3:4	10	10	..	10
DDD	Impact Gap	0.3	0.55	..	0.7
EEE	Coeff of Restitution	0.3	0.3	..	0.3
STEPS	Minimum Steps/period	20	20	..	20
CYCLES	Minimum cycles (periods)	75	75	..	75
LIMIT2	maximum between prints	6	6	..	6
RANGE	Steady State tolerance	2.0%	2.0%	..	2.0%
MAXCARRY	Total maximum carries	80	80	..	80
ALLPACT	Print all impacts? (yes/no)	no	no	..	no
OK_CHAT	OK if chatters? (yes/no)	yes	yes	..	yes
MAXCHAT	Allowable chatter	8	8	..	8
INITIAL VALUES OF SYSTEM		=========	=========	..	========
	TTT	467.106	529.821	..	523.711
	XXX1	-0.00308	-0.00305	..	-0.00373
	VVV1	-0.00115	-0.00217	..	0.000987
	XXX2	-0.01087	0.005030	..	-0.04651
	VVV2	-0.01334	-0.03271	..	-0.04209
	XXX3	-0.01691	0.054026	..	-0.15939
	VVV3	-0.04253	-0.09367	..	-0.16936
	XXX4	0.047212	0.163644	..	0.030299
	VVV4	0.050600	0.136442	..	0.003801

RK_COMPL

PROGRAM LISTING

Start up macro

```
\0          {menubranch MENU1}        < also called \X
```

Menu for performing functions

```
MENU1 ──┬── COMPILE
        │   Compile data
        │   {branch COMPILE}                               [Page 3]
        │
        ├── SETUP
        │   Import files to be compiled
        │   {goto}COMMENT2~{?}
        │   {goto}STACK~
        │   {quit}
        │
        ├── BROWSE
        │   Move about the spreadsheet within the macro
        │   {menubranch MENU2}                             [Page 2]
        │
        └── QUIT
            Quit the macro
            {quit}
```

Menu for moving about the spreadsheet
~~~~~~

```
MENU2 ──┬── MACROS
        │   MENUS  COMPILE
        │   {menubranch MENU3}
        │
        ├── COMMENTS
        │   Go to the message section
        │   {goto}COMMENT1~
        │   {menubranch MENU1}                    [Page 1]
        │
        ├── STACK
        │   Go to the input stack
        │   {goto}STACK~
        │   {menubranch MENU1}                    [Page 1]
        │
        └── IMPORTZONE
            Go to the importzone
            {goto}IMPORTZONE~
            {menubranch MENU1}                    [Page 1]
```

Menu for moving about the macro
~~~~~~

```
MENU3 ──┬── MENUS
        │   Go to the menu macros
        │   {goto}\0~{left}
        │   {menubranch MENU1}                    [Page 1]
        │
        └── COMPILE
            Go to the top of the Main macro
            {goto}COMPILE~
            {left}{up 2}
            {menubranch MENU1}                    [Page 1]
```

Main Compile Program Macro
~~~~~~

```
COMPILE     {goto}COMMENT1~{?}
            {goto}STACK~{?}
            /rncMARK1~{bs}~
LOOP2       /rv~FILENAME~
            {windowson}{windowsoff}
            {goto}IMPORTZONE~
            /fcce{COMBINE}                                        [Page 4]
            {right 3}{down}
            /rv~REASON~{down 2}
            /rv~X1_AVG~{down}
            /rv~X2_AVG~{down}
            /rv~X3_AVG~{right 2}
            /rv~STDEV_X3~{up}
            /rv~STDEV_X2~{up}
            /rv~STDEV_X1~{right 3}{down}
            /rv~T_IMPACT~{down}
            /rv~T_CARRY~{down 2}{left}
            /rv~PEAKS~{down}
            /rv~X2_MAX~{down}
            /rv~X2_MIN~{down}
            /rv~X2_SDEV~{down 7}
            /rv~U_IMPACT~{down}
            /rv~U_CARRY~{right}
            /rv~D_CARRY~{up}
            /rv~L_IMPACT~{down}{right 3}
            /rv~TIME~
            {goto}MARK1~{end}{down 2}
            /rvGATHERED~~
            {goto}MARK1~{right}
            {if @cellpointer("contents")~NOMORE}{branch SAVE}    [Page 4]
            /rncMARK1~{bs}~
            {branch LOOP2}
```
~~~~~~

```
X1_AVG        0.0459         < GATHERED
STDEV_X1         0.3%        <
X2_AVG        0.0424         <
STDEV_X2         0.8%        <
X3_AVG        0.4154         <
STDEV_X3         0.5%        <
PEAKS             20         <
X2_MIN       0.04121         <
X2_MAX       0.04270         <
X2_SDEV      0.00040         <
T_IMPACT     240.620         <
U_IMPACT         112         <
L_IMPACT         114         <
T_CARRY      243.789         <
U_CARRY           17         <
D_CARRY           18         <
TIME           352.2         <
REASON      - Program stopped <
```

```
Macro to save file at completion of compiling
~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~

SAVE        {windowson}{panelon}
            /fsRK_COMPL~r
```

```
Subroutine with name of file to import from
~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~

COMBINE     INTEGRAT\RK_BIN\
FILENAME    SA13L2_
            S~

NOMORE           999          < range for comparing to end of stack
```

COMMENT 1

After you press ENTER, move the curser to after the last column of file data you want to retrieve. When you press ENTER again, the program will copy the value NOMORE (999) into that cell. Then move to the first column of files you want to compile and press ENTER a third time. That file and all those to the files that are to the right of the cursor will be compiled until the cursor senses the cell with the contents 999.

After compiling all the files this program saves itself so that the data will be retained in case of a power outage.

Press ENTER to continue.

COMMENT 2

The files to be compiled can be set up in various ways. The most common is to import the same "STACK' from file "RK_STACK" that was used to create them originally. The macro will move you to the Stack sheet and then quit. You can either import the stack or set it up in any way you want. To restart press {alt}X.

Be sure the items line up with the names on the left and stop just above the section titled GATHERED.

Put the first file in the cell called START.

Press ENTER to continue with macro execution.

```
¦IMPORTZONE
¦^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^¦
¦ SA13L2_ - Program stopped by operator                          16-Mar-91 ¦
¦---------------------------------------------------------------------------¦
¦ XXX1  = 0.0459 @ 0.3%            FIRSTS ¦ WWWF    =          1 ¦
¦ XXX2  = 0.0424 @ 0.8%   IMPACT   240.62 ¦ DDD     =      0.001 ¦
¦ XXX3  = 0.4154 @ 0.5%   CARRY    243.79 ¦ EEE     =        0.3 ¦
¦---------------------------------------------------------------------------¦
¦ MMM1  =   1000 ¦ Over Last       20  Peaks   ¦ OK_CHAT =        yes ¦
¦ KKK1  =   1000 ¦ X2 Peaks   0.04270 Maximum ¦ ALLPACT =         no ¦
¦ ZETA1 =   1.0% ¦            0.04121 Minimum ¦ SS Quit =       1.0% ¦
¦ MMM2  =      5 ¦            0.00040 Std Dev ¦   Start Clock Time  ¦
¦ KKK2  =      5 ¦ MAXCARRY=       80 total   ¦   Start    03:54 PM ¦
¦ ZETA2 =   1.0% ¦ MAXCARRY=       80 total   ¦   Finish   06:20 PM ¦
¦ MMM3  =    0.5 ¦ MAXCHAT =        6 /side   ¦  Elapsed      02:26 ¦
¦ KKK3  =    0.5 ¦    FOOH =        1 F       ¦   Start Model Time  ¦
¦ ZETA3 =   1.0% ¦  WITHIN =  1.0E-10 L       ¦   Start       240.6 ¦
¦ MMM4  =   0.05 ¦ Impacts :    Upper  Lower  ¦    Step     0.31416 ¦
¦ WR2:1 =      1 ¦ Impacts :      112    114  ¦   Expect      868.9 ¦
¦ WR3:1 =      1 ¦   Carry :       17     18  ¦   Actual      352.2 ¦
¦vvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvv¦
```

Stack input file Start

		VVVVVVVVVV					
FILENAME		SAC3W2B	SA13E2B	SA13G2B	...	SAW3V2B	999
WWWF		0.83	0.85	0.85	...	1.16	
MMM1		1000	1000	1000	...	1000	
KKK1		1000	1000	1000	...	1000	
ZETA1		1.0%	1.0%	1.0%	...	1.0%	
MRAT1:2		200	200	200	...	200	
WRAT2:1		1	1	1	...	1	
ZETA2		1.0%	1.0%	1.0%	...	1.0%	
MRAT2:3		10	10	10	...	10	
WRAT3:1		1	1	1	...	1	
ZETA3		1.0%	1.0%	1.0%	...	1.0%	
MRAT3:4		10	10	10	...	10	
DDD		0.3	0.55	0.7	...	0.2	
EEE		0.3	0.3	0.3	...	0.3	
STEPS		20	20	20	...	20	
CYCLES		75	75	75	...	75	
LIMIT2		6	6	6	...	6	
RANGE		2.0%	2.0%	2.0%	...	2.0%	
MAXCARRY		80	80	80	...	80	
ALLPACT		no	no	no	...	no	
OK_CHAT		yes	yes	yes	...	yes	
MAXCHAT		8	8	8	...	8	
INITIAL	TTT	467.106	529.821	523.711	...	280.690	
	XXX1	-0.00308	-0.00305	-0.00373	...	0.002477	
	VVV1	-0.00115	-0.00217	0.000987	...	-0.00222	
	XXX2	-0.01087	0.005030	-0.04651	...	0.002399	
	VVV2	-0.01334	-0.03271	-0.04209	...	0.017596	
	XXX3	-0.01691	0.054026	-0.15939	...	-0.05492	
	VVV3	-0.04253	-0.09367	-0.16936	...	-0.02250	
	XXX4	0.047212	0.163644	0.030299	...	0.011828	
	VVV4	0.050600	0.136442	0.003801	...	0.027516	

Note to user: This page follows the previous page without any blank rows!

GATHERED	X1_AVG	0.0034	0.0038	0.0038	...	0.0030
	STDEV_X1	2.3%	4.3%	6.6%	...	3.9%
	X2_AVG	0.0184	0.0291	0.0387	...	0.0200
	STDEV_X2	7.0%	15.2%	15.1%	...	14.2%
	X3_AVG	0.0521	0.0937	0.1318	...	0.0449
	STDEV_X3	12.8%	17.0%	12.1%	...	21.9%
	PEAKS	20	20	20	...	20
	X2_MIN	0.01672	0.02487	0.02854	...	0.01534
	X2_MAX	0.02423	0.04093	0.04971	...	0.03099
	X2_SDEV	0.00210	0.00557	0.00620	...	0.00418
	T_IMPACT	468.117	530.507	539.282	...	285.000
	U_IMPACT	81	89	60	...	65
	L_IMPACR	69	75	63	...	64
	T_CARRY	647.298	720.567	750.839	...	577.476
	U_CARRY	2	4	2	...	0
	D_CARRY	0	2	2	...	0
	TIME	1055.3	1099.0	1094.4	...	704.4
	REASON	- Ran to	- Program-	Ran to	...	- Ran to

RK_GRAPH

PROGRAM LISTING

```
\0      {goto}COMMENT1~          <Start-up Macro
\X      {panelon}                < If Control Break or quit is used
        {windowson}              to stop the program this macro will
        {indicate}               reset the display if required and
        {menubranch CHOICE}      call up the master menu.
```

MENUS

```
CHOICE──┬─IMPORT
        │ Run the Program
        │ {IMPORT}                                                [Page 6]
        │ {menubranch CHOICE}
        │
        ├─GRAPH
        │ Set up the graph for this particular file
        │ {SETGRAPH}                                              [Page 3]
        │ {TITLES}                                                [Page 5]
        │ {menubranch CHOICE}
        │
        ├─SAVE
        │ Save data in this format and erase old database file
        │ {SAVE}                                                  [Page 6]
        │ {menubranch CHOICE}
        │
        ├─CONDENSE
        │ Erase existing database to condense file size
        │ {goto}TABLE~
        │ {down}
        │ /re{end}{home}~
        │ {menubranch CHOICE}
        │
        ├─BROWSE
        │ Just look around the Spreadsheet (Restart with {alt}X)
        │ {windowsoff}
        │ {menubranch BROWSE}                                     [Page 2]
        │
        └─QUIT
          Get out of all macros and reset window & panel
          {panelon}
          {indicate}
          {windowson}
          {quit}
```

```
BROWSE──┬─MACROS
        │ MENUS   GRAPH_SET   TITLES   IMPORT   SAVE
        │ {menubranch MACROS}
        │
        ├─TABLE
        │ Output Table
        │ {goto}TABLE~{branch ADJUST2}
        │
        └─COMMENTS
          1_COMMENT   2_COMMENT    TITLES
          {menubranch WHICH}

WHICH  ─┬─1_COMMENT
        │ Comment 1
        │ {goto}COMMENT1~{branch ADJUST2}
        │
        ├─2_COMMENT
        │ Comment 2
        │ {goto}COMMENT2~{branch ADJUST2}
        │
        └─TITLES
          Main title options
          {goto}FIRSTTITLE~{branch ADJUST2}


MACROS──┬─MENUS
        │ Top of menus
        │ {goto}MENUS~{branch ADJUST2}
        │
        ├─GRAPH_SET
        │ Subroutine to set graph ranges
        │ {goto}SETGRAPH~{branch ADJUST}
        │
        ├─TITLES
        │ Subroutine to set plot titles
        │ {goto}TITLES~{branch ADJUST}
        │
        ├─IMPORT
        │ Subroutine to import a new database
        │ {goto}IMPORT~{branch ADJUST}
        │
        └─SAVE
          Subroutine to save this file as a database file
          {goto}SAVE~{branch ADJUST}

ADJUST    {up 2}{left}
ADJUST2   {windowson}{windowsoff}
          {menubranch CHOICE}
```

Subroutine to facilitates setting up the initial graph data ranges
~~~~~~

```
SETGRAPH {goto}COMMENT2~{?}
         {windowsoff}
         {goto}TABLE~
         /grgtxq
         {windowson}
         /gx{down 5}{?}.{end}{down}~q
         {menubranch RANGES}


RANGES┬─A
      │ Move cursor to top of A-Range, hit ENTER
      │ {windowsoff}{goto}RANGES~/c~RANGE~{goto}TABLE~
      │ {windowson}{panelon}/ga{?}.{end}{down}~ola{?}~qq
      │ {menubranch FORMAT}                              [Page 4]
      │
      ├─B
      │ Move cursor to top of B-Range, hit ENTER
      │ {windowsoff}{goto}RANGES~{right}/c~RANGE~{goto}TABLE~
      │ {windowson}{panelon}/gb{?}.{end}{down}~olb{?}~qq
      │ {menubranch FORMAT}                              [Page 4]
      │
      ├─C
      │ Move cursor to top of C-Range, hit ENTER
      │ {windowsoff}{goto}RANGES~{right2}/c~RANGE~{goto}TABLE~
      │ {windowson}{panelon}/gc{?}.{end}{down}~olc{?}~qq
      │ {menubranch FORMAT}                              [Page 4]
      │
      ├─D
      │ Move cursor to top of D-Range, hit ENTER
      │ {windowsoff}{goto}RANGES~{right3}/c~RANGE~{goto}TABLE~
      │ {windowson}{panelon}/gd{?}.{end}{down}~old{?}~qq
      │ {menubranch FORMAT}                              [Page 4]
      │
      ├─E
      │ Move cursor to top of E-Range, hit ENTER
      │ {windowsoff}{goto}RANGES~{right4}/c~RANGE~{goto}TABLE~
      │ {windowson}{panelon}/ge{?}.{end}{down}~ole{?}~qq
      │ {menubranch FORMAT}                              [Page 4]
      │
      └─F
        Move cursor to top of F-Range, hit ENTER
        {windowsoff}{goto}RANGES~{right5}/c~RANGE~{goto}TABLE~
        {windowson}{panelon}/gf{?}.{end}{down}~olf{?}~qq
        {menubranch FORMAT}                              [Page 4]
```
~~~~~~

```
FORMAT─┬─ LINES
       │  Display with lineonly
       │  {paneloff}
       │  /gof
RANGE  │  E   <──────────────────────────┬─range is three cells wide
       │  lqqq                           │
       │  {menubranch MORE}              │
       │                                 │
       ├─ SYMBOLS                        │
       │  Display with symbols only      │
       │  {paneloff}                     │
       │  /gof                           │
RANGE  │  E   <──────────────────────────┤
       │  sqqq                           │
       │  {menubranch MORE}              │
       │                                 │
       └─ BOTH                           │
          Display with both line and symbols
          {paneloff}                     │
          /gof                           │
RANGE     E   <──────────────────────────┘
          bqqq
          {menubranch MORE}

MORE  ─┬─ FINISHED
       │  Finished selecting ranges
       │  {return}
       │
       └─ CONTINUE
          Select more of the data ranges
          {menubranch RANGES}
```

[Page 3]

Subroutine to set the graph titles

```
~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~

TITLES   {goto}FIRSTTITLE~
         {menubranch F_MENU}

F_MENU──┬──RETAIN
        │  Retain existing title
        │  {menubranch YTITLE}                          [Page 6]
        │
        ├─ AAA
        │  Chose title AAA
        │  /cAAA~RETAIN~
        │  {menubranch YTITLE}                          [Page 6]
        │
        ├─ BBB
        │  Chose title BBB
        │  /cBBB~RETAIN~
        │  {menubranch YTITLE}                          [Page 6]
        │
        ├─ CCC
        │  Chose title CCC
        │  /cCCC~RETAIN~
        │  {menubranch YTITLE}                          [Page 6]
        │
        ├─ DDD
        │  Chose title DDD
        │  /cDDD~RETAIN~
        │  {menubranch YTITLE}                          [Page 6]
        │
        ├─ EEE
        │  Chose title EEE
        │  /cEEE~RETAIN~
        │  {menubranch YTITLE}                          [Page 6]
        │
        ├─ FFF
        │  Chose title FFF
        │  /cFFF~RETAIN~
        │  {menubranch YTITLE}                          [Page 6]
        │
        └─ OTHER
           Type in a new title
           {getlabel 39 CHARACTER OR LESS TITLE  - ,RETAIN}
           {menubranch YTITLE}                          [Page 6]
```

```
YTITLE-┬- DISPLACEMENT
       |  Y-axis is displacement
       |  /gotyFAKE{esc}DISPLACEMENT~qq
       |  {branch STEP1}
       |
       ├- VELOCITY
       |  Y-Axis is Velocity
       |  /gotyFAKE{esc}VELOCITY~qq
       |  {branch STEP1}
       |
       └- NONE
          Do not label Y-Axis
          /gotyFAKE{esc}~qq
          {branch STEP1}

STEP1     /gotxFAKE{esc}TIME~
          tfFAKE{esc}
          Displacement of Mass 2        < @left(RETAIN,39)
          ~tsFAKE{esc}
          FILENAME :
          SA2___C                        < @upper(@left(FILENAME,7))
          ~qvq
```

Subroutine to import database file to be graphed
~~~~~~

```
IMPORT    {goto}TABLE~
          {down}
          /re{end}{home}~
          {getlabel Type file to retrieve from RK_BIN - ,FILENAME}
          /fcce
          INTEGRAT\RK_BIN\
FILENAME  SA2___CT
          ~
```

Subroutine to save file and erase old data base file
~~~~~~

```
SAVE      /fs{esc}
          INTEGRAT\RK_CHIVE\
          SA2___C              < @left(FILENAME,7)
          G~
          /few                 < erase old database
          INTEGRAT\RK_BIN\
          SA2___CT             < @upper(FILENAME)
          ~y
```

COMMENT 1

This macro is specifically designed to facilitate the creation of graphs froma the RK*_MDOF programs. You should know which programs you want to investigate prior to starting this program.

Press {alt}X to restart the macro.

COMMENT 2

This macro will erase all the previous settings and facilitate the setting of new ones.

Your first choice will be to move to the top of the X range. As with all the selections from this macro, only move to the top of the section and press ENTER. Do not define the complete range yourself.

If you want to quit this portion of the macro press {CNTL}{BREAK}

Press {alt}X to restart the macro.

FIRSTTITLE

FIRST TITLE CHOICES

RETAIN	Displacement of Mass 2
AAA	Displacement of Mass 1
BBB	Displacement of Mass 2
CCC	Displacement of Mass 3
DDD	Velocity of Mass 2
EEE	Velocity of Mass 3
FFF	Velocity of Mass 4

Appendix C

Spreadsheet Design and Programming Techniques

Table of Contents

1 Calculation Spreadsheet

Figure C.1 contains a typical calculation spreadsheet with the different columns identified by alphabetic characters. The purpose of each column is described here.

1.1 Columns A,B and C

These columns contain the descriptive information and data that guide the user or other technical person through the calculations. Using more than one column here allows the descriptions and comments to be divided into headings and sub-categories. Indented descriptions are usually dependant on items which they follow. The comments are detailed enough to describe the source and purpose of the numerical value that follows.

1.2 Column D

This column contains the "Range Name" for the cell immediately to the right. Using range names that are anagrams makes it easier to write and check the subsequent equations that use the value. Standardization of Range Names e.g. all angles might have names beginning with the letter A, mimics typical algebraic notation makes reading an equation without constantly referring back to the cell address possible. Range names can be mistaken for cell addresses if there is a such an cell. For example, while it is possible to name a range AB25, if this is entered in an equation or formula, the spreadsheet will use the value located in cell address AB25. To avoid this possibility range names should contain at least three alphabetic characters before a numeric character.

1.3 Column E

Most numeric values whether input or calculated are located in a single column. The equations can more easily be seen as the spreadsheet is examined by moving down the single column. Range names can be assigned quickly by using the { / Range Name Label Right } command. There are exceptions to this when using Data Tables.

1.4 Column F

This column contains the units of the numeric values.

1.5 Column G

This column helps identify the source or purpose of the numeric values. Some examples of these might be: input, field dimension, constant etc. In this example the notation "input" is used to inform other users of the spreadsheet that only those values should be modified; by implication all other values are derived.

Columns

A | B | C	D	E	F	G
Parameters of the Forcing Function:				
Force amplitude	FOOH	1	F	
Forcing Frequency	WWW	1	R/T	input
Parameters of the supporting structure:				
Mass	MMM1	1000	M	input
Spring constant	KKK1	1000	F/L	input
Percentage of damping	ZETA1	1.0%		input
Resultant calculated values:				
Critical damping	CRIT1	2000		
Actual damping	CCC1	20		
Natural Frequency	WWWN1	1	R/T	
Desired mass ratio of MASS 1 / MASS 2	MRAT1:2	10		input
Resultant Required value of Mass 2	MMM2	100	M	
Desired Ratio of Natural Freq. 2:1	WRAT2:1	1		input
Resultant Nat. Frequency of Mass 2	WWN2	1.0000	R/T	
and Spring Constant of Mass 2	KKK2	100	F/L	
Percentage of damping for mass 2	ZETA2	1.0%		input
Resultant calculated values:				
Critical damping	CRIT2	200		
Actual damping	CCC2	2		
Desired mass ratio of MASS 2 / MASS 3	MRAT2:3	10		input
Resultant Required value of Mass 3	MMM3	10	M	
Desired Ratio of Natural Freq. 3:1	WRAT3:1	0.83		input
Resultant Nat. Frequency of Mass 3	WWWN3	0.8300	R/T	
and Spring Constant of Mass 3	KKK3	6.8890	F/L	
Percentage of damping for mass 3	ZETA3	30.0%		input
Resultant calculated values:				
Critical damping	CRIT3	16.600		
Actual damping	CCC3	4.980		
Natural Frequency values for combined Masses				
Masses 1 and 2 held together	WWWN12	0.9535	R/T	
Masses 2 and 3 held together	WWWN23	0.9535	R/T	
Masses 1 , 2 and 3 held together	WWWN123	0.9492	R/T	
A | B | C	D	E	F	G

Figure C.1: Typical Calculation Sheet

2 Spreadsheet Subsections

In large spreadsheets, especially involving macros, the width of columns that suits a calculation spreadsheet described above would not suit a data table or a macro. To accommodate this a method of staggering different sheets in the same spreadsheet is used. Setting the sheets in different columns allows the widths to be adjusted to suit. Setting the sheets in different rows allows the use of the convenient row insert and delete commands without concerns about altering other sheets not visible on the screen. A schematic of this is given in Figure C.2.

Typically each sheet is set up to the width of the screen but there are exceptions. Sheet 2 in Figure C.2 overlaps the columns of the sheets below. This format is used in several of the programs presented in this thesis. Except for the first couple of columns , the information contained in this sheet is imported as required during execution of the macro. The accidental deletion of a column during modification of the program is of no concern. This sheet can be quite wide and is therefore set up and to the left of the complete spreadsheet. The overall size of the spreadsheet is determined by the intersection of the furthest column to the right with the lowest row. Setting some of these columns above other columns reduces the extent of the spreadsheet which reduces calculation, retrieval and storage time. Sheet 5 in this example contains a large data table with too many columns to be displayed on a regular screen.

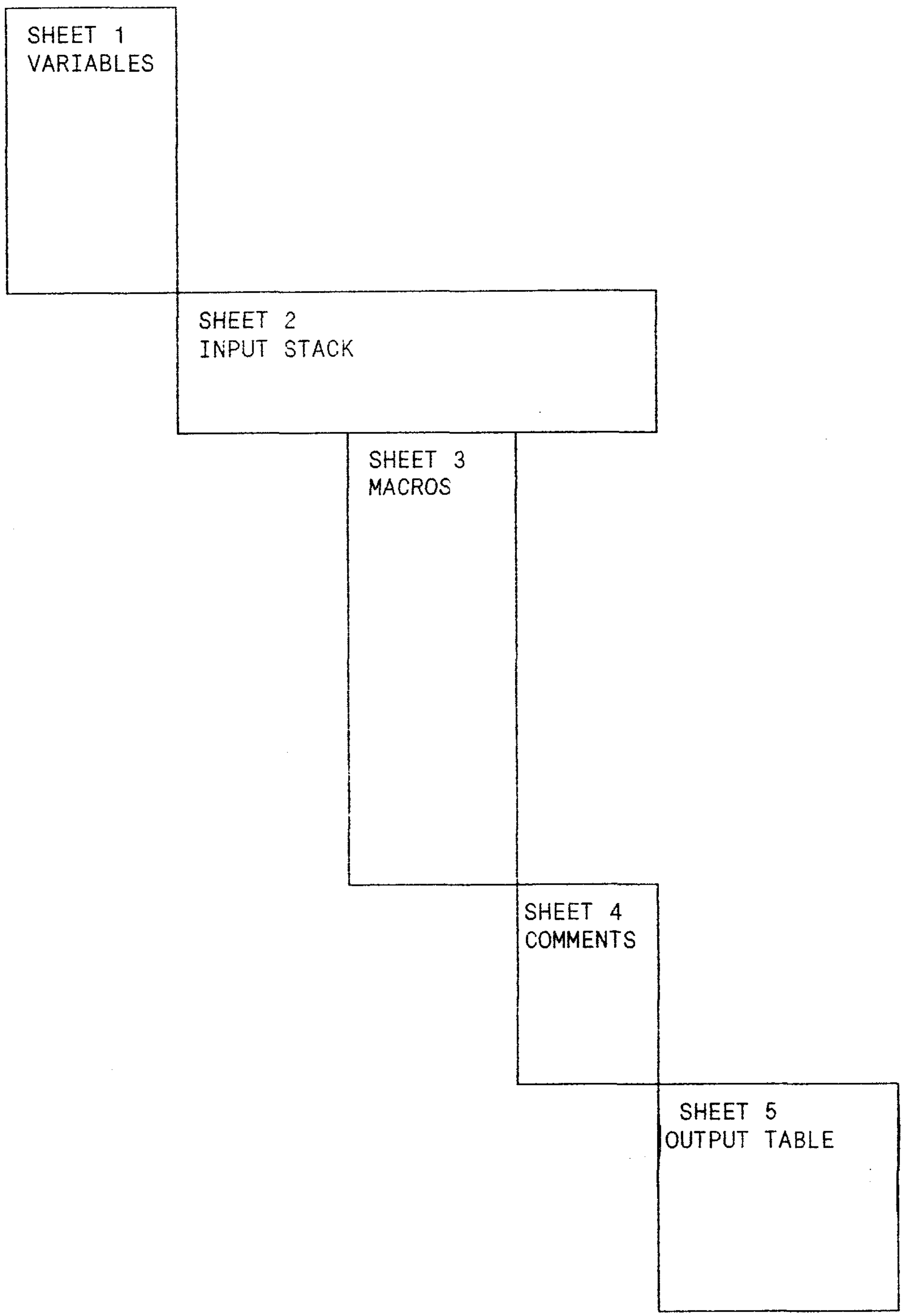


Figure C.2: Staggered Spreadsheet Format

3 Understanding Macros

This thesis presents a number of programs specially written for vibration analysis and others to facilitate typical spreadsheet usage. Although a knowledge of spreadsheets is required, the basic operations are generally menu driven and user friendly. It is not necessary to understand in detail how they are designed. The purpose of this section is to explain enough about macros so that an average spreadsheet user can read the macros presented herein and follow what they are doing. With experience, a macro is as easy to read as a flowsheet.

Macros are used to automate the operation of a spreadsheet. They can execute almost any instruction that the user would do by hand. They consist of a sequence of keystrokes, duplicating what the user would type in on the keyboard, entered into cells as labels and given a special range name.

3.1 Naming & Invoking a Macro

A macro is named by giving the first cell a range name beginning with a back slash and then a single alpha character e.g. \F. The macro is invoke by holding down the Alt key and typing in F ({alt}F). Upon typing in this command the spreadsheet starts executing the keystrokes in that cell.

3.2 Developing a Sample Macro

To insert three rows at above cell address A25 a user moves to cell A25 and hit the slash symbol [/] to display the following menu:

Worksheet Range Copy Move File Print Graph Data System Quit

The command for inserting rows is a **Worksheet** command so the user would hit "W" to select this option. The following menu is then displayed:

Global Insert Delete Column Erase Titles Window Status Page

To select **Insert**, the user types in "I". The user is then asked if either a row or a column is to be displayed by the menu:

Column Row

Typing in "R" selects **Row** and the panel displays:

Enter row insert range: A25..A25

To insert three rows the user moves the cursor down twice so that three rows are highlighted i.e. A25..A27. The user then presses ENTER and three rows are inserted above what used to be cell A25 but is now cell A28. The macro to preform this function would be:

{goto}A25~/wir{down 2}~

It can be seen that the macro basically consists of each keystroke that the user would have made. Some clarifying comments are:

i. All of the keyboard commands such as {home}, {delete}, {up} etc. are typed into the macro in the manner shown in this sentence. The macro treats it as if that key had been struck.

ii. ENTER is indicated by ~.

iii. To indicate multiple pressing of any keyboard commands a space then the number of repeats is included inside the brackets e.g. {right}{right} can be written as {right 2}.

A macro, once invoked, continues until there are no more keystrokes in the cell or the cell immediately below it. This macro could be written as:

```
{goto}A
25
~
'/w
ir{dow
n 2}~
```

and it would still preform the same function. Normally in the programs presented in this thesis the macro is broken up into lines which represent separate actions. In this case:

```
{goto}A25~
/wir{down 2}~
```

The macro has to be invoked with the proper style of range name. In this thesis the name is usually noted in the cell to the left of the first line:

```
\F    {goto}A25~
      /wir{down 2}~
```

Macros are labels, not equations and are not updated if there are changes in the spreadsheet. Therefore, the macro should not refer to cell A25 as has been done here. For example, once the three lines have been inserted the information previously contained in cell A25 would now be in cell A28. Cell A25 must be given a range name, say TARGET. The macro would read:

```
\F    {goto}TARGET~
      /wir{down 2}~
```

After the macro is executed, the cell with the range name target would have the address A28. Invoking the macro again would put three lines from A28 to A30.

3.3 Upper / Lower Case

The macro does not distinguish between upper or lower case characters. The procedure that has been followed in these programs is that any standard LOTUS spreadsheet command or routine has been entered in lower case. Any user defined range names or subroutines have been entered in upper case.

3.4 User Defined Subroutines

Normally a macro reads keystrokes sequentially down a column of entries. The user can define a subroutine which is identified by being contained within the bracket style { }. As always, the name can not be one representing a standard spreadsheet key word or function. Upon encountering this range name, the macro moves to the cell with that range name and continues executing keystrokes. Upon reaching the end of that column of instructions (or encountering the spreadsheet key word {return}) the macro returns to the position immediately after where the subroutine was invoked and continues. Subroutines can call subroutines.

3.5 Advanced Macro Commands

There are many commands available for use only in macros. Some of these emulate standard spreadsheet commands, e.g. {if ARGUMENT}, while others request use input to continue with the macro e.g. {getlabel PROMPT STRING, LOCATION}. Many will look familiar to a programmer experienced with other computer languages. A description of each command and it's use is beyond the scope of this thesis. The macros has been written with numerous comment statements which should make the operation clear. The reader is referred to the LOTUS reference manual for detailed descriptions.

4 Macros Spreadsheets

Figures C.3 and C.4 contain a printout of portions of a macro developed in this thesis. The commands in this example are only a portion of the macro described in Appendix A. They have been grouped to display certain characteristics of the macro design. The notation used in these programs is that any user defined routines and range names are given in upper case. All standard LOTUS commands are given in lower case. The columns have been identified with alphabetic characters and are described here.

4.1 Column A

The "Range Names" for any cells located in the column to the right are located here. This facilitates creating the range names and following through the macro operation. Macros must use range names rather than cell addresses because unlike equations contained within cells, macros are not updated when referenced cells are moved. Some range names, extending over more than one cell are given in other columns.

4.2 Column B (can overlap columns to the right)

This contains the macro commands. Macros continue executing as long as there are commands in the cell they are presently in or the cell immediately below it. If they encounter an empty cell execution is stopped and control is returned to the keyboard. Macro execution can be moved to another column of cells by the use of branching or menu commands. Generally, the purpose of a particular column of commands is described by a line above it and separated from it by a line (======).

4.3 Columns C

This column will contain portions of user defined menus. If required the menu would extend into the columns to the right. User defined menus are normally grouped on a separate sheet but the function of some are more easily understood if they are contained in the main body of the macro. They are usually either/or selections and can extend into this column.

4.4 Columns D, E, F, G & H

These columns can contain various items.

4.4.1 User defined macros can extend into these columns.

4.4.2 Descriptive comments about operating sequences in the macro line to their left. A comment pertaining to several lines is noted by using arrows (<). Some lines of the macro actually contain formulas which are only displayed if the cursor is at the cell. The formulas are typed in as comments.

4.4.3 Some range names refer to a column of values and there may be overlapping of names. These are noted in these columns and their extent given by arrows (<).

```
Columns
 A       | B       | C       | D       | E       | F        | G          | H          |

Subroutine: Record values at impact. Check chatter & steady state
=====================================================================
IMPACT   {panelon}{indicate BANG}{paneloff}{beep}
         /rvYES~FLAG1~      < set flag indicating there was an impact
         {RECORD}           <subroutine
         {SWAP}             <subroutine
         /rvVVR3~VVV3~      < There is an energy transfer between
         /rvVVR4~VVV4~        masses 3 and 4 which change velocity
         {RECORD}           <subroutine
         {CHATTER}          <subroutine
         {STEADY}           <subroutine
         {if TERMNATE=YES}{return}  < end if chatter or steady state
         /rvNORMSTEP~HHH~
         {panelon}{indicate FREE}{paneloff}

FLAG1    no                 < flag to tell that impact has been sensed


Subroutine: Checks if impact damper velocity settled to within range.
=====================================================================
STEADY   {if REG24=0}{branch STEP5}
         {if @std(REGS9)/@avg(REGS9)<RANGE}{branch STEP11}
STEP5    /rvREGS7~REGS8~              < The moving average of the
                                        impact damper velocities is
                                        incremented.
STEP11   /rvYES~TERMNATE~
         /rvRESULT4~RESULT~

REG24                       < REGS8  < REGS9
                  < REGS7   <        <
                  <         <        <
                0 <                  <        < @abs(VVV4)

 A       | B       | C       | D       | E       | F        | G          | H          |
```

Figure C.3: Macro Extracts

5 Moving About The Spreadsheet

A difficulty with the staggered spreadsheet format described in Section 2.0 can be that finding data is onerous if only the "page" or "tab" commands are utilized. One of the standard macro commands creates a user defined menu which can be used to move about the spreadsheet. Figures C.5 (a) and C.5 (b) contain typical user defined menus used in one of the programs described in this thesis. Figure C.5 (a) contains the menus as they would be viewed on the screen. Because the contents of one cell overlap the next cell to the right those contents are obscured and can only be read by moving the cursor to that cell. In Figure C.5 (b), the same menus have been stretched so that all the contents are visible. The menus have been linked with lines to show the flow path.

A menu is created by listing the options the user wants to select from side by side in cells in a row (Line 2). The left cell is given a range name (MENU2) which in this example is displayed in the cell immediately to it's left. When executing a macro, upon encountering a menu command (Line 1) the macro displays the appropriate menu which is displayed in the panel just as a normal spreadsheet command. Immediately below each selection is a description (Line 3) which is displayed if that option is highlighted. Selecting an option causes macro execution to continue at the line below the description (Line 4). In these menus, that command is either a {goto} command which moves the cursor to a range located at the tope left of the sheet selected or another {menubranch} command. Some of the individual sheets are long enough that it is useful to have range names for areas along their length. In this example the MENU3 is for moving about the macro and the range names are of various subroutines.

In all cases after moving the cursor to the selected position the macro displays the operating menu (MENU1). If the user wants to make revisions or move around within a particular sheet he selects to quit the macro.

```
        {menubranch MENU2}                                      (1)

Menu for moving about the spreadsheet
=========================================
MENU2   MACROS   COMMENTS STACK                                 (2)
        Go to theGo to theGo to the input stack                 (3)
        {menubran{goto}MES{goto}STACK~                          (4)
        {menubran{menubranch MENU1}

Menu for moving about the spreadsheet
=========================================
MENU3   MENUS    COMPILE  EVEREST  RECORD   IMPORT
        Go to theGo to theGo to the input stack
        {goto}\0~{goto}COM{goto}EVE{goto}REC{goto}TOPRANGE~{left}{up 2}

        {menubran{left}{up{menubran{menubran{menubranch MENU1}
        {menubranch MENU1}
```

Figure C.5 (a): As Displayed User Defined Menu

```
        {menubranch MENU2}                                      (1)

Menu for moving about the spreadsheet
=========================================
MENU2 ─┬── MACROS                                               (2)
       │   Go to the macro section                              (3)
       │   {menubranch MENU3}                                   (4)
       │
       ├── COMMENTS                                             (2)
       │   Go to the message section                            (3)
       │   {goto}MESSAGE~                                       (4)
       │   {menubranch MENU1}
       │
       └── STACK                                                (2)
           Go to the input stack                                (3)
           {goto}STACK~                                         (4)
           {menubranch MENU1}

Menu for moving about the spreadsheet
=========================================
MENU3 ─┬── MENUS
       │   Go to the menu macros
       │   {goto}\0~{left}
       │   {menubranch MENU1}
       │
       ├── COMPILE
       │   Go to the top of the main macro
       │   {goto}COMPILE~
       │   {left}{up 3}
       │   {menubranch MENU1}
       │
       ├── EVEREST
       │   Go to the input stack
       │   {goto}EVEREST~{left}
       │   {menubranch MENU1
       │
       └── RECORD
           Go to the section to record peaks
           {goto}RECORD {left}
           {menubranch MENU1}
```

Figure C.5 (b): Expanded User Defined Menu

APPENDIX D

Solution to the Three Degree-of-Freedom System Equations

A schematic of the system and the free body diagrams are given in Figure D.1. Gathering the terms from the free body diagrams gives the following equations.

$$m_1 \frac{d^2x_1}{dt^2} + (c_1+c_2) \frac{dx_1}{dt} + (k_1+k_2)x_1 - c_2 \frac{dx_2}{dt} - k_2x_2 = F_0 \sin Wt$$

$$m_2 \frac{d^2x_2}{dt^2} + (c_3+c_2) \frac{dx_2}{dt} + (k_3+k_2)x_2 - c_3 \frac{dx_3}{dt} - k_3x_3 - c2 \frac{dx_1}{dt} - k_2x_1 = 0$$

$$m_3 \frac{d^2x_3}{dt^2} + c_3 \frac{dx_3}{dt} + k_3x_3 - k_3x_2 - c_3 \frac{dx_2}{dt} = 0$$

The expected solution in the steady state can be obtained by assuming that,

$$x_i(t) = \bar{x}_i \sin Wt \qquad i = 1,2,3$$

After substituting the assumed form of the solution for the three system coordinates into the equations of motion, the amplitude and the corresponding phase angle may be obtained as,

Maximum Displacement $X_1 = ((A*E+B*F)^2+(B*E-A*F)^2)^{1/2}/(E^2+F^2)$

$X_2 = ((G*E+H*F)^2+(H*E-G*F)^2)^{1/2}/(E^2+F^2)$

$X_3 = ((J*E+L*F)^2+(L*E-J*F)^2)^{1/2}/(E^2+F^2)$

Phase Angle $phi_1 =$ TAN(H,G)/TAN(B,A)

$phi_2 =$ TAN(L,J)/TAN(B,A)

$phi_3 =$ TAN(F,E)/TAN(B,A)

Where:

$$A = [(m_2*m_3*W^4)-(W^2*k_3*m_2)-(c_3*(c_3+c_2)*W^2)$$
$$-((k_3+k_2)*m_3*W^2)+(k_3*(k_3+k_2))-k_3^2+(c_3^2*W^2)]*F_0$$

$$B = [-(m_2*c_3*W^3)-((c_3+c_2)*m_3*W^3)+(k_3*(c_3+c_2)*W)$$
$$+((k_3+k_2)*c_3*W)-(2*(k_3*c_3*W))]*F_0$$

$$G = [-(m_3*k_2*W^2)-(c_2*c_3*W^2)+(k_3*k_2)]*F_0$$

$$H = [-(c_2*W^3*m_3)+(k_2*c_3*W)+(k_3*c_2*W)]*F_0$$

$$J = [+(k_2*k_3)-(c_2*c_3*W^2)]*F_0$$

$$L = [+(k_2*c_3*W)+(k_3*c_2*W)]*F_0$$

$$E = -(m_1*m_2*m_3*W^6))+(W^4*m_1*m_3*(k_3+k_2))+(m_3*W^4*(c_1+c_2)*(c_3+c_2))$$
$$+((k_1+k_2)*W^4*m_2*m_3)-((k_1+k_2)*(k_3+k_2)*m_3*W^2)+(W^4*(c_3+c_2)*c_3*m_1)$$
$$+(c_3*(c_1+c_2)*W^4*m_2)-((c_1+c_2)*(k_3+k_2)*W^2*c_3)$$
$$-((k_1+k_2)*(c_3+c_2)*c_3*W^2)+(k_3*W^4*m_1*m_2)$$
$$-(W^2*m_1*(k_3+k_2)*k_3)-((c_1+c_2)*(c_3+c_2)*W^2*k_3)-(k_3*(k_1+k_2)*W^2*m_2)$$
$$+((k_1+k_2)*(k_3+k_2)*k_3)-(m_3*c_2^2*W^4)+(m_3*k_2^2*W^2)$$
$$+(2*(k_2*c_2*c_3*W^2))+(c_2^2*W^2*k_3)-(k_2^2*k_3)+(k_3^2*W^2*m_1)-(c_3^2*W^4*m_1)$$
$$+(2*(k_3*c_3*(c_1+c_2)*W^2))-(k_3^2*(k_1+k_2)))+((k_1+k_2)*c_3^2*W^2)$$

$$F = +(W^5*m_3*m_1*(c_3+c_2))+((c_1+c_2)*W^5*m_2*m_3)-((c_1+c_2)*(k_3+k_2)*W^3*m_3)$$
$$-(k_1+k_2)*(c_3+c_2)*W^3*m_3)+(c_3*W^5*m_1*m_2)-(W^3*m_1*(k_3+k_2)*c_3)$$
$$-((c_1+c_2)*(c_3+c_2)*c_3*W^3)-((k_1+k_2)*c_3*W^3*m_2)+((k_1+k_2)*(k_3+k_2)*c_3*W)$$
$$-(m_1*k_3*W^3*(c_3+c_2))-((c_1+c_2)*W^3*m_2*k_3)+((c_1+c_2)*W*(k_3+k_2)*k_3)$$
$$+(k_3*(k_1+k_2)*(c_3+c_2)*W)+(2*(m_3*c_2*k_2*W^3))+(c_2^2*c_3*W^3)-(k_2^2*c_3*W)$$
$$-(2*(c_2*k_2*k_3*W))+(2*(W^3*k_3*c_3*m_1))-(k_3^2*(c_1+c_2)*W)$$
$$+(c_3^2*W^3*(c_1+c_2))-2*((k_1+k_2)*k_3*c_3*W))$$

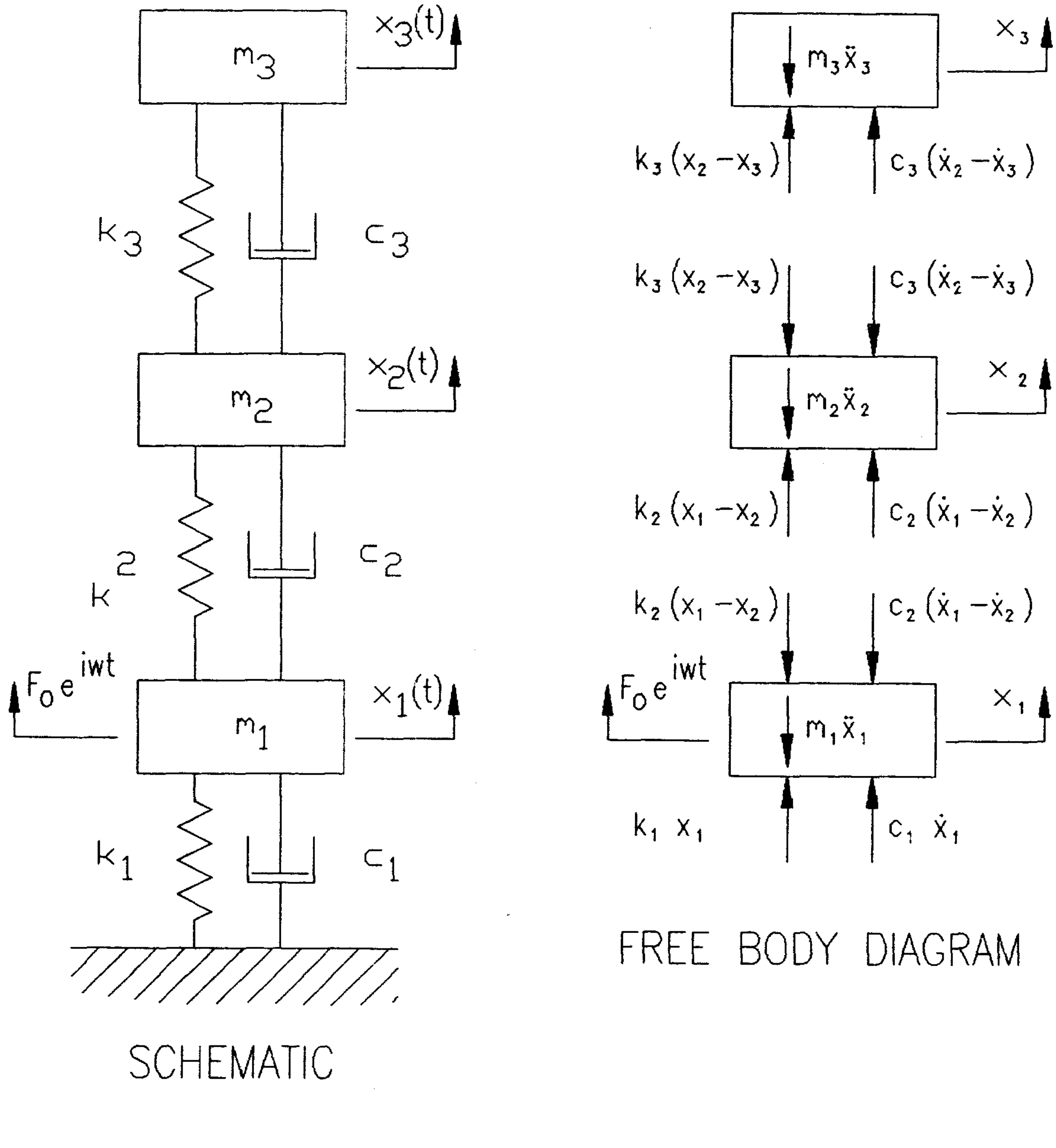
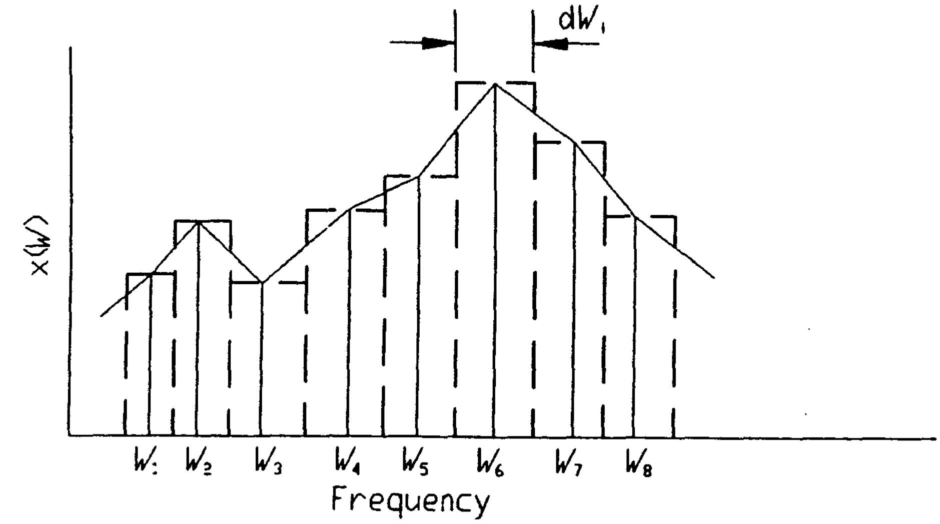


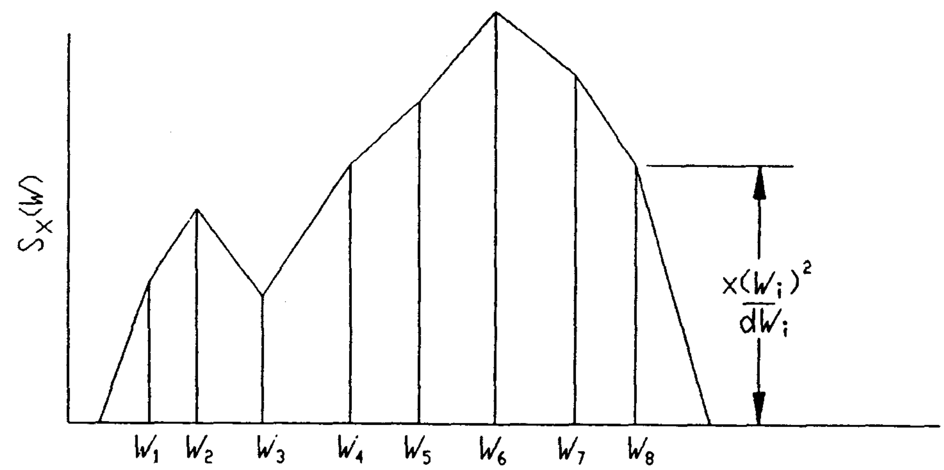
FIGURE D.1: Schematic of the Three Degree-of-Freedom and associated Free Body Diagrams

APPENDIX E

Determination of RMS Amplitude Equations



For a precise value, dW is usually a constant, small value.
For an approximate value dW can vary as represented above.



Mean Square Density (Power Spectral Density)

To determine area under the $S_X(W)$ curve from 0 to infinity,

$$\text{SIGMA} = \sigma_X^2 = \int_0^\infty S_X(W)dW \quad \text{- area under } S_X(W) \text{ curve}$$

If the response over only a portion of the curve is required,

$$\text{SIGMA} = \sigma_X^2 = \sum_{i=1}^{8} S_X(W_i)(W_i - W_{i-1})$$

in either case

σ_X = RMS of x over the specified frequency range.