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**myBWMod**  
**version 1.0**

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# 1. Introduction

## **1.1 Scope**

This document describes in brief the usage of myBWMod version 1.0. The Bouc-Wen model is described in chapter 2. Next, the main features of the program are presented.

## **1.2 Program requirements**

The minimum requirements are:

- Operating System: Microsoft® Windows /NT/2000/XP/Vista
- Visual Basic 6 Service Pack 5 runtime libraries.

## **1.3 Abbreviations**

SDOF:            Single Degree of Freedom

ODE:            Ordinary Differential Equation

## **1.4 About myBWMod (my Bouc-Wen Modification) version 1.0**

This program implements the modification of the well-known Bouc-Wen model which was presented recently [1]. The program was developed and used for research purposes.

Some important notes:

- The software is provided "as is". Make sure to read the terms of usage in the about form.
- At this moment, this manual provides only a small number of guidelines on how to use the software. Future releases of this manual will include the description of more program features.
- The program has *not* been designed to provide the fastest execution possible. A number of system parameters have been set in such a way so

as to facilitate debugging, although they may entail a significant overhead.

- If you are interested in this work or require further information, do not hesitate to contact professor V.K. Koumouis ([vkoum@central.ntua.gr](mailto:vkoum@central.ntua.gr)) or A.E. Charalampakis ([achar@mail.ntua.gr](mailto:achar@mail.ntua.gr))

## 2. Bouc Wen Model

### 2.1 General

The Bouc – Wen model is a smooth hysteretic model which is very popular because of its versatility and simplicity. It was first introduced by Bouc in 1967 [2]. In 1976, Wen [3] extended the model and demonstrated its versatility by producing a variety of hysteretic patterns.

### 2.2 Formulation

According to Bouc-Wen model, the restoring force of a SDOF system can be written as:

$$F(t) = a \cdot \frac{F_y}{u_y} \cdot u(t) + (1-a) \cdot F_y \cdot z(t) \quad (7.2.1)$$

where,  $F_y$  is the yield force,  $u_y$  is the yield displacement,  $a$  is the ratio of post-yield to pre-yield (elastic) stiffness and  $z(t)$  is a dimensionless hysteretic parameter obeying a single differential equation with zero initial condition:

$$\dot{z}(t) = \frac{1}{u_y} \left[ A - |z(t)|^n \cdot (\gamma \cdot \text{sign}(\dot{u}(t)) \cdot z(t) + \beta) \right] \cdot \dot{u}(t) \quad (7.2.2)$$

where,  $A, \beta, \gamma, n$  are dimensionless quantities controlling the shape of the hysteresis loop.

The equation of motion for a SDOF system with linear viscous damping  $c$  is given as:

$$m \cdot \ddot{u}(t) + c \cdot \dot{u}(t) + F(t) = f(t) \quad (7.2.3)$$

where,  $u(t)$  is the displacement,  $F(t)$  is the restoring force,  $f(t)$  is the excitation force. Substituting (7.2.1) into (7.2.3) we obtain:

$$m \cdot \ddot{u}(t) + c \cdot \dot{u}(t) + a \cdot \frac{F_y}{u_y} \cdot u(t) + (1-a) \cdot F_y \cdot z(t) = f(t) \quad (7.2.4)$$

Equations (7.2.2) and (7.2.4) are transformed into a state-space form as follows:

$$\begin{cases} x_1(t) = u(t) \\ x_2(t) = \dot{u}(t) \\ x_3(t) = z(t) \end{cases} \quad (7.2.5)$$

$$\begin{cases} \dot{x}_1(t) \\ \dot{x}_2(t) \\ \dot{x}_3(t) \end{cases} = \begin{cases} x_2(t) \\ -\frac{1}{m} \cdot \left[ c \cdot x_2(t) + a \cdot \frac{F_y}{u_y} \cdot x_1(t) + (1-a) \cdot F_y \cdot x_3(t) - f(t) \right] \\ \frac{1}{u_y} \cdot \left[ \left( A - |x_3(t)|^n \cdot \left( \gamma \cdot \text{sign}(x_2(t) \cdot x_3(t)) + \beta \right) \right) \cdot x_2(t) \right] \end{cases} \quad (7.2.6)$$

The above system of three first order non-linear ODEs is solved numerically following Runge-Kutta 4<sup>th</sup> – 5<sup>th</sup> order or Livermore stiff ODE integrator which is based on a “predictor-corrector” scheme [4].

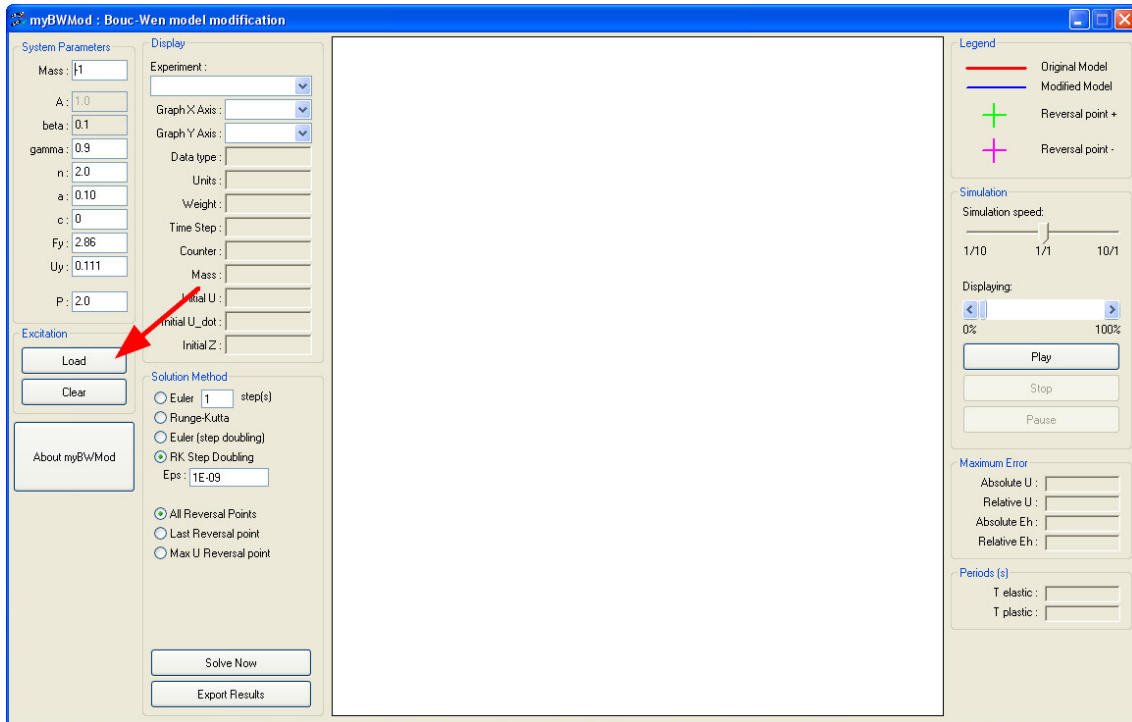
### **2.3 Parameter Constraints**

A number of parameter constraints are necessary. In particular,  $A=1$  and  $\beta + \gamma = 1$  should be imposed for reasons of mathematical and physical consistency of the model [1]. By default, these constraints are active in the program.

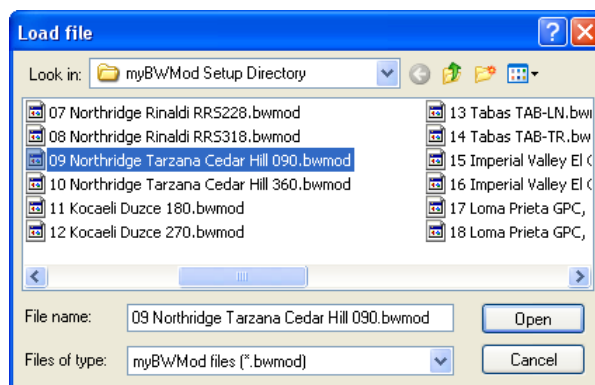
## 3. myBWMod

### 3.2 Excitation

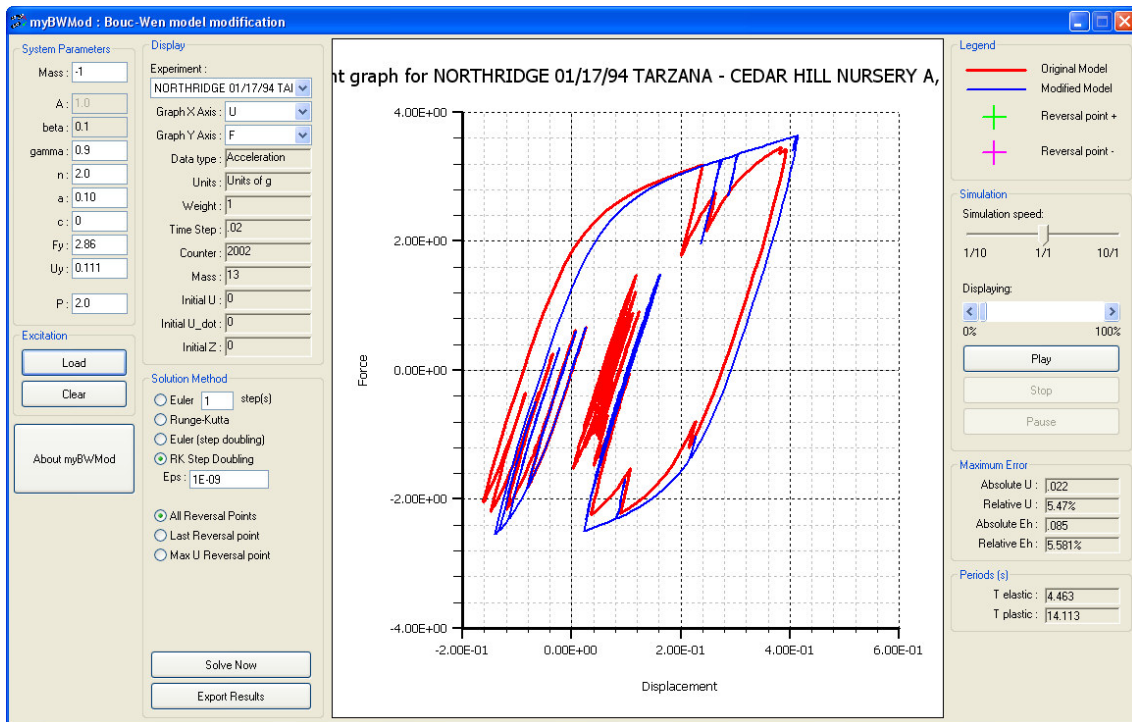
The first step is to load the excitation. Click the "Load" button on the left:



Select the "09 Northridge Tarzana Cedar Hill 090.bwmod" file from the main directory of the program:



As soon as you load the file, the program will evaluate the response of the model. Consistent unit system is used.



The model parameters are provided by the frame entitled "System parameters" on the left. Parameter  $A$  is set to unity while the equality  $\beta + \gamma = 1$  is enforced at all times.

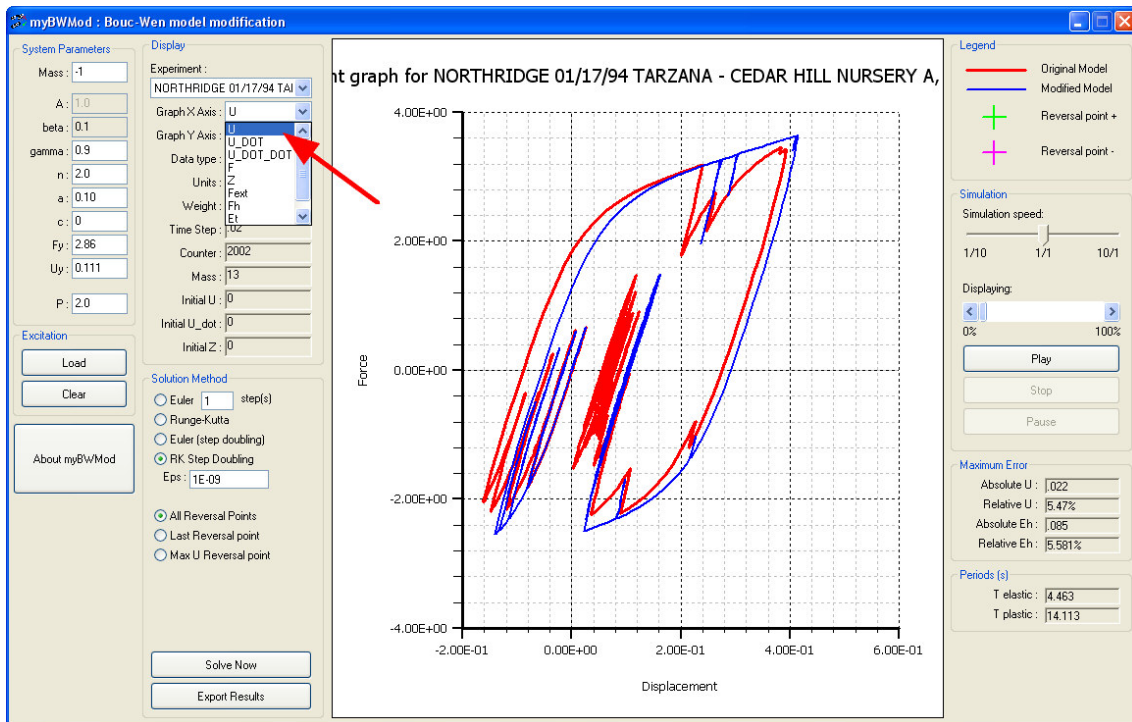
A negative mass parameter indicates that the mass specified within the data file should be used (in this case, mass is equal to 13, as indicated in the "Display" frame). Specify a positive value for mass in the "System Parameters" frame to override this value.

### 3.3 Graph

The program automatically draws the response of both the original and modified model. The response of the original model is drawn using a red line. The response of the modified model is drawn using a blue line. In certain cases, the active reversal points may appear as crosses during the simulation.

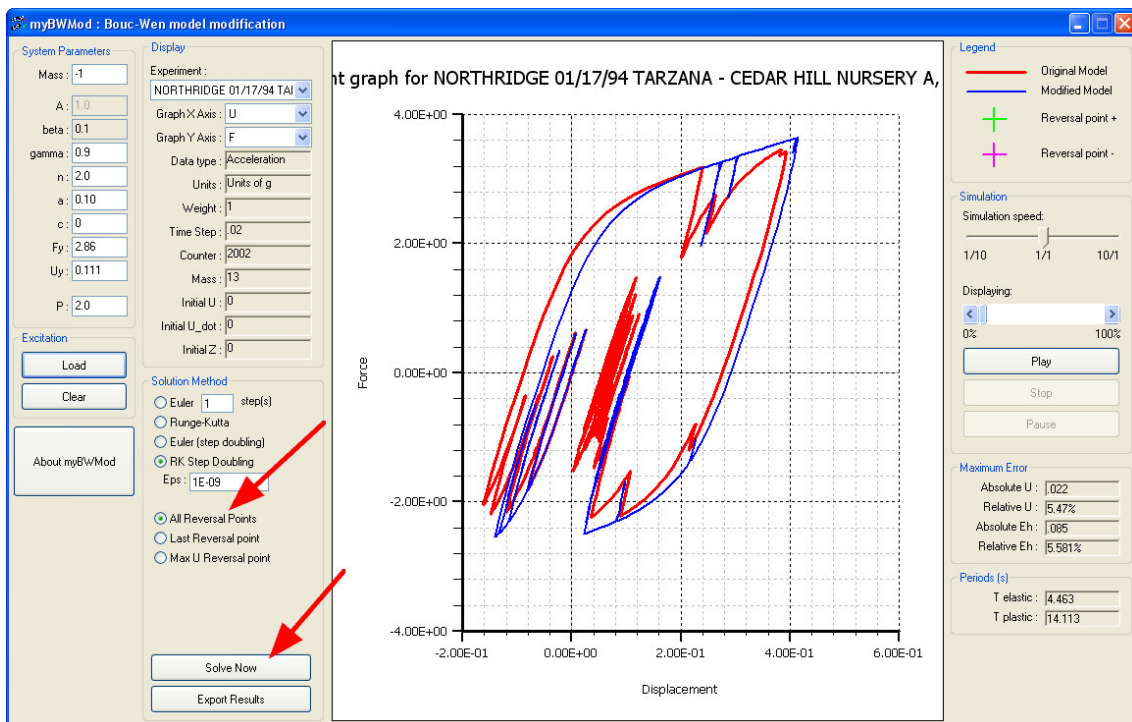
You can select the quantity that corresponds to the X and Y axes by using the drop-down lists in the "Display" frame:





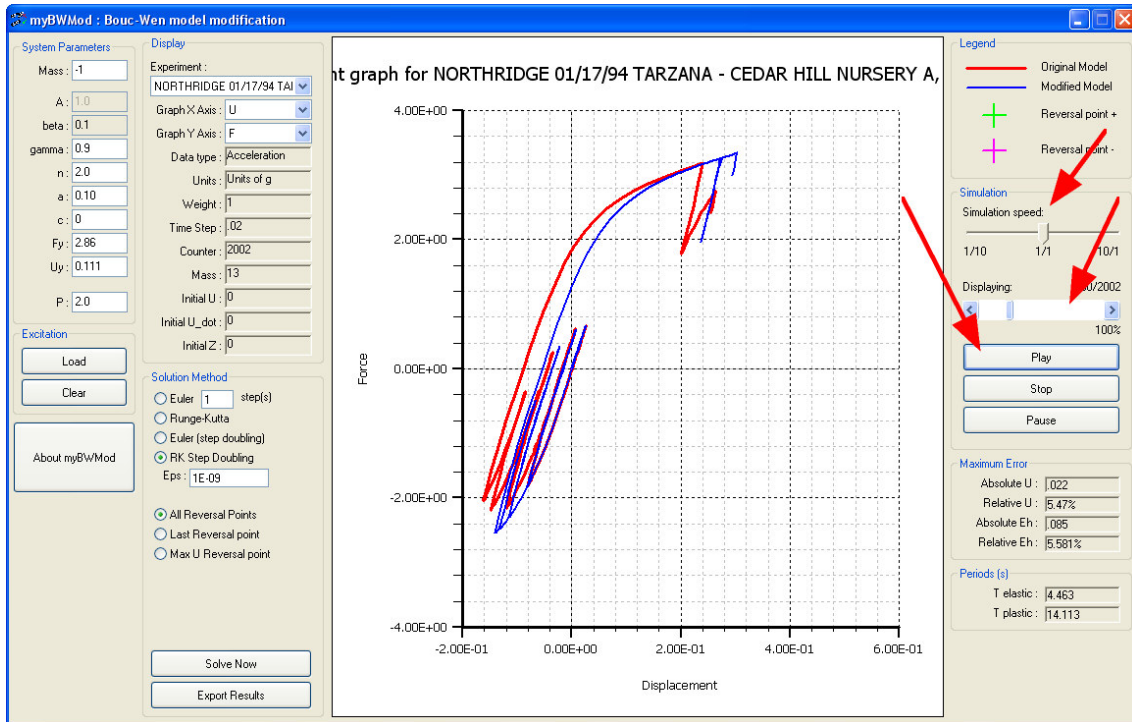
### 3.4 Selection of reversal points

In order for the modified model to be effective, appropriate reversal points must be employed [1]. Select the appropriate method using the respective option button. Note that "All Reversal Points" (meaning all *active* reversal points [1]) is the recommended option. Next, hit the "Solve Now" button:



### 3.5 Simulation

To view the simulated response of both the original and modified model, hit the "Play" button in the "Simulation" frame. You can control the progress and speed of the simulation by using the appropriate controls, as indicated in the screenshot:



## References

- [1] Charalampakis, A. E., Koumousis, V. K., "A Bouc-Wen model compatible with plasticity postulates", *Journal of Sound and Vibration*, 322:954-968 [doi:10.1016/j.jsv.2008.11.017](https://doi.org/10.1016/j.jsv.2008.11.017).
- [2] R. Bouc. "Forced vibration of mechanical systems with hysteresis", *Proceedings of the Fourth Conference on Non-linear oscillation*, Prague, Czechoslovakia (1967).
- [3] Y. K. Wen. "Method for random vibration of hysteretic systems", *J. Eng. Mech. ASCE* **102**, 249-263 (1976).
- [4] Alan C. Hindmarsh Scientific Computing. "ODEpack, a Systemized Collection of ODE solvers", R. S. Stepleman et al. (eds.) North-Holland, Amsterdam, 1983.