One-dimensional Finite Penetration Model

User's Guide

1. Introduction

The one-dimensional finite penetration model (FEM 18) is a projectile penetration calculation model designed with the "axial differential - radial analytical" concept, mainly focusing on the macroscopic structural response of the projectile during penetration.

The model has such characteristics:

a) Based on dynamic cavity expansion model and Poncelet formula, the target's condition is simplified into drag fields.
b) The force calculation is achieved with finite element along the rotational axis of the projectile. Each finite element is a ring with certain radius, and the force/moment applied on it can be analytically calculated, no matter how the scenario varies. The total force/moment then can be calculated by summarization, which is both efficient and effective compared to Warren's 2-dimensional surface differentiation method. The computational complexity of rigid dynamics increases linearly with the number of axial element division.
c) When projectile penetrates single/multiple targets normally, the rigid kinematics/dynamics is solvable, projectile's deformation considering targets' coupling effect (or not) are also solvable.
d) When projectile penetrates single/multiple targets obliquely, the rigid kinematics/dynamics is solvable, projectile's deformation without targets' coupling effect are also solvable.
e) The material of projectile can be rigid, elastic, elastic-plastic with linear hardening, and Bauschinger's effect can be introduced.
f) The buckling criterion can be assumed, and the preferred buckling type (beam-like or shell-like) can be estimated.
g) Multiple minor models can be introduced, and their parameters can be adjusted to refine the calculation and demonstration.
h) Calculation with multiple conditions and parallel calculation are both supported to boost the calculation efficiency and facilitate the research.

The model has the following applicable scope:

a) The geometric shape of the projectile is a rotating axis-symmetric body, with a monotonically continuous contour line.
b) The projectile moves within one flat surface without any three-dimensional

trajectory.

c) The targets’ material is considered continuous and there are no mutations present.

d) The projectile exhibits rigid, elastic, or elastoplastic mechanical behavior during penetration.

e) The model does not consider plasticity and the projectile-target coupling effect during oblique penetration.

How to use the model:

Method 1:

a) **main.m**: adjust and run；

b) After running, the program will automatically save the settings file (xx_info.mat) and calculation results (xx_result.mat) to the project directory folder.

Method 2 (previous setting file required):

a) **main_translation.m**: run, select the setting file to be interpreted. Then the setting file is translated into main_preparation.m.

b) **main_preparation.m**: adjust and run.

c) After running, the program will automatically save the settings file (xx_info.mat) to the project directory folder.

d) **main_execution.m**: run, select the setting file to be executed.

e) After running, the program will automatically save the results file (xx_result.mat) to the project directory folder.

2. Parameter Interpretation

All user-input parameter is stored in a structure variable maned ‘info’, which contains such twig structure: info.project_name, info.config, info.simulation, info.plot. Note that info.project_name is the project affix, info.config contains initial settings of targets and projectile, info.simulation contains calculation setting, info.plot contains post-processing settings.

2.1 info.project_name

Project affix, string.

2.2 info.config

2.2.1 info.config.medium.Wall_loc

The coordinates of the leading and trailing edges of the target plate. It can be a scalar or a vector. The default unit is m.

Interpretation: The model is constructed based on the scenario shown in Figure 1. The x-axis from left to right is the direction of penetration depth, and the y-axis from bottom to top is the direction of offset. The targets are placed perpendicular to the x-axis and have infinite length in the y-axis direction.

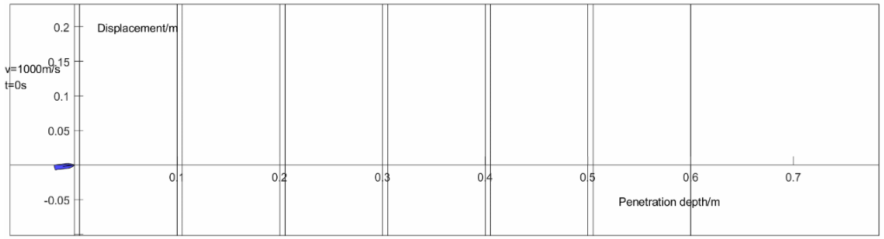

Fig. 1 Config of penetration scenario

If it is a semi-infinite target, then the variable is a scalar, and the value is the x-axis coordinate of the interface.

If it is a single-layer target, the variable is a three-dimensional vector, and the specific format is:

[leading edge's x coordination; trailing edge's x coordination;
retrieving interface's x coordination]

If it is a n-layer targets, the variable is a (2n+1)-dimensional vector, and the specific format is:

[leading edge's x coordination of Target 1; trailing edge's x coordination of Target 1;
…;
leading edge's x coordination of Target n; trailing edge's x coordination of Target n;
retrieving interface's x coordination]

Note that:

a) Strongly recommend adding the retrieving interface x coordinate. Although the research focus may not include the retrieving of the projectile, the presence of the retrieving medium can enable the calculation to end soon, thereby reducing unnecessary calculations.
b) The model does not limit the spatial position order of target plates 1 to n. But for readability, it is recommended that users input the x-axis coordinates of each target from left to right.
c) If there is spatial overlap between the two target boards, the program will not report an error. Suggest users to check the compatibility of the space.

2.2.2 info.config.medium.fai

Friction angle of target material in Mohr Coulomb yield model. The default unit is rad.

Interpretation: This parameter is only required to obtain the recommended values of parameters *A* and *B* for the dynamic cavity expansion model, or to estimate the transient stress acting on any part of the target.

2.2.3 info.config.medium.Y

Uniaxial compressive strength of target material. The default unit is Pa.

Interpretation: This parameter is only required to obtain the recommended values of parameters *A* and *B* for the dynamic cavity expansion model, or to estimate the transient stress acting on any part of the target.

2.2.4 info.config.medium.E

Young's modulus of target material. The default unit is Pa.

Interpretation: This parameter is only required to obtain the recommended values of parameters *A* and *B* for the dynamic cavity expansion model, or to estimate the transient stress acting on any part of the target.

2.2.5 info.config.medium.f

Uniaxial tensile strength of target material. The default unit is Pa.

Interpretation: This parameter is only required to obtain the recommended values of parameters *A* and *B* for the dynamic cavity expansion model, or to estimate the transient stress acting on any part of the target.

2.2.6 info.config.medium.rho0

Static density of target material. The default unit is kg/ m^3.

Interpretation: This parameter is only required to obtain the recommended values of parameters *A* and *B* for the dynamic cavity expansion model, or to estimate the transient stress acting on any part of the target.

2.2.7 info.config.medium.A

Dynamic cavity expansion model's parameter *A*. The default unit is Pa.

Interpretation: The dynamic cavity expansion model considers the stress situation of each contact point: if each contact point is subjected to normal stress σ, then there is

$$\sigma = A + Bu_n^2 \tag{1}$$

Where *A*,*B* are dynamic cavity expansion model's parameter， u_n is the normal expansion velocity. Assume the friction coefficient is μ, there is tangential stress τ:

$$\tau = \mu\left(A + Bu_n^2\right) \tag{2}$$

2.2.8 info.config.medium.B

Dynamic cavity expansion model's parameter *A*. The default unit is kg/ m^3. It's meaning can be seen in (1).

2.2.9 info.config.medium.mu

Dynamic cavity expansion model's parameter μ. Dimensionless. It's meaning can be seen in (2).

2.2.10 info.config.medium.psi

Resistance attenuation angle ψ. Dimensionless. If the angle between the penetration velocity and the local normal direction of the projectile is greater than 90°-ψ, the local force/moment is multiplied by the attenuation coefficient, and the specific function is in interp_theta.m. The introduction of this angle is to improve the computational stability during oblique penetration.

2.2.11 info.config.medium.free_edge

Whether to consider the free-surface effect. Logical.

2.2.12 info.config.projectile.config

The contour lines of a projectile. Matrix. Note that the penetrating projectile is formed by the rotation of a cluster of contour lines.

Interpretation: The contour lines are given in rows from the outside to the inside. For each contour line, its starting point is located at the tip of the projectile, connected to the middle point through a straight line or arc, and its ending point is located on the plane where the projectile tail is located.

Format for straight line: ***[x-displacement; y-displacement; 0]***
Format for arc: ***[x-displacement; y-displacement; curvature radius]***

Curvature radius is generally positive, meaning that the contour line is convex. For the same contour line, all code of straight lines and arcs are written on the same line, and the program will interpret them in a "three count one line" manner. For different contour lines, the length of the final instruction may also vary due to the number of lines and arcs they contain. To save all contour information as a matrix, it is necessary to add 0 after the corresponding row of simpler contour lines to align with the corresponding row of complex contour lines.

```
Example:
[0.01 0.5 0 25.35 7.38 47.25 53.4 0 0 0 0 0 0 0 0 0 0 0;
19.691 0 0 0.56 0.9 1 13.98 3.27 31.5 39.52 0 0 0 1.33 0 5 0
0;
 73.751 0 0 0 5.5 0 5 0 0 0 0 0 0 0 0 0 0 0];
```

Translated as: On the outermost contour line, starting from the tip of the projectile, first move straightly in the x-direction by 0.01 and y-direction by 0.5 to the first midpoint. Furthermore, move with an arc of 47.25 curvature radius in the x-direction by 25.35 and in the y-direction by 7.38 to the second midpoint. Finally, move 53.4 in a straight line with 53.4 in x-direction to the plane where the tail of the projectile is located.

On the middle contour line, starting from the tip of the projectile, first move straightly in the x-direction by 19.691 to the first midpoint. Furthermore, move with an arc of 1 curvature radius in the x-direction by 0.56 and in the y-direction by 0.9 to the second midpoint. Then, move with an arc of 31.5 curvature radius in the x-direction by 13.98 and in the y-direction by 3.27 to the third midpoint. Later, move in a straight line with 39.52 in x-direction to the fourth midpoint. Later, move 1.33 in a straight line in y-direction to the fifth midpoint. Finally, move 5 in a straight line in x-direction to the plane where the tail of the projectile is located.

On the innermost contour line, starting from the tip of the projectile, first move straightly in the x-direction by 73.751 to the first midpoint. Later, move in a straight line with 5.5 in y-direction to the second midpoint. Finally, move 5 in a straight line in x-direction to the plane where the tail of the projectile is located.

The outermost and middle contour lines surround the shell, the middle and innermost contour lines surround the charge, and the innermost contour line and the axis of the projectile surround the tail cover. The number of contour lines strictly corresponds to the number of materials and structures.

2.2.13 info.config.projectile.config_name

Name of projectile's contour lines, string.

2.2.14 info.config.projectile.beta

Projectile's geometric scale, dimensionless scalar.

2.2.15 info.config.projectile.num_mesh

The number of axial elements division for projectiles. Dimensionless integer.

Interpretation: This value affects the overall calculation accuracy. In the calculation of penetrating rigid body dynamics, it linearly affects the overall computational complexity. In structural response calculations, it squarely affects the overall computational complexity.

2.2.16 info.config.projectile.bar

The rod model in the structural response analysis of projectiles. Can be one of `'Constant', 'Variable', 'Love'`, or `'MH'`.

Interpretation: `'Constant'` and `'Variable'` represents the traditional theory of variable cross-section rods, which states that the projectile does not experience radial displacement when subjected to axial force. `'Constant'` method adopts constant bar elements, while `'Variable'` adopts variable ones. `'Love'` represents the Love rod theory, which states that the axial strain of the projectile is proportional to the radial strain when subjected to axial force. `'MH'` represents the Mindlin Herrmann theory, in which the axial strain and radial strain of the projectile under axial force are related by differential equations and mutually influence each other.

2.2.17 info.config.projectile.beam

The beam model in the structural response analysis of projectiles. Can be one of `'Euler'` or `'Timoshenko'`.

Interpretation: `'Euler'` represents traditional beam theory. `'Timoshenko'` represents the Timoshenko beam theory, which considers the effects of shear and moment of inertia more than traditional beam theory.

2.2.18 info.config.projectile.xi

The vibration damping coefficient ξ of the projectile. Dimensionless scalar.

2.2.19 info.config.projectile.plastic

Whether the plasticity of the projectile material considered in structural response calculations. Logical. The constitutive equation under elastic-plastic calculation is linear hardening.

2.2.20 info.config.projectile.consti

The mode of plastic hardening in structural response calculation. Integer 1, 2, 3 or a vector composed of them. The vector length strictly corresponds to the number of materials and structures. For example, if the structures defined by the contour line are the shell, charge, and tail cover, then this term should be a 3x1 vector, where each value represents the plastic hardening relationship of the shell, charge, and tail cover.

`Interpretation:` 1, 2, and 3 respectively represent the kinematic, independent, and isotropic plastic hardening relationships, and the rules defined by the three are shown in Fig. 2. For kinematic, AA '=BB'; For independent, CB''=OA; For isotropic, B'''C=BC.

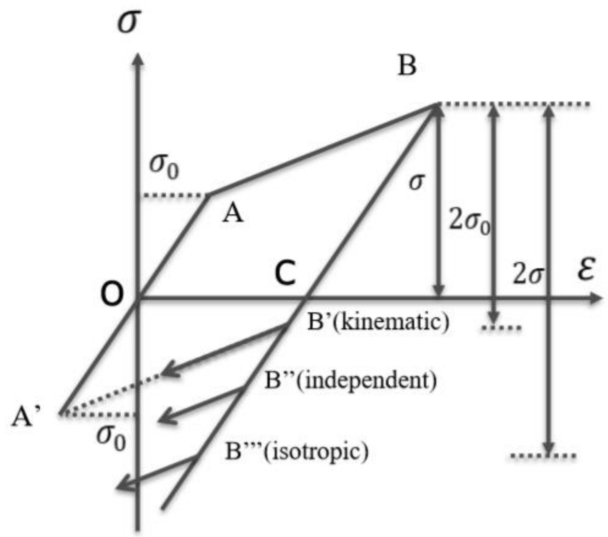

Fig. 2 The mode of plastic hardening

2.2.21 info.config.projectile.rho

The material density of each structure of the projectile. The default unit is kg/m^3. Vector length strictly corresponds to the number of materials and structures.

2.2.22 info.config.projectile.E

The material's Young's modulus of each structure of the projectile. The default unit is Pa. Vector length strictly corresponds to the number of materials and structures.

2.2.23 info.config.projectile.G

The material's shear modulus of each structure of the projectile. The default unit is Pa. Vector length strictly corresponds to the number of materials and structures.

2.2.24 info.config.projectile.Y

The material's yield strength of each structure of the projectile. The default unit is Pa. Vector length strictly corresponds to the number of materials and structures.

2.2.25 info.config.projectile.D

The material's tangent modulus of each structure of the projectile. The default unit is Pa. Vector length strictly corresponds to the number of materials and structures.

2.2.26 info.config.projectile.v0

Initial velocity of projectile's centroid. The default unit is m/s.

2.2.27 info.config.projectile.fai

ϕ , initial angle of fall of the projectile. The default unit is rad.

Interpretation: Angle of fall refers to the angle between the axis of the projectile and the normal direction of the target. The definition of its positive direction is shown in Fig. 3. The definitions of the x-axis and y-axis are the same as those in Fig. 1.

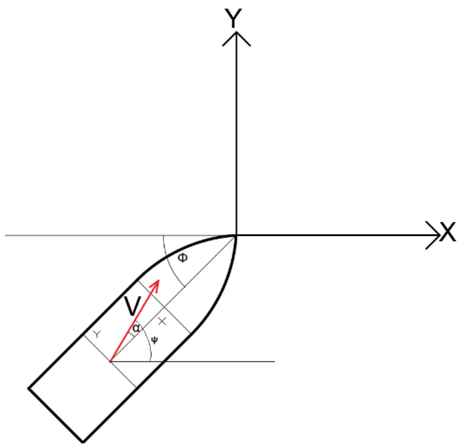

Fig. 3 The definition of penetration's angles

2.2.28 info.config.projectile.alpha

α , initial angle of attack of the projectile. The default unit is rad.

Interpretation: The angle of attack is the angle between the axis of the projectile and the velocity of the projectile's centroid. The definition of its positive direction is shown in Fig. 3. The definitions of the x-axis and y-axis are the same as those in Fig. 1.

2.2.29 info.config.projectile.omega

Initial angular velocity of the projectile. The default unit is rad/s.

2.2.30 info.config.projectile.m0

The total mass of the projectile m_0. The unit is kg. This parameter is generally not included and is automatically calculated by the program. When this setting is included, the total mass of the projectile will be based on the user input value.

2.2.31 info.config.projectile.I0

The total moment of inertia of the projectile I_0. The unit is kg m^2. This parameter is generally not included and is automatically calculated by the program. When this setting is included, the total mass of the projectile will be based on the user input value.

2.3 info.simulation

2.3.1 info.simulation.coupled

Whether to utilize coupling calculation between projectile penetration and structural response. Logical.

Interpretation: Under the coupling calculation, the force on the projectile and the structural response iterates with each other during the penetration process. In non-coupled calculations, the projectile is assumed to be rigid during penetration, and the force-time history is obtained as input for structural response calculations.

2.3.2 info.simulation.parallel

Whether to perform parallel calculations for each condition. Logical.

Interpretation: Parallel computing between different conditions is achievable. However, for a single condition, there is no parallel computing method as the rear state depends on the front state.

2.3.3 info.simulation.dt_default

The default time step of the solver. The default unit is s.

Interpretation: To ensure efficient and stable calculation of structural response, the step size during penetration remains unchanged.

2.3.4 info.simulation.t_max

The longest duration of simulation. The default unit is s. If this time is exceeded, the simulation stops.

Interpretation: In deep penetration calculations, the program obtains the estimated penetration duration based on empirical formulas and compares with it to obtain the smaller value.

2.3.5 info.simulation.vmin

The minimum velocity of the projectile's center of mass. The default unit is m/s. If the speed is lower than this, the simulation stops.

2.4 info.plot

2.4.1 info.plot.frame_option

Frame selection criteria. Can be 'Time' or 'Data'.

Interpretation: If it is' Time ', it specifies that the simulation time gap between two frames of animation is the same. If it is' Data ', it is specified that the number of calculation steps between two frames of animation is the same. This option is only applicable to branches that require animation.

2.4.2 info.plot.num_frame

The total number of frames in the animation. Dimensionless scalar. This option is only applicable to branches that require animation.

2.4.3 info.plot.saving

Whether to save the animation file. Logical.

2.4.4 info.plot.vibration_analysis

Whether to conduct vibration analysis. Logical.

2.4.5 info.plot.vibration.option

The demonstrated variables in the vibration plot. Can be one of `'X'; 'Y'; 'N'; 'M'; 'EA'; 'GA'; 'Sigma'; 'Epsilon'; 'PlasticEp'; 'Ac'; 'V'` or their combination. Respectively, they represent: Axial displacement X, longitudinal displacement Y (caused by bending moment), axial force N, bending moment M, real-time tensile and compressive stiffness EA, real-time shear stiffness GA, axial stress Sigma, axial strain Epsilon, equivalent plastic strain PlasticEp, axial acceleration Ac, radial strain V (inward or outward, caused by axial force).

Interpretation: Combination format: ***'Variable1, Variable 2…, Variable n'***

Example:`'Ac,V,N'`, with comma as separation.

2.4.6 info.plot.vibration.modal

Whether to use modal analysis method to solve structural response. Logical. This option is only applicable in elastic decoupling analysis.

2.4.7 info.plot.vibration.modal_plot

How to demonstrate the result of modal analysis. Can be one of: `''; 'Curve'; 'Color'`, which means no demo, first 3 modes in curve, first 3 modes in projectile's overall deformation.

2.4.8 info.plot.vibration.tip_fix

Should the tip of the projectile be refined. Logical. If refined, the area and moment of inertia of the first 1/10 of the length of the projectile are assigned corresponding values at the 1/10 section, thereby reducing the degradation of the stiffness and mass matrices at the tip of the projectile. If not refined, the model will calculate the area and moment of inertia of the first 1/10 of the projectile length in the normal way, which may cause matrix deterioration.

2.4.9 info.plot.vibration.buttom_fix

Should the tail cover be refined. Logical. If refined, the tail cover will not contribute stiffness to the projectile, but only add mass. If not corrected, the tail cover will be rigidly connected to the projectile, contributing both stiffness and mass.

2.4.10 info.plot.vibration.radial

Whether to consider radial forces. Logical. This option is only valid for MH models. If considered, the radial force that causes radial deformation will be applied to the projectile. If not considered, the radial force will not be input.

2.4.11 info.plot.vibration.expression

How to present the results of structural response. Can be one of: `''`, `'animation'; 'bisect';` or `'mesh'`. They respectively represent no demo, the curve animation of the selected variable, the time history plot of the variable at the specified section, and the waterfall plot of the variable.

2.4.12 info.plot.vibration.location

The cross-sectional position corresponding to the time history of the structural response variable. A scalar between 0 and 1 or its combination vector. 0 represents the tail of the projectile, 1 represents the tip. This is only valid when 'bisect' is selected for info.plot.vibration.expression.

2.4.13 info.plot.history_animation

Whether to demonstrate history animation of the penetration. Logical.

2.4.14 info.plot.animation.projectile.map

The variable reproduced by the shading on the projectile in the animation. Can be one of: `' '; 'Normal'; 'Shear'; 'Overall'` and `'Vibration'`. The first four represent uncolored, normal stress, shear stress, and total stress, respectively. For `'Vibration'`, the animation will be displayed in the projectile coordinate system, targeting the content specified in the variable 'info.plot.vibration.expression' (regardless of the value of 'info.plot.vibration.analysis', as long as `'Vibration'` is selected here, it will be displayed).

2.4.15 info.plot.animation.projectile.num_mesh

The radial mesh distribution of the projectile in the animation. Dimensionless Integer.

Interpretation: This variable only affects the drawing accuracy and efficiency of the reproduction animation, while does not affect the simulation calculation.

2.4.16 info.plot.animation.medium.map

The variable reproduced by the shading on the target in the animation. Can be one of `' '; 'Stress'; 'Component'`, which represent uncolored, stress and response region distribution.

2.4.17 info.plot.animation.medium.num_mesh

The grid mesh distribution of the target in the animation. Dimensionless Integer.

Interpretation: This variable only affects the drawing accuracy and efficiency of the reproduction animation, while does not affect the simulation calculation.

2.4.18 info.plot.animation.num_source

The number of equivalent cavity sources of the target in the animation. Dimensionless Integer.

Interpretation: This variable only affects the drawing accuracy and efficiency of the target status in the reproduction animation, while does not affect the simulation calculation. If the value is too high, it might affect demonstration efficiency.

2.4.19 info.plot.animation.transparency

Transparency of coloring in the animation. Scalar ranging from 0 to 1. The higher the value, the closer the drawing is to transparency.

2.4.20 info.plot.other_plot

Whether to plot other variable’s relationship. Logical.

2.4.21 info.plot.other.x_loc

The point to be present in the plot. It can be ‘center’ or ‘top’, which means centroid and projectile’s tip respectively.

2.4.22 info.plot.other.x

The variable representing variable x in variable relationship analysis. The optional variable name is one of: `'x', 't', 'y', 'vx', 'vy', 'v', 'a', 'alpha', 'fai', 'psi', ‘omega'`. The variable names refer to: penetration displacement x, time t, offset distance y, normal penetration velocity vx, offset velocity vy, velocity v, acceleration a, angle of attack alpha, angle of fall fai, tilt angle psi (psi = fai+alpha), and angular velocity omega.

Interpretation:

a) The tilt angle psi represents the angle between the velocity of the projectile's center of mass and the normal direction of the target. The definition of its positive direction is shown in Fig. 3.

b) If multiple plot is requested, the format is:

'Variable x in Fig. 1, Variable x in Fig. 2,…, Variable x in Fig. n'

Meanwhile, in the `info.plot.other.y` term, the format is:
'Variable y in Fig. 1, Variable y in Fig. 2,…, Variable y in Fig. n'

For example:

```
info.plot.other.x = 't,x,x';
info.plot.other.y = 'alpha,y,fai';
```

This indicates the request to draw three graphs. Figure 1 depicts the time-angle of attack relationship, Figure 2 depicts the penetration displacement-offset distance relationship (i.e. trajectory), and Figure 3 depicts the penetration displacement-angle of fall relationship.

2.4.23 info.plot.other.y

The variable representing variable y in variable relationship analysis. The optional variable name and meaning is the same as them in `info.plot.other.x`

3. Multiple selection and binding

3.1 Multiple selection of variable

The model supports multiple selection of variables. That is, a variable corresponds to multiple values, and each condition will inherit different values of the variable.

Single selection of variables is like:
Variable a = Value a_1

Multiple selection of variables is like:
Variable a = {Value a_1, Value a_2,…, Value a_n}

If multiple variables are set as multiple selection, the generated conditions will traverse all possible combinations of variables. Each condition has its own project suffix and will be stored, calculated, and analyzed.

Example: info.project_name = 'Test', and two variables are set as multiple selection:

Variable a = { Value a_1, Value a_2,…, Value a_n}
Variable b = { Value b_1, Value b_2,…, Value b_m}

And there will be n×m conditions, ranging from ***(a_1, b_1)***to ***(a_n, b_m)***. Their name ranges from ***'Test a1 b1'*** to ***'Test an bm'***.

3.2 Binding

If there are multiple variables set as multiple selection, the total number of conditions will become large, and some of them are unnecessary to calculate. To avoid this, binding variable settings can be introduced to eliminate conditions not needed. The format is:

binding = ***{ { Variable x_{11}, Variable x_{12}, …Variable x_{1n_1}},***
{ Variable x_{21}, Variable x_{22},…Variable x_{2n_2}},
…,
{ Variable x_{m1}, Variable x_{m2},…Variable x_{mn_m}} }

Which means: n_1 variables ***{ x_{11}, x_{12}, …x_{1n_1}}*** are bind together, n_2 variables ***{ x_{21}, x_{22}, …x_{2n_1}}*** are bind together,…,n_m variables ***{ x_{m1}, x_{m2}, …x_{mn_m}}*** are bind together. There are m "bindings" in total. For every binding, the variables inside correspond to each other without traverse.

Example:

```
info.config.projectile.v0 = {1000, 950, 900};
info.config.projectile.fai = {10/180*pi, 5/180*pi, 0/180*pi};
info.config.projectile.alpha = {0/180*pi, 1/180*pi,
2/180*pi};

binding =
{{'config.projectile.fai','config.projectile.alpha'},...
           };
```

Which means: the initial angle of fall (`config.projectile.fai`) and angle of attack (`config.projectile.alpha`) is bound, while initial velocity (`config.projectile.v0`) is independent from binding. In this scenario, the initial angle of fall and initial angle of attack can only be taken as:

```
(10/180*pi, 0/180*pi);
(5/180*pi, 1/180*pi);
(0/180*pi, 2/180*pi);
```

With the traverse of initial velocity, there are 9 conditions:

```
(10/180*pi, 0/180*pi, 1000);
(5/180*pi, 1/180*pi, 1000);
(0/180*pi, 2/180*pi, 1000);
(10/180*pi, 0/180*pi, 950);
(5/180*pi, 1/180*pi, 950);
(0/180*pi, 2/180*pi, 950);
(10/180*pi, 0/180*pi, 900);
(5/180*pi, 1/180*pi, 900);
(0/180*pi, 2/180*pi, 900);
```

If there is no binding setting, a total of 27 conditions will be generated. Therefore, binding operations can reduce unnecessary conditions.

Note: For each binding, the values of its internal variables correspond one-to-one. This indicates that the possible number of values for each variable should be the same. For example:

```
info.config.projectile.v0 = {1000, 950, 900};
info.config.projectile.fai = {10/180*pi, 5/180*pi};
info.config.projectile.alpha = {0/180*pi, 1/180*pi,
2/180*pi};

binding =
{{'config.projectile.fai','config.projectile.alpha'},...
           };
```

It is illegal. Although there is binding between initial angle of fall and attack, the numbers of selection are 2 and 3 respectively, and the correspondence cannot be achieved.

If binding is applied, it is suggested to check the one-to-one correspondence between variables before running.

4. Program for generating the contour lines of oval-shaped projectiles

To quickly generate the contour lines of the oval shaped projectile (info.config.projectile.config), the Config generator_oval() function was designed, which can has the output [Config, Config name]. The program generates a contour cluster consisting of two contour lines, and the projectile is composed of shell and charge.

Multiple selection and binding is also supported in this program, and the format is the same introduced before.

4.1.1 info.project_name

Name of the contour cluster corresponding to info.config.projectile.config_name.

4.1.2 info.oval.d

Projectile's diameter, default unit: m.

4.1.3 info.oval.l2d

Ratio of projectile's length to diameter, dimensionless.

4.1.4 info.oval.CRH

Ratio of projectile's oval head's curvature radius to diameter, dimensionless.

4.1.5 info.config.projectile.dt

Ratio of shell's thickness to projectile's diameter, dimensionless.

4.1.6 info.config.projectile.ls2l

The ratio of the distance between the vertex of projectile's cavity and the tip of the projectile to its total length, dimensionless.

4.1.7 info.config.projectile.b2l

The ratio of the thickness of the tail cover to projectile's diameter, dimensionless.

4.1.8 info.config.projectile.CRH2

Ratio of projectile's inner cavity's oval curvature radius to inner cavity's diameter, dimensionless.

5. Buckling analysis

Buckling_test_load.m can determine whether the penetrating projectile undergoes buckling at any time during the penetration process and what kind of buckling (beam mode or shell mode) can occur by recalling the results of specific xx_result.mat.

Buckling_test_modal.m can export the bending mode at specified time (t_now)

It is necessary for info.plot.vibration_analysis and info.plot.vibration.buttom_fix to be `'true'`, and info.plot.vibration.option to be `'N,EA,GA,V'`