FRICTION ANALYSIS:
BLOCK ON AN INCLINED SURFACE

Programmed by Hussam Dandashli

The Friction Analysis program analyzes a block on an inclined surface with adjustable roughness, and provides various information about its status (i.e. tipping or slipping) under the selected loading and surface conditions.
When the program starts, the screen will look similar to Fig. 1 under the default parameters, which can be called by choosing option 1 from menu "**Edit**".

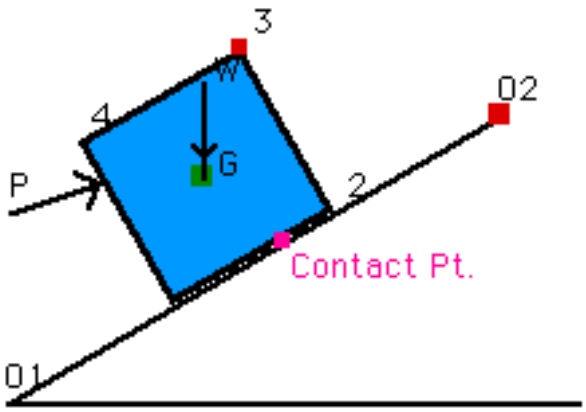


Fig. 1. Default setting.

The program is interactive. The surface slope, corner vertex 3, center of gravity, point of application and direction of the force applied can all be interactively changed with the aid of the mouse (selecting and dragging with mouse button down). The new configuration will be drawn as soon as the mouse button is released.

The program has three functions:

1- Setting parameter values:

The following are the default values set for the various program parameters at initialization:

Surface roughness (**Ms**) = 0.900 ,
Surface slope (**angS**) = 30 degrees,
Weight of block (**W**) = 147.00 units,

External force value (**P**) = 100.00 units,
Force direction (**angP**) = 20.00 degrees,
Gravitational acceleration (**g**) = 9.80 .

The numerical values for these parameters can be changed by selecting the appropriate option from the menu "**Edit**".

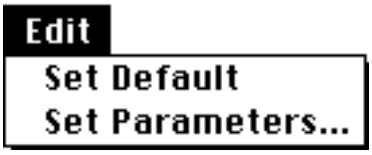


Fig. 2.1 Edit menu

Set Default will restore initial parameters, while **Set Parameters** will give the user the option to change some design parameters shown in Figure 2.2.

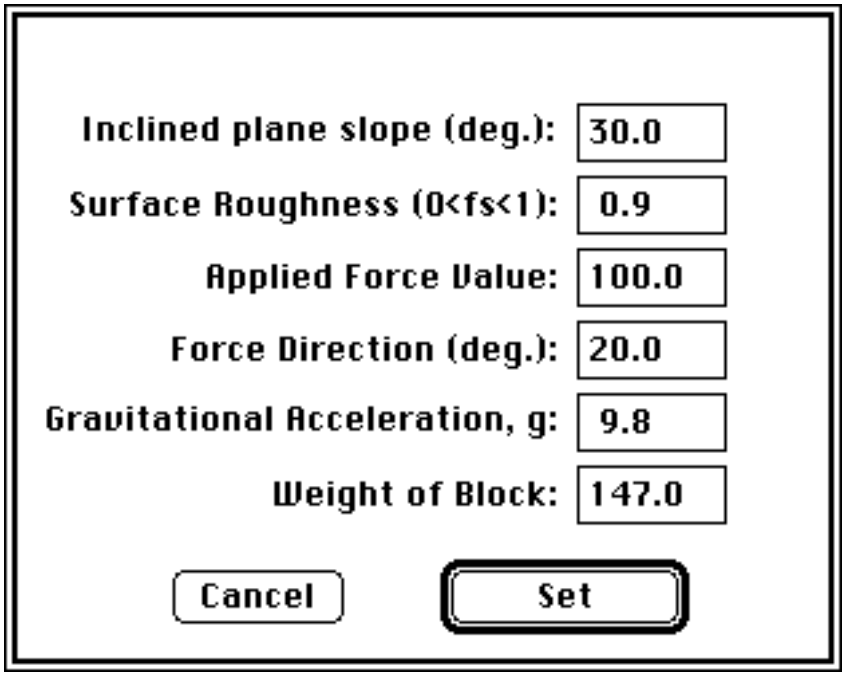


Fig. 2.2 Edit menu options

Some of the above parameters can be changed interactively through the mouse:

a- Application point of applied force :
Dragging the arrow tip while holding the button down will change the point of application to the desired location when the mouse button is released.

b- Direction of applied force:
The direction of the force can be changed by dragging the arrow tail to the orientation desired.

c- Angle of inclination:
The incline slope can be varied by dragging the square at **O2** with the mouse to the desired location.

d- Location of center of mass:
The center of mass can be dragged to any point on the block, hence creating a non-homogeneous block.

e- Size of the block:
The dimension of the block can be altered by dragging point 3, the upper right corner, .

The parameters can be reset at any time to the default values from the first option of the menu "**Edit**".

2- Analysis

Analysis includes finding the point of contact of the block on the surface, the numerical values for the normal and friction forces, magnitudes of the applied force to cause impending motion, and the animation of the motion in the case of tipping or sliding. This is done automatically whenever any parameter is altered.
The other two options were designed to enhance the visualization by animating the impending motion or by reducing unwanted numbers on the

screen or showing them. As the block start to rotate, the initial position of the force and center of gravity will be shown on the screen.

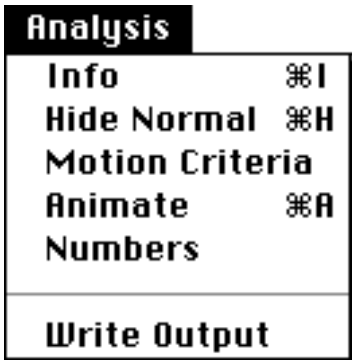


Fig. 3.1 Analysis options.

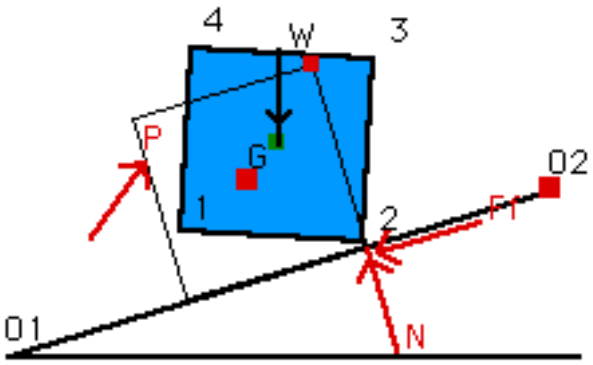
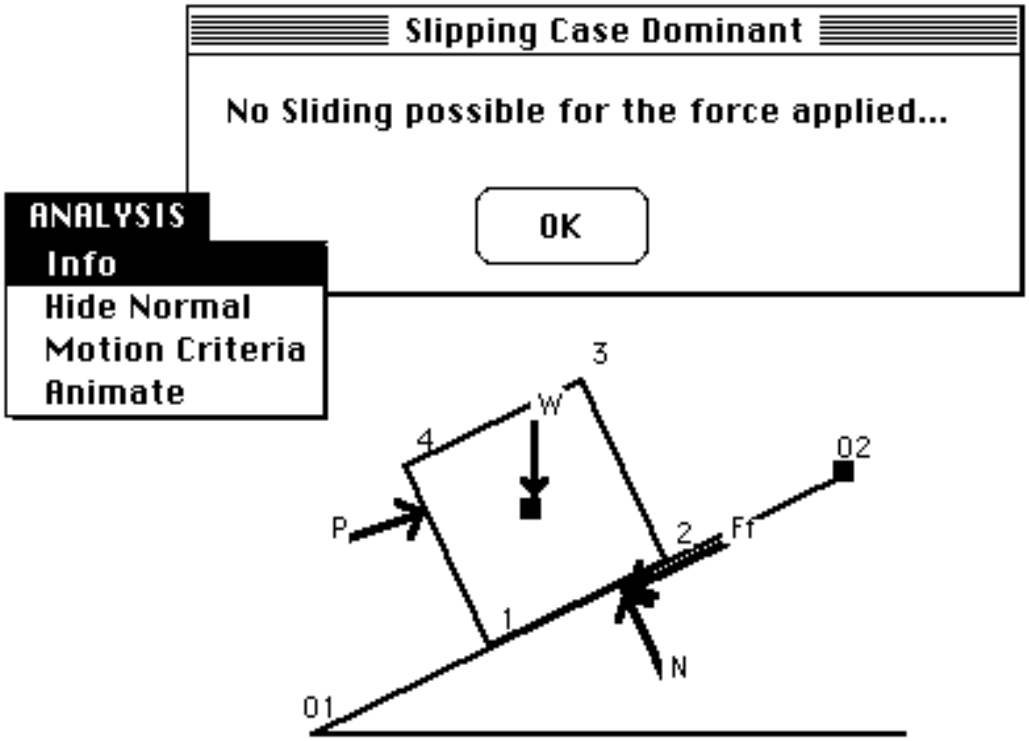


Fig 3.2 Initial position of block before rotation.

3- Visualization

Messages about the status of the block and the drawing of the friction and normal forces will appear if the "**Info**" option of the menu "**Analysis**" is chosen. The arrows representing the forces can be removed if the option "Hide Normal" from menu "**Analysis**" is chosen.



FiFig.

4.1 Requesting information about the status of the block

As the applied force increases in magnitude, the block might start moving by either slipping or rotating and eventually tipping over as in Figs 4.2 and 4.3.

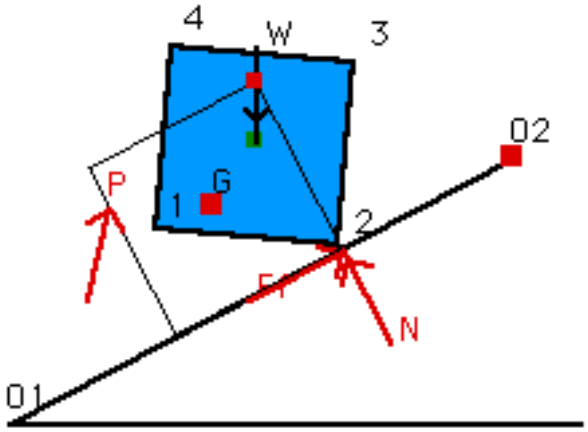


Fig. 4.2 Block starts to move.

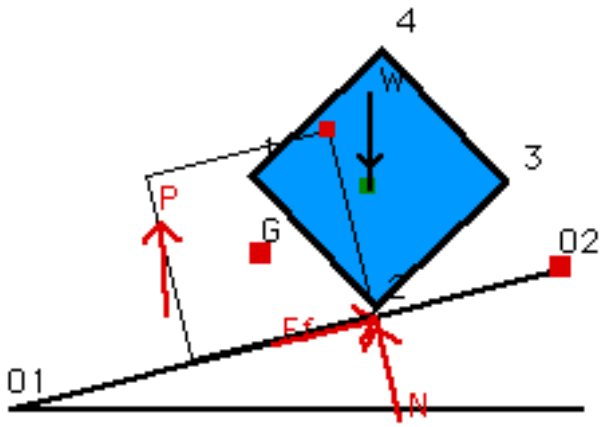


Fig. 4.3 Block will tip over.

One look at the information displayed from "**Motion Criteria**" option from "**Analysis**", Fig. 4.4, can aid in predicting what will happen if the force magnitude is increased.

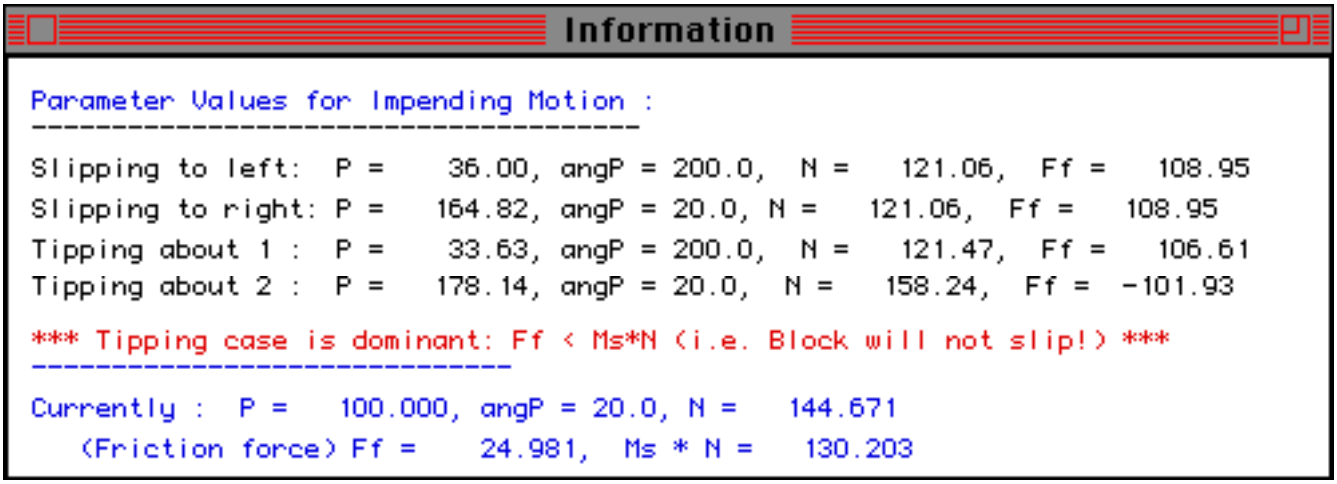


Fig. 4.4 Information window requested by "Motion Criteria".

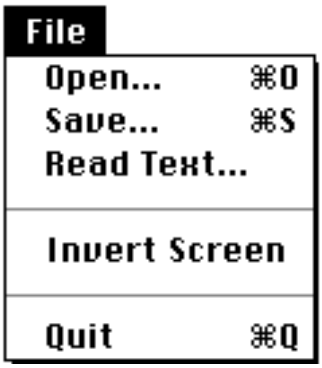
If the block moves, the program will automatically animate its motion. Further animation can be requested from the menu "**Analysis**".
In addition, a grid can be displayed if desired by selecting the proper item in the menu "**Grid**".

SUMMARY OF MENU OPTIONS:

Apple Menu

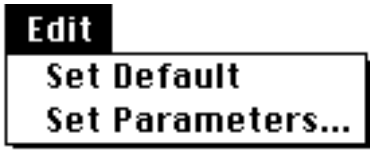
About...: Shows logo and credits.
Help...: Displays an on-line help.

File Menu



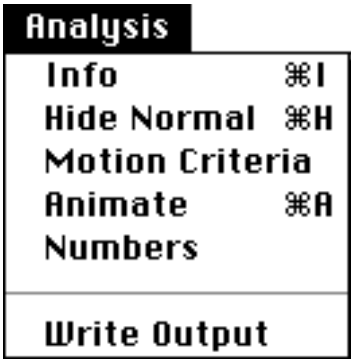
Open... : Loads an input file.
Save... : Saves current settings as an input file.
Read Text... : Displays any text file in the console window.
Invert Screen : Toggles the background color between black and white.
Quit: Terminates the program.

Edit Menu



Default Settings: Initializes the program to the default parameters,
Set Parameters: changes the current parameters according to Fig. 2.2.

Analysis Menu



Info: Displays a message containing the status of the block under the loading and surface conditions. It also draws arrows representing the normal and friction forces,

Hide/Show Normal: Hides/shows the normal and friction force arrows,

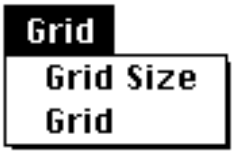
Motion Criteria: Calculates current normal and friction force magnitudes and also calculates the forces needed for impending motion,

Animate: Animates the motion of the block in the cases of tipping or sliding. This option will be inactive if the block doesn't tip or slide.

Hide/Show Numbers: Removes/shows all numbers and letters.

Write Output: writes the analysis information to a text file.

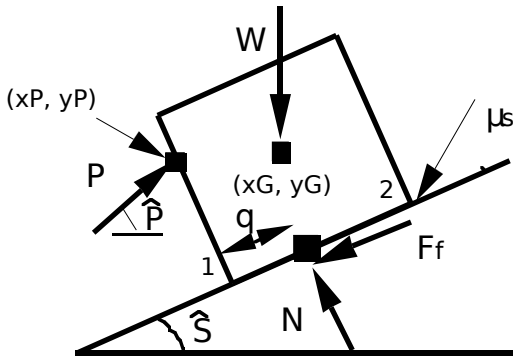
GRID Menu



Grid Size: Specify any desired grid size,

Show/Hide Grid: Draws/Hides a grid in the design area,

EQUATIONS USED:



1- Point of contact , q, relative to corner 1 of the block:

$$q = \frac{\left(-P\left[(xP - x1).\sin\hat{P} + (yP - y1).\cos\hat{P} \right] + W\left[xG - x1 \right] \right)}{\left\langle \left\langle P.\sin(\hat{S} - \hat{P}) + W.\cos\hat{S} \right\rangle \right\rangle}$$

2- Impending Tipping about i:

$$P_i = \frac{W(xG - xi)}{\left[(xP - x1).\sin\hat{P} - (y1 - yP).\cos\hat{P} \right]}$$

$$F_{fi} = -P.\cos(\hat{P} - \hat{S}) + W.\sin\hat{S}$$

$$N_i = P.\sin(\hat{S} - \hat{P}) + W.\cos\hat{S}$$

3- Impending Slipping in direction of i:

$$P_1 = \frac{\left[-W.(\mu_s.\cos\hat{S} - \sin\hat{S}) \right]}{\left[\mu_s \sin(\hat{S} - \hat{P}) + \cos\hat{S}(-\hat{P}) \right]} \qquad P_2 = \frac{\left[W.(\mu_s.\cos\hat{S} + \sin\hat{S}) \right]}{\left[\mu_s \sin(\hat{P} - \hat{S}) + \cos\hat{S}(-\hat{P}) \right]}$$

$$N_1 = \frac{\left[W.\cos\hat{P} \right]}{\left[\mu_s \sin(\hat{S} - \hat{P}) + \cos\hat{S}(-\hat{P}) \right]} \qquad N_2 = \frac{\left[W.\cos\hat{P} \right]}{\left[\mu_s \sin(\hat{P} - \hat{S}) + \cos\hat{S}(-\hat{P}) \right]}$$

$$F_1 = \mu_s.N_1 \qquad F_2 = \mu_s.N_2$$

4- At a given P:

$$F_f = -\left[P\cos(\hat{P} - \hat{S}) \right] + W.\sin\hat{S}$$

$$N = \left[P\sin(\hat{S} - \hat{P}) \right] + W.\cos\hat{S}$$

Sample Output from Save option:

```
============================================================
Forces (P, N, Ff) are in units of force, ie Newton or Lb force.
Angles (angP{P direction} and angS{slope inclination} in degrees.
============================================================

============================================================
NEW CASE :
Parameter Values for Impending Motion :
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System Parameters :
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Incline slope = 31.21 degrees
Surface roughness = 0.900
Ext Force P magnitude = 100.00 units
Force direction = 20.00 degrees
Block weight = 147.00 units.
Width = 75, Height = 75 pixels
Gravitational acceleration g = 9.80
Slipping to left:  P = 31.99,  angP = 200.0,  N = 119.50,  Ff = 107.55
Slipping to right: P = 163.79, angP = 20.0,   N = 119.50,  Ff = 107.55
Tipping about 1 :  P = 33.57,  angP = 200.0,  N = 119.19,  Ff = 109.11
Tipping about 2 :  P = 197.41, angP = 20.0,   N = 164.11,  Ff = -117.47

***** Tipping case is dominant *****
----------------------------------------
Currently :
P = 100.000, angP = 20.0,  N = 145.167,  Ff = 21.915,  Ms * N = 130.650
```