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A Computational Software for PCM Snow Avalanche Model

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Abstract

Some numerical methods were applied to PCM snow avalanche model for calculation of avalanche dynamics and the software named NUM-PCM 1.0 was developed. The implemented numerical methods included Euler (1st and 2nd order Taylor Polynomial), Midpoint, Modified Euler, and Runge-Kutta Order Four method. Once results from numerical calculation were obtained, every approach was compared using NUM-PCM 1.0, Also, friction parameter, mass-to-drag parameter, and delta (horizontal distance) parameter of the model were tested with different scenarios. It was found that run-out distance decreased when the other parameters were constant with increasing of friction value. While mass-to-drag was increasing, velocity of the avalanche was also increasing, although the run-out distances were close to each other. In addition, it was determined that when the horizontal distance exceeds 50 meters, even if the velocity values of avalanche are close in each method, avalanche with high velocity is stopped harshly without reaching the run-out zone.

Keywords: Avalanche Dynamics, Euler Method, Numerical Approach, NUM-PCM 1.0, PCM Model, Runge-Kutta

1. Introduction

Due to adverse effects of snow avalanches, governmental agencies have tried to protect people, settlements and traffic routes by using active and passive measures for a long time (Petrascheck and Kienholz, 2003). Risk assessment studies have become increasingly important within avalanche protection works (Fuchs et al., 2004) which may require large financial resources for effective protection measurements (Barbolini et al., 2000). For the design of protection works, avalanche dynamics such as run-out distance, flow height, velocity, and impact pressure are needed (Oller et al., 2010; Borstad and McClung, 2009). In addition, detailed inventory of avalanches is indispensable for reliable avalanche dynamics calculations and calibration of model parameters (Oller et al., 2010).

Analytical models, statistical models, and most recently numerical models have been employed to calculate avalanche dynamics (Oremus, 2006). The avalanche models can be divided into two main categories: empirical models and dynamic models. Empirical models are based on statistical or comparative calculation methods whereas dynamic models try to reproduce avalanche motion from release zone to run-out (Sovilla, 2004). In general, dynamic models are used when the velocity of avalanches must be estimated for calculation of impact pressures and when the run-out distances are required (McClung and Schaerer, 1993). Several avalanche dynamics models and procedures are available for computing avalanche velocity, run-out distance, flow depth, deposit depth, and lateral extend (Mears, 1992). The avalanche dynamics calculations have been performed to hazard assessment and determination of the design values for protection measures (Perla et al., 1980; Christen et al., 2002; Fuchs et al., 2004; Christen et al., 2010; Oller et al., 2010). These existing models vary from very simple theoretical models to complicated computational models. One dimensional (1D) models of which earlier represent the terrain as a sequence of segments, predict the velocity of the center line of the path (Jamieson et al., 2008). Two dimensional (2D) models also can estimate flow depth or lateral extend whereas 3D models can estimate both (Jamieson et al., 2008). Simple models have been used for more than 80 years to get estimations of important avalanche dynamics such as velocity, pressure and run-out distances (Oremus, 2006). Snow avalanche dynamics especially became a research issue in Europe after catastrophic avalanche winter of 1950/51 (SLF, 1951) with resulting of Voellmy equation (Voellmy, 1955).

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The earliest avalanche dynamics model dates back to the 1920s (Ancey, 2013), while Voellmy-Salm model (Voellmy, 1955; Salm, 1966; Salm, 1968) which is used for avalanche speed and run-out distance is the first attempt to describe the motion of an avalanche mathematically (Barbolini et al., 2000). Although this model has been used by engineers for many years (Perla et al., 1980), it is too restrictive regarding assumptions on the avalanche path (Oremus, 2006). Because the Voellmy-Salm model is encumbered by the need to choose a mid-slope reference position for calculations in order to overcome this flaw, Perla et al. (1980) developed the PCM model. This model is an extension of the original Voellmy (Mears, 1992). Also, as Oremus (2006) stated, Eglit et al. (1960) from Moscow State University made modifications to the Voellmy. In this modified model, there is an upper limit placed on the dry sliding friction parameter. Another modified model from Voellmy is the Norwegian NIS model which predicts the velocity, flow height and run-out distance with reasonable degree of accuracy (Norem et al., 1989). The main difference from Voellmy of NIS model is that the model contains no plug-flow regime and the velocity profile through the depth of the snow is not constant (Oremus, 2006).

In recent years, advancement of computer technologies and the increasing knowledge about physical processes in avalanches have permitted the development of new calculation models (Sovilla, 2004). AVAL 1D (Christen et al., 2002), one of the newest dynamic models, allows the simulation of avalanches in one dimension and reproduce run-out distance, flow velocities and impact pressures (Oller et al., 2010). FL-1D and SL-1D modules of the program can simulate dense flow avalanches and powder snow avalanches, respectively (Christen et al., 2002). One dimensional numerical models require that primary avalanche flow direction and flow width must be defined by the user (Christen et al., 2010) while two and three dimensional models can resolve these problems although entirely new software design is required. RAMMS is a reliable tool which was developed by a team of experts at Institute for Snow and Avalanche Research and the Swiss Federal Institute for Forest, Snow and Landscape Research. RAMMS is able to simulate avalanche dynamics in two dimensions. Another 2D avalanche model is named SAMOS which was developed by the Advanced Simulation Technology (AVL) of Graz, Austria (Johannesson et al., 2001) to simulate powder snow avalanche in 3D form. The model is based on similar assumptions regarding avalanche dynamics as other 2D avalanche models used in France and Switzerland. ELBA+, which was developed by University of Bodenkultur (Austria), is one of the commercially available Voellmy-based 2D snow avalanche dynamic software.

The PCM model which was described earlier calculates velocity for the center-of-mass along the avalanche path. The numerical solutions of equation are based on two parameters: a coefficient of friction μ (or Coulomb friction), and a ratio of avalanche mass-to-drag M/D or turbulence coefficient ξ (which is applied to velocity square) (Salm, 2004). Today, the values of these parameters are still research issue. It is important to have the knowledge of friction coefficient since dynamics model calculations need it to estimate the behavior of the flow (Bartelt et al., 2013). Coefficient of friction (μ) dominates when the flow is close to stopping, while turbulence coefficient (ξ) dominates when the flow is running quickly (Bartelt et al., 2013). Friction coefficient μ depends generally on volume and type of avalanches whereas turbulence coefficient ξ depends on track shape which is defined as laterally confined or unconfined. The values of μ and ξ can be estimated only roughly from existing data (Perla et al., 1980). As McClung and Schaerer (1993) stated, for determination of μ and ξ, an estimate of maximum velocity or a similar estimate of velocity somewhere along the path is needed. Although the parameters (μ and ξ) have not been directly measured, these have been calibrated by fitting observed run-outs with model (Gubler, 1993). Although the upper limit of μ is equally controversial, because avalanches have initiated from rest on 25° slopes and deceleration of large avalanches is unlikely unless slope angle is less than 25°, μ is less than 0.5 and in general, between 0.1 and 0.5 (Perla et al., 1980). As Gubler (1993) stated for dense flow avalanches, μ varied from 0.155 to 0.30, ξ varied from 400 to 1000 m/s^2 in most cases. However, as stated in RAMMS user manual (Bartelt et al., 2013), friction parameters are classified depending on altitude, track shape (such as unchannelled, channeled, gully, and flat), and return period of avalanches. For example, for 300-year period, μ varies from 0.14 (in flat slopes and at above 1500 m.a.s.l for large avalanches) to 0.44 (in gully slopes and at below 1000 m.a.s.l for tiny avalanches), ξ varies from 900 (in gully slopes and at below 1000 m.a.s.l for tiny avalanches) to 4000 m/s^2 (in flat slopes and at above 1500 m.a.s.l for large avalanches).

In this study, certain numerical approaches were applied to PCM avalanche dynamics model in order to calculate velocity along the avalanche path in one dimension as well as impact pressure and run-out distances. For numerical solutions of linear differential equation which gives square velocity, a computer program named NUM-PCM 1.0 was developed using C# programming language with .NET framework in Microsoft Visual Studio Environment. The NUM-PCM 1.0 calculates avalanche dynamics from starting point to the run-out distance and draw charts for visualization of motion along the path

.

Numerical solution approaches which were used in the study can divide into two main categories: Euler's method and Runge-Kutta Order Four method. Euler's method uses first order Taylor polynomial to solve ordinary differential equations numerically. But, certain methods are available to improve Euler's method to reach precise calculation results such as second order Taylor polynomial, Midpoint method and also Modified Euler's method. In this study, for constant values of model parameters, each numerical approach was evaluated, and also different μ, M/D, and delta (horizontal distance) values were tested considering different scenarios and were evaluated effects of these coefficients on the velocity and run-out distances of given avalanche path.

2. Materials and Methods

2.1. The PCM Avalanche Dynamics Model

The PCM model which is used to compute velocity and acceleration along the avalanche profile is an extension of the original Voellmy. The PCM model predicts only center-of-mass position and velocity (Mears, 1992). Hence, force-momentum formula for the avalanche center-of-mass is as given below:

$$\left(\frac{1}{2}\right)\left(\frac{dV^2}{ds}\right) = g(\sin\theta - \mu\cos\theta) - \left(\frac{D}{M}\right)V^2 \quad (1)$$

In this equation which is linear differential equation in V^2, V is velocity, S is distance, μ is a coefficient of sliding friction, θ is local slope angle, M is mass, D is dynamic drag, and g is gravitational acceleration. The solutions of the equation depends on μ and M/D, adjustable parameters (Perla et al., 1980). The analytical solutions of the equation are troublesome because θ, μ and M/D are functions of position "S" (Perla et al., 1980).

In the model, avalanche terrain, which is represented by a centerline profile, was divided into small segments (Figure 1). Slope angle is considered as constant over the length of the segment. If the speed at the beginning of the i^th^ segment is V_i^A and the avalanche does not stop within the segment, then the speed V_i^B at the end of the i^th^ segment can be computed by following equation:

$$V_i^B = \left[\alpha_i \left(\frac{M}{D}\right)_i (1 - \exp\beta_i) + (V_i^A)^2 \exp\beta_i\right]^{0.5} \quad (2)$$

where $\alpha_i = g(\sin\theta - \mu_i\cos\theta)$ and $\alpha_i = 2L_i/(M/D)_i$. If the avalanche stops before the segment ends, the stopping distance S from beginning of the i^th^ segment is:

$$S = \left[\left(\frac{M}{D}\right)_i/2\right]\ln\left[1 - (V_i^A)^2/\alpha_i\left(\frac{M}{D}\right)_i\right] \quad (3)$$

Velocity at the bottom of a segment V_i^B is used to compute velocity V_{i+1}^A at the top of the next segment. This calculation is repeated downslope until the center of mass stops before the end of a segment. V_i^B couldn't always be substituted directly for V_{i+1}^A because it is sometimes necessary to include a correction for momentum change at the slope transitions. When $i > i+1$ is a correction, based on the conservation of linear momentum used is:

$$V_{i+1}^A = V_i^B\cos(\theta_i - \theta_{i+1}) \quad (4)$$

2.2. Euler's Method

Euler's method, which is easily programmable special form of Taylor polynomials, is one of methods used for approximate solution of ordinary differential equations. Calculations are made depending on knowledge initial value after truncation of higher order derivatives of Taylor polynomial (Karagöz, 2001). A continuous approximation to the solution will not be obtained, instead, approximation will be generated at various values in the interval (Burden and Faires, 1997). Once the approximation is obtained at the points, the approximate solution at other points in the interval can be obtained by interpolation (Burden and Faires, 1997). In order to derive Euler's method using Taylor polynomial following equation is used.

$$y_{i+1} = y_i + hy'_i \quad (5)$$

In the equation, h is the step size. If this equation is adapted to Equation 1, following equation can be obtained.

$$V^2{}_{i+1} = V^2{}_i + \Delta s\left(2g(\sin\theta - \mu\cos\theta) - 2\left(\frac{D}{M}\right)V^2{}_i\right) \quad (6)$$

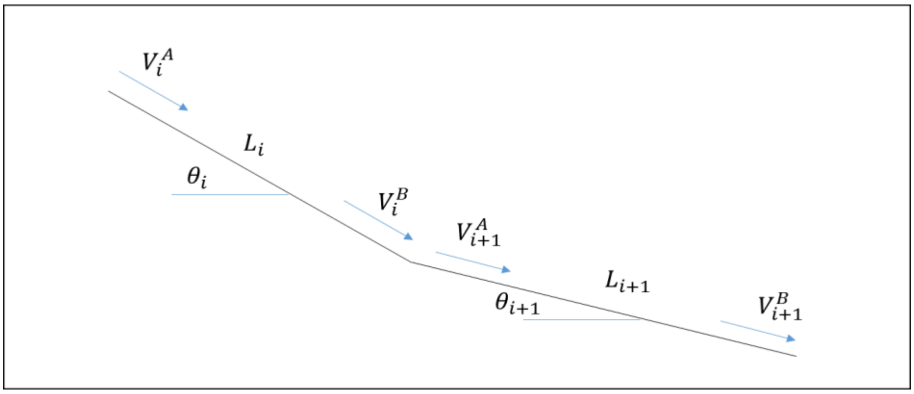


Figure 1. Consecutive profile segments used in the PCM avalanche-dynamics model (Mears, 1992; Perla et al., 1980)

In equation Δs correspond to h in Equation (5). Euler's method is simple through it is not required addition derivatives but in order to obtain more sensitive results, lower step sizes are required (Karagöz, 2001). Hence, Euler's method is able to be improved using higher order Taylor's polynomial. Second order Taylor polynomial is given in Equation 7.

In this study, second order Taylor polynomial was applied to Equation 1. The adapted formula is given in Equation 8. In Euler's method, slope at beginning of the interval is used for approximate calculation. Other approaches which are used to improve Euler's method are to use midpoint slope of the interval and to use the average of slope at the beginning of the interval and slope at the end of the interval. The formula of the first approach called Midpoint method (Burden and Faires, 1997) is given in Equation 9.

The problem in the midpoint method is calculation of derivative at the $(i+\frac{1}{2})^{th}$ step. The Euler's method is able to use to overcome this problem. The method adapted to Equation 1 is given in Equation 10. The formula of second approach called Modified Euler (Burden and Faires, 1997) is given in Equation 11. The problem in the midpoint method is calculation of derivative at the $(i+1)^{th}$ step alike midpoint method. The method adapted to Equation 1 is given in Equation 12 and 13.

$$y_{i+1} = y_i + hy'_i + \frac{h^2}{2!}y''_i \tag{7}$$

$$V^2_{i+1} = V^2_i + \Delta s\left(2g(sin\theta - \mu cos\theta) - 2\left(\frac{D}{M}\right)V^2_i\right) - \left(\frac{\Delta s^2}{2}\right)\left(2\left(\frac{D}{M}\right)\left(2g(sin\theta - \mu cos\theta) - 2\left(\frac{D}{M}\right)V^2_i\right)\right) \tag{8}$$

$$y_{i+1} = y_i + hy'_{i+\frac{1}{2}} \tag{9}$$

$$V^2_{i+1} = V^2_i + \Delta s\left[2g(sin\theta - \mu cos\theta) - 2\left(\frac{D}{M}\right)\left(V^2_i + \left(\frac{\Delta s}{2}\right)\left(2g(sin\theta - \mu cos\theta) - 2\left(\frac{D}{M}\right)V^2_i\right)\right)\right] \tag{10}$$

$$y_{i+1} = y_i + \frac{h}{2}(y'_i + y'_{i+1}) \tag{11}$$

$$V^{2\prime}_{i+1} = V^2_i + \Delta s\left(2g(sin\theta - \mu cos\theta) - 2\left(\frac{D}{M}\right)V^2_i\right) \tag{12}$$

$$V^2_{i+1} = V^2_i + \left(\frac{\Delta s}{2}\right)\left[2g(sin\theta - \mu cos\theta) - 2\left(\frac{D}{M}\right)V^2_i + \left(2g(sin\theta - \mu cos\theta) - 2\left(\frac{D}{M}\right)V^{2\prime}_{i+1}\right)\right] \tag{13}$$

2.3. Runge-Kutta Order Four Method

Another important method which is used for approximate calculation ordinary differential equation is Runge-Kutta method. Although Taylor's methods have the desirable property, because of disadvantage of requiring the computation and evaluation of the derivatives, it is rather complicated and time consuming (Burden and Faires, 1997). Hence, Runge-Kutta Order Four method is adapted to Equation 1. The formulas of Runge-Kutta Order Four method are as follows;

$$y_{i+1} = y_i + \frac{1}{6}(k_1 + 2k_2 + 2k_3 + k_4) \tag{14}$$

$$k_1 = hy'_i \tag{15}$$

$$k_2 = h(y'_{i+\frac{1}{2}} + \frac{k_1}{2}) \tag{16}$$

$$k_3 = h(y'_{i+\frac{1}{2}} + \frac{k_2}{2}) \tag{17}$$

$$k_4 = h(y'_{i+1} + k_3) \tag{18}$$

The adapted formulas are also given in following equations:

$$V^2_{i+1} = V^2_i + \left(\frac{1}{6}\right)[k_1 + 2k_2 + 2k_3 + k_4] \tag{19}$$

$$k_1 = \Delta s\left(2g(sin\theta - \mu cos\theta) - 2\left(\frac{D}{M}\right)V^2_i\right) \tag{20}$$

$$k_2 = \Delta s\left[\left(2g(sin\theta - \mu cos\theta) - 2\left(\frac{D}{M}\right)V^2_{i+\frac{1}{2}}\right) + \frac{k_1}{2}\right] \tag{21}$$

$$k_3 = \Delta s\left[\left(2g(sin\theta - \mu cos\theta) - 2\left(\frac{D}{M}\right)V^2_{i+\frac{1}{2}}\right) + \frac{k_2}{2}\right] \tag{22}$$

$$k_4 = \Delta s\left[\left(2g(sin\theta - \mu cos\theta) - 2\left(\frac{D}{M}\right)V^2_{i+1}\right) + k_3\right] \tag{23}$$

2.4. Impact Pressure Calculation

Avalanches can produce very large dynamic forces on objects. Estimation of impact pressures of avalanches is important because of it is requirement for engineers in design of protection structures. Impact pressure is a function of speed and density of moving material. Although any avalanches have great destructive potential, in general dry flowing avalanches are considered most destructive due to their high flow density and speeds (McClung and Schaerer, 1993). Formula of impact pressure used in this study as follow

$$I = pV^2 \tag{24}$$

where I (kPa) is impact pressure, p (tonm^{-3}) is density of snow and V (ms^{-1}) is velocity.

2.5. Model Application

The data from a well-known avalanche path in Karaçam Region of Trabzon in Turkey were used in the model application (Figure 2). The location of the avalanche is between N 601629.3-4494092.2 and E 603172.1-4492451.3 in UTM European Datum 1950. The avalanche path which has not complex structure includes release zone, track, and run-out zone which closely differentiable from each other (Volk et al., 2015). Some key properties of Karaçam avalanche path are given in Table 1.

For modelling avalanche dynamics in the selected area, coordinates X, Y, and Z of points over the centerline of the avalanche path were obtained from topographical map with scaled of 1:25000. The coordinates of points were saved as a text file as showed in the Figure 3, because of the NUM-PCM 1.0 reads requiring data from text files. Coordinate information of the avalanche must be written as spaced with tab control of keyboard after defining path name.

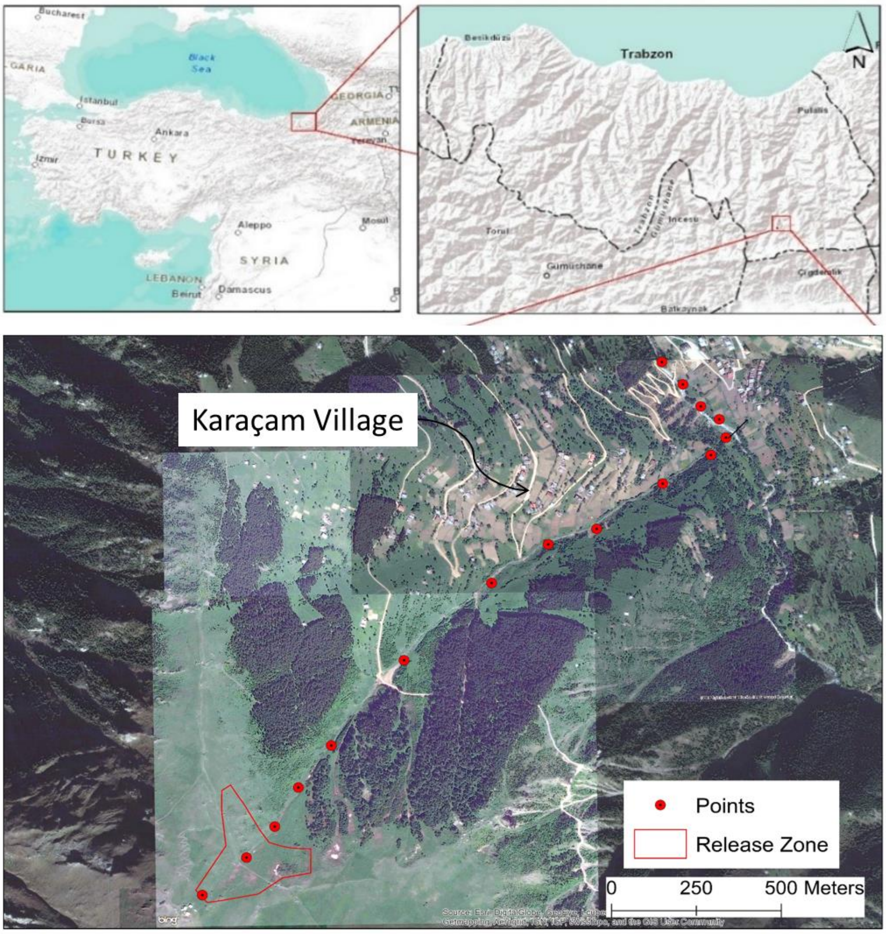
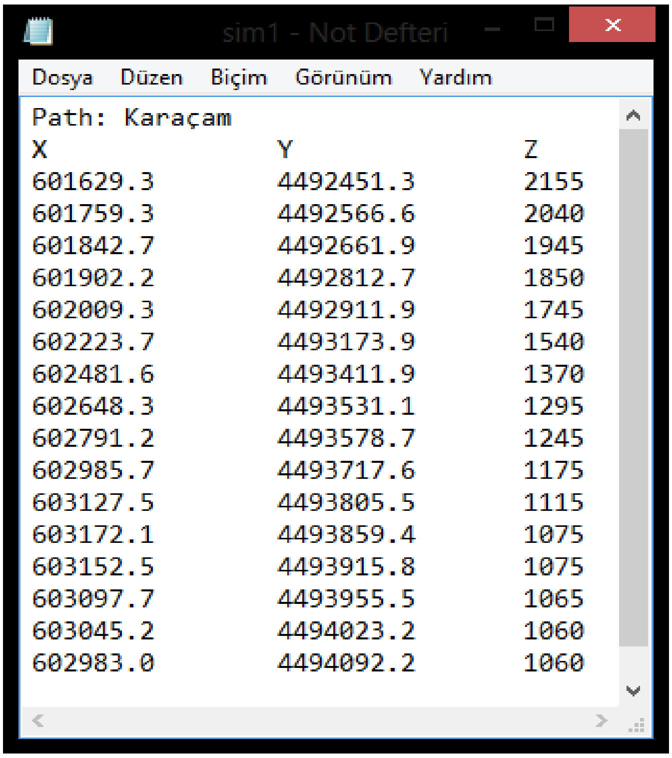


Figure 1. Location of Karaçam Region and avalanche

Table 1. Some key properties of Karaçam avalanche path

Properties	Values
Avalanche Track Length	2435 m
Avalanche Track Altitude	1060 m – 2155 m
Release Zone Altitude	1970 m – 2155 m
Release Zone Slope	35° – 45°
Release Zone Width	90 m – 300 m

The interface of the NUM-PCM 1.0 is depicted in Figure 4. All parameters related to the model such as initial value, friction value, mass-to-drag value, delta (horizontal distance), and flow density are able to be adjusted over the main interface window of the program. Users can also select the numerical method desired to use. The NUM-PCM 1.0 calculates snow dynamics numerically by using Euler (1st Order and 2nd Order), Midpoint, Modified Euler, and Runge-Kutta Order Four method. After locating the text file which contains coordinate information clicking browse button and completion of adjusting desired properties of model, users can run the model by clicking on calculate button. The calculation results are automatically stored into computer as a text file. Each method has separate text file which contains calculation results. A sample display of calculation results as text file is indicated in Figure 5. Users are able to access the calculation results by clicking calculation results button. These text files provide the users with velocity and impact pressure values of each calculation step. After the numerical calculation is successfully completed, users are also able to select type of graphics (Velocity graph or Impact Pressure graph) as shown in Figure 6 and access the graph by clicking on plot chart button.



sim1 - Not Defteri

Dosya Düzen Biçim Görünüm Yardım

Path: Karaçam

X	Y	Z
601629.3	4492451.3	2155
601759.3	4492566.6	2040
601842.7	4492661.9	1945
601902.2	4492812.7	1850
602009.3	4492911.9	1745
602223.7	4493173.9	1540
602481.6	4493411.9	1370
602648.3	4493531.1	1295
602791.2	4493578.7	1245
602985.7	4493717.6	1175
603127.5	4493805.5	1115
603172.1	4493859.4	1075
603152.5	4493915.8	1075
603097.7	4493955.5	1065
603045.2	4494023.2	1060
602983.0	4494092.2	1060

Figure 2. Text file which contains Coordinate X, Y, and Z information, respectively

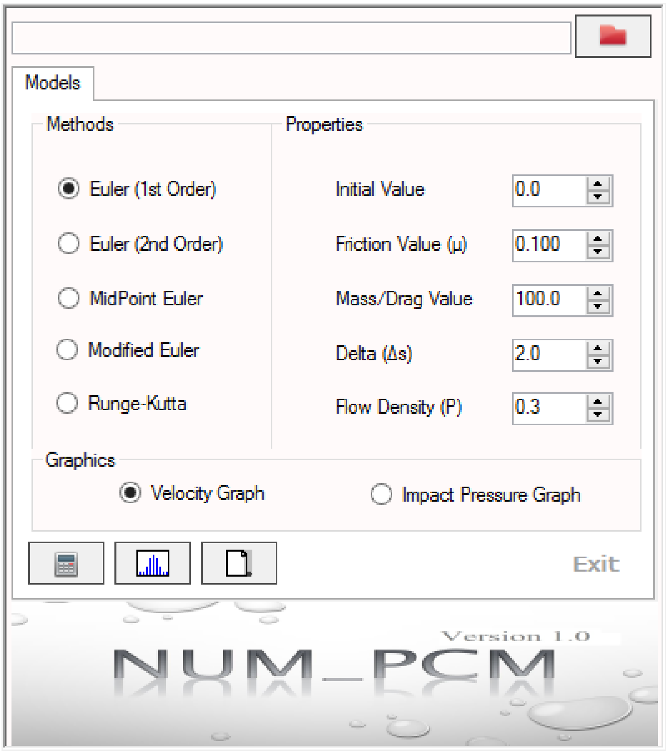
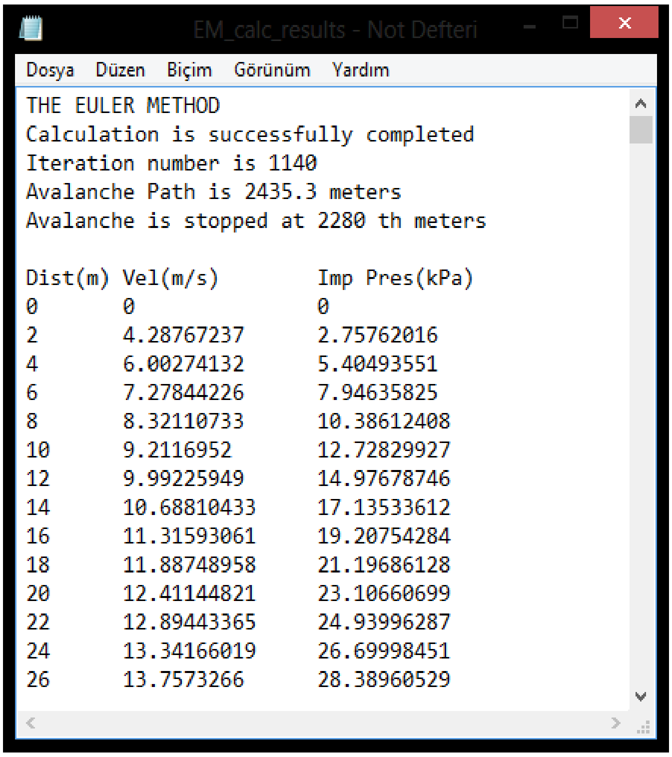


Figure 3. User interface of the NUM-PCM 1.0



EM_calc_results - Not Defteri

Dosya Düzen Biçim Görünüm Yardım

THE EULER METHOD
Calculation is successfully completed
Iteration number is 1140
Avalanche Path is 2435.3 meters
Avalanche is stopped at 2280 th meters

Dist(m)	Vel(m/s)	Imp Pres(kPa)
0	0	0
2	4.28767237	2.75762016
4	6.00274132	5.40493551
6	7.27844226	7.94635825
8	8.32110733	10.38612408
10	9.2116952	12.72829927
12	9.99225949	14.97678746
14	10.68810433	17.13533612
16	11.31593061	19.20754284
18	11.88748958	21.19686128
20	12.41144821	23.10660699
22	12.89443365	24.93996287
24	13.34166019	26.69998451
26	13.7573266	28.38960529

Figure 5. An example image of calculation results text file.

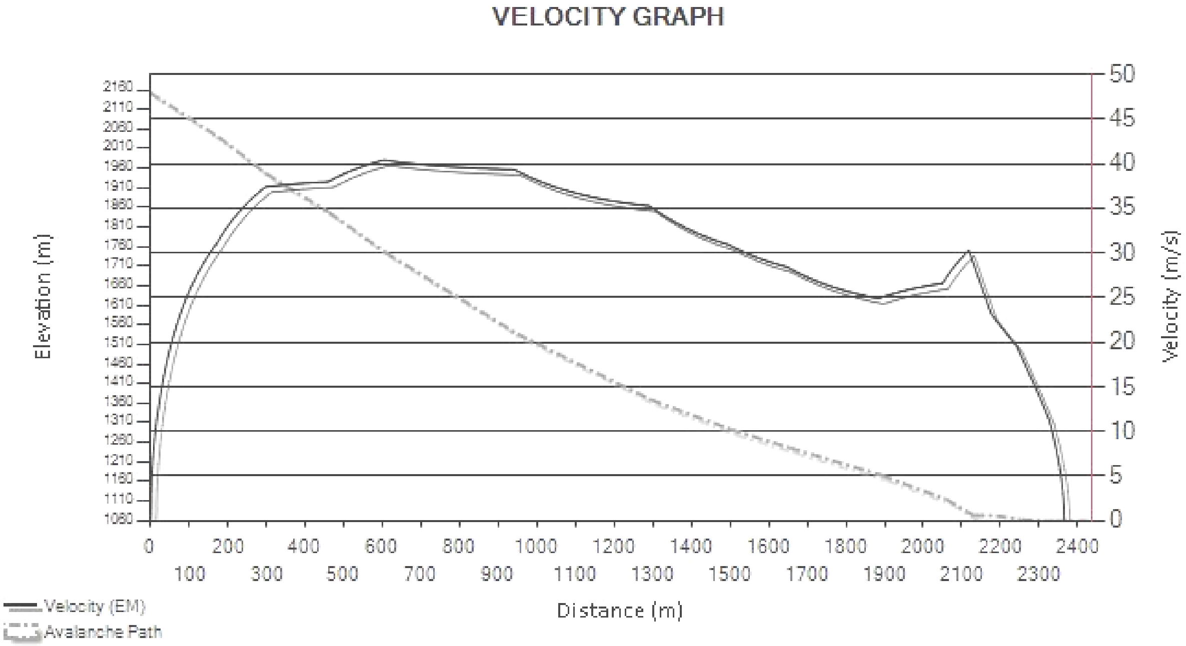


Figure 6. An example depiction of output graph of NUM-PCM 1.0

In the model application, different numerical methods were applied to PCM method for calculation avalanche velocity and impact pressure for Karaçam Avalanche. Results of the corresponding methods were then compared. The differences between the methods were evaluated in terms of velocity, impact pressure, and also run-out distance depending on different values of μ and M/D parameters as well as delta (horizontal distance). For this reason, different scenarios were considered and a number of different values of parameters were tested. In order to compare the results of different numerical approaches, same model parameters were predetermined: initial value equals 0, μ value equals 0.15, M/D value equals 400, and horizontal distance equals 2 meters. The effects of different μ values, ranging between 0.15-0.50, over the run-out distances were evaluated by setting the other parameters as constant. The effects of different values of M/D ranging between 400-1000 m/s^2 over the velocity was also evaluated. In addition, the effects of horizontal distance in terms of calculation results were evaluated. The horizontal distances (calculation steps or delta value) tested in this study ere 1, 2, 5, 10, 20, 50, 75, and 100 meters.

3. Results and Discussion

Numerical calculation of avalanche dynamics such as velocity, impact pressure, and run-out distance were made with Euler method (1st order Taylor Polynomial), Euler method (2nd order Taylor Polynomial), Midpoint method, Modified Euler method, and Runge-Kutta Order Four method by using developed software named NUM-PCM 1.0. It was showed that these numerical approaches are able to apply PCM model which uses a linear differential equation for calculation of avalanche velocity. Calculation results of applied numerical approaches were evaluated in terms of differences between velocity and between run-out distances. These results are depicted graphically in Figure 7.

When the μ value was 0.15, M/D value was 400 m/s^2, and delta was 2 meters, the run-out distance of avalanche in Euler method (1st order Taylor Polynomial), Midpoint method, and Modified Euler method was calculated same as 2366 meters. The shortest run-out distance was found in Euler method (2nd order Taylor Polynomial) as 2282 meters, it was 2300 meters in Runge-Kutta Order Four method. Although three methods have the same run-out distance value, Euler method (1st order Taylor Polynomial) did not provide the same velocity values with Midpoint method and Modified Euler method. On the other hand, the Midpoint method and Modified Euler method had the same velocity values in each calculation step. In each method, velocity was able to reach maximum value at 604th meters. The maximum velocity in Euler method (2nd order Taylor Polynomial) was less than 30 m/s, whereas the maximum velocities in the other four methods could reach about 41 m/s.

Impact pressure of the avalanche was also similar to velocity because of the impact pressure is a function of the velocity. The smallest maximum pressure was calculated as 262 kPa in Euler method (2nd order Taylor Polynomial), whereas the highest maximum pressure was calculated as 519.1 kPa in Runge-Kutta Order Four method. Midpoint method and Modified Euler method had the same pressure value as 489.5 kPa, while Euler method (1st order Taylor Polynomial) had very close value to these as 489.9 kPa.

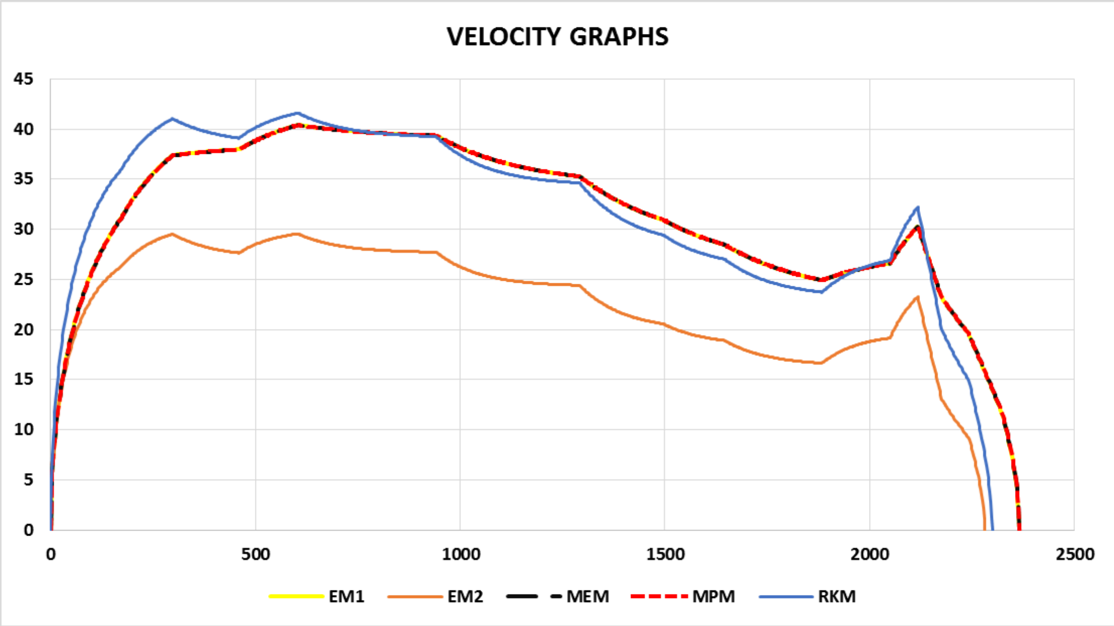


Figure 7. The velocity graphs of each method; EM1: Euler method (1st order Taylor Polynomial), EM2: Euler method (2nd order Taylor Polynomial), MEM: Midpoint method, MPM: Modified Euler method, RKM: Runge-Kutta Order Four method

Effects of changing on the μ value over the run-out distance are depicted in Figure 8, while the other model parameters were constant (delta is 2 m and M / D is 400 m/s^2). For 0.15 of μ value, the run-out distance calculated as 2366 meters. However, for 0.50 of μ value, the run-out distance shortened to 1302 meters. In these conditions, when μ value was selected higher than 0.31, avalanche could move only two out of three partition of the track. Figure 9 indicates the effects of changing values of μ between 0.15-0.50 over the run-out distances depending on M/D changing between 400-1000 m/s^2.

The effects of M/D parameter over the velocity and run-out distance were depicted graphically in Figure 10. While M/D value was increasing, velocity of the avalanche was also increasing when the run-out distances of the avalanche had close values.

The effects of horizontal distance on results were depicted graphically in Figure 11. As the calculation results tested depending on the horizontal distance of numerical solution, while the horizontal distance was increasing, although the maximum velocity of avalanche had close or the same values, run-out distance of avalanche was decreasing. When the horizontal distance was higher than 50 meters, numerical solution was harshly stopped at high velocity values at smaller run-out distances. This solution is far from the realistic situation of the avalanche movement.

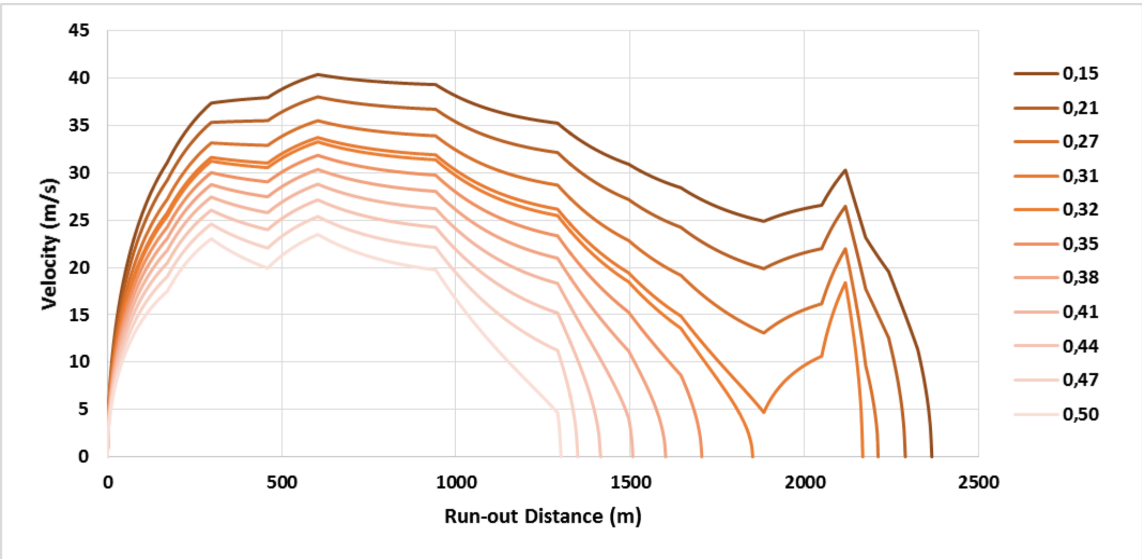


Figure 8. Changing of run-out distance depending on different friction values

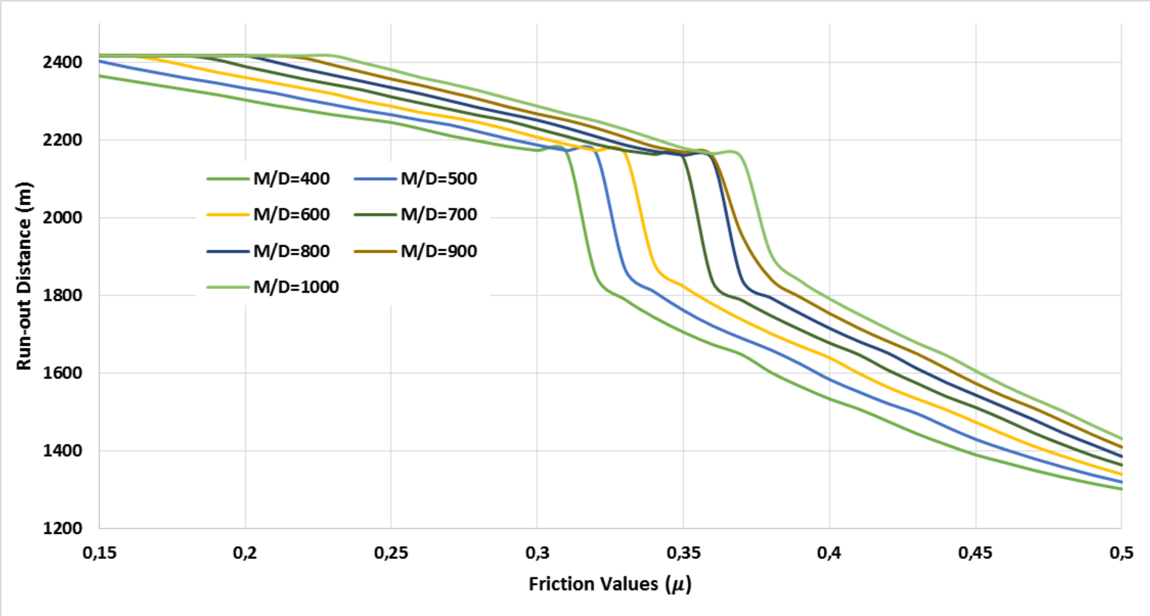


Figure 9. Changing of run-out distance depending on different friction values for each M/D values between 400-1000 m/s^2

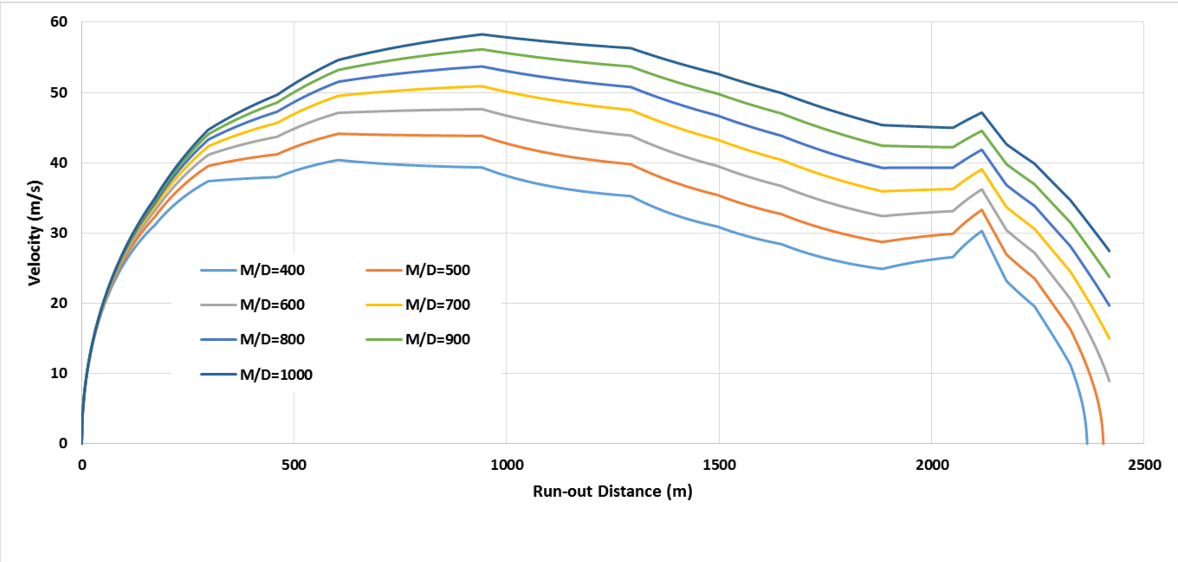


Figure 10. Changing of velocity and run-out distance depending on mass-to-drag value

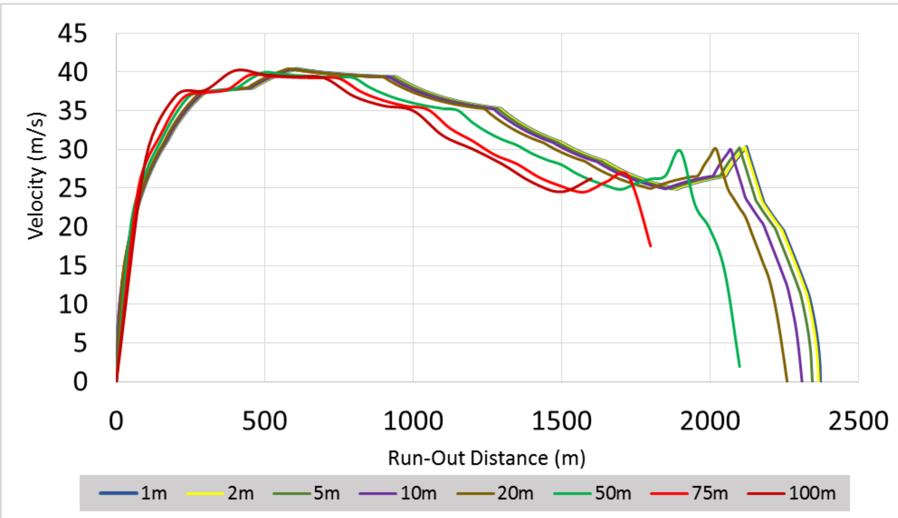


Figure 11. The graphical depiction of effects of horizontal distance on results

For the first analysis of avalanche problem of low frequency event (i.e. 100 yr), it is highly recommended to use appropriate M/D (i.e. 1000) values. Furthermore, μ parameter and horizontal distance also influence simulation results. Since, PCM model sensitive to μ and M/D parameters even small changes causes considerable effect on velocity and run-out distance. Thus, it is advised that model parameters must be chosen appropriately for given avalanche. Otherwise, for higher μ and higher M/D values velocity will be unrealistically very high from real situation and model will be able to stop the avalanche at high velocity values harshly due to numerical solution.

In addition to friction parameters, because the velocity square formula of PCM model was solved numerically, horizontal distance (or step size of calculation which affects the precision) becomes very important parameter of the model. Hence, it is advised that selection of horizontal distance for numerical calculation must be made between 2 and 20 meters.

4. Conclusions

NUM-PCM 1.0 developed for numerical calculation of avalanche dynamics calculation approach of PCM model. Since, PCM Model uses Mass-to Drag concept instead of M/D parameters defining run-out distance more comply then real situation when it was compared with classical Voellmy approach. It was aimed to provide practitioners with simple, user-friendly, and well-calibrated tool. Software can be used for general practice and it can provide quick analyze of the avalanche path. Longitudinal profile can easily be generated from maps or even from Google Earth and results can be visualized efficiently.

The usage of developed software doesn't require high-level of computer skills. All parameters and numerical solution methods are easily defined by users with click corresponding buttons. However, demanding expert knowledge to the users still very high and requiring considerable snow avalanche process know-how to select appropriate starting conditions and friction parameters.

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