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Numerical Modelling of Wheel on the Snow

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Abstract

In the present study, a numerical model is developed for wheel-snow interaction using finite element method based software. For this aim, the model of tire is designed using SolidWorks and ANSYS Design modeler. The analyses of the prepared models are performed using ANSYS Explicit Dynamics considering Mooney-Rivilin tire model. Frictional relationship between wheel and snow ground is established considering snow erosion as linear, in the analyses. Six different mesh sizes are considered, the effect of mesh size and number on the accuracy of the obtained results and solution time is discussed. Finally, it is concluded that models with 0.025 m and 0.02 m mesh sizes give more accurate results than the others and a strong linear proportion exists between the number of iteration and the mesh size.

Keywords: Finite Element Method; Modelling; Snow; Wheel; Mesh size.

1. Introduction

The basic function of the wheel is to ensure contact between the vehicle and the surface of coating. This contact is provided by volcanized rubber which is covering of the tread. The contact area between tire tread and ground is an average 150cm$^{2.}$ The contact between wheel and road surface provides the vehicle driving comfort and road holding. Friction force between wheel and snow, vertical force of vehicle, directional and angular velocity are the important parameters that effect the performance of the vehicle. At the same time, it has been observed that the internal pressure of the wheel is effective in handling, also [1].

The numerical analysis of wheel using finite element method is usually performed with three different methods, the first one is analyzing the contact area; the second one is designing and analyzing the two-dimensional model, and the last one is analyzing the discretized three-dimensional model. From the results of experimental analyses, it has been found that the third method proves more accurate results than the other methods [2-7].

According to previous studies, for isotropic systems the node-centered and triangular mesh cell-centered approaches presented more accurate results than the other ones. At the same time for quadrilateral mesh cell-centered approach is also accurate. Moreover, it should be noted that minimum required element number in the forward plastic zone must be equal to sum of the number of elements in plastic zone and loading cycles planned to be applied in the [8-10].

In recent days, experimental analyses are more costly than numerical ones such as finite element analysis, however, in case of unconscious use finite element method may cause loss of time. In order to get similar results, it is necessary to select the correct system. Hence, discretization known as a part of the system and plays an important role in gaining time [11-13].

The purpose of this study is to determine the value of the tire and its sinking on the snow, shear stress, strain and stresses occurred on the snow, which is designed by ANSYS software [14] based on finite element method. The model of tire is designed by SolidWorks, then in ANSYS Design modeler, snow material on the surface contacts, dimensions are prepared in 1.8×1.4×0.2m. The analysis of the prepared models are done by ANSYS Explicit Dynamics. It's designed for the 195/60 R15 wheel with size specifications to observe its effects on the snow, in the model, internal pressure of wheel is defined 200 kPa. In the ANSYS program, for the wheel model used, Mooney- Rivilin tire model is utilized. In the structure of radial tires, ropes are placed in the wheel's pattern vertical and steel wires are on the heel connection. At the same time, the used wires in body and heel parts are placed parallel in pattern of wheel. Frictional relationship between wheel and snow ground is established. And friction coefficient of ANSYS program is assumed to be 0.3. Snow erosion is considered linear. A vertical force of 4.5 kN was applied to the wheel. To increase the quality of the element of the snow surface, element size is defined as 0.02 m. The wheels both perform rotating and displacement movement, angular and shift speed, for the forward movement of the wheels from rim center, it's placed in the center of wheel. In this case limit time 0.2 second is given for the solution.

2. Modeling of Tire on Snow

ANSYS-Explicit dynamics software is used to analyze the model where the modeling of wheels and snow materials is described as well as the 195/60R15 wheel is designed in Solidworks software. This model is defined in Step format in ANSYS Design modeler. Fig. 1. shows, snow material designed in Design modeler with 1.8m length, 1.4m width and 0.2m height as tangent to the wheel tread. Mesh dimensions were selected as 0.015m, 0.02m, 0.025m, 0.03m, 0.035m and 0.04 m.

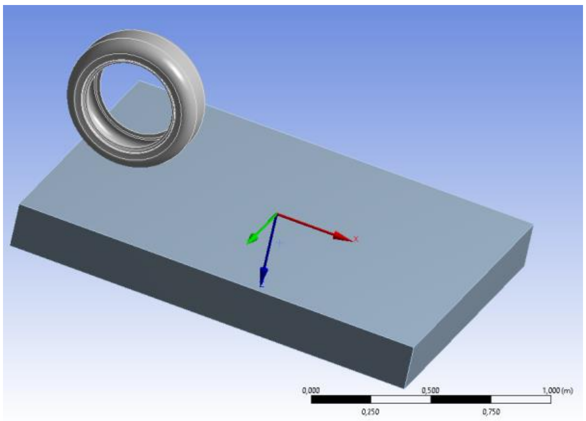

Fig. 1. Solid Works model of wheel and snow

The inner liner, tread and sidewall of the wheel are described as Mooney-Rivilin hyper-elastic material, hence two parameter Mooney-Rivilin strain energy potential is defined as follow:

$$W = C_{10}(I_1 - 3) + C_{01}(I_2 - 3) + \frac{1}{d}(J - 1)^2 \tag{1}$$

where, W, I_1, I_2, C_{10}, C_{01} and d are strain energy potential, first deviatoric strain invariant, second deviatoric strain invariant, material constants characterizing the deviatoric deformation of the material and material incompressibility parameter, respectively.

Besides, the initial shear modulus is defined as:

$$\mu = 2(C_{10} - C_{01}) \tag{2}$$

The material properties are available in ANSYS material library [14], as C_{10}=150 kPa; C_{01}= 15 kPa, ρ=1000 kg/m^3.

In the structure of radial tires body ply is perpendicular to tread pattern. The body ply model is presented in Fig. 2. Here, the following material properties were considered: E_{ply}=9.87 GPa; ν_{ply}=0.3; ρ_{ply}=1500 kg/m^3.

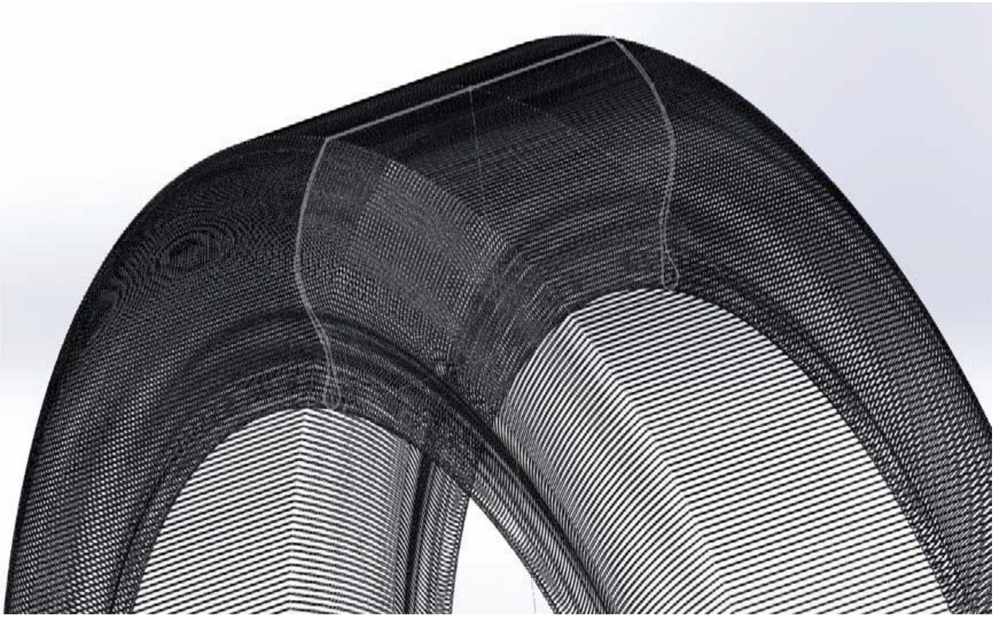

Fig. 2. The Model of Body Ply

The belts are placed parallel to tread pattern and the model is illustrated in Fig. 3. Here, the following material properties were considered: E_{belt}=172.2GPa; ν_{belt}=0.3; ρ_{belt} =5900 kg/m^3.

Fig. 3. The Model of Belts

Snow can be regarded as the cellular form in which ice crystals stick together. Here the low-density snow material is defined as Drucker-Prager model and the considered material properties are $E_{D\text{-}P}$=13.79 MPa; $\nu_{D\text{-}P}$=0.3; $\rho_{D\text{-}P}$=200 kg/m^3, $\delta_{D\text{-}P}$=5 kPa $\phi_{D\text{-}P}$=22.538^o, where δ and ϕ represents Drucker-Prager cohesion and Drucker-Prager friction angle, respectively.

The average load for each wheel of vehicles is 4.5 kN. Directional and angular velocities are selected as 0.5 m/s and 1 rad/s, respectively, an internal pressure of 200 kPa is defined to the wheels and the coefficient of friction of snow is defined as 0.3.

3. Illustrative Examples

In this section, six numerical analyses are performed to examine the given problem. Analyses were performed ANSYS Explicit dynamics. Here, the wheel moved 0.2 seconds after it is left on the snow. During this time the wheel has traveled 10 cm. The type of mesh is automatically selected, and the mesh sizes are defined as described in the modeling section.

Example 1:

In the first example, sinking on the snow for different mesh sizes is examined and results are presented in Fig. 4. It is found that except the mesh size of 0.015 m, all models have shown almost similar results. By considering the other mesh sizes in the last part, tire sinkage is between 12 and 14 cm on snow. By observing the size as if mesh 0.02 and 0.25 m, nearly the same results happened. At the same time, the values in the models of 0.035 and 0.04 m in mesh size which are close to each other are exhibited while. The 0.035 m mesh size model exhibited values close to 0.030, while the values in the beginning are similar to the 0.04 m mesh size model. However, considering the previous studies, the 0.025 and 0.02 m mesh size models show more accurate results than the other models.

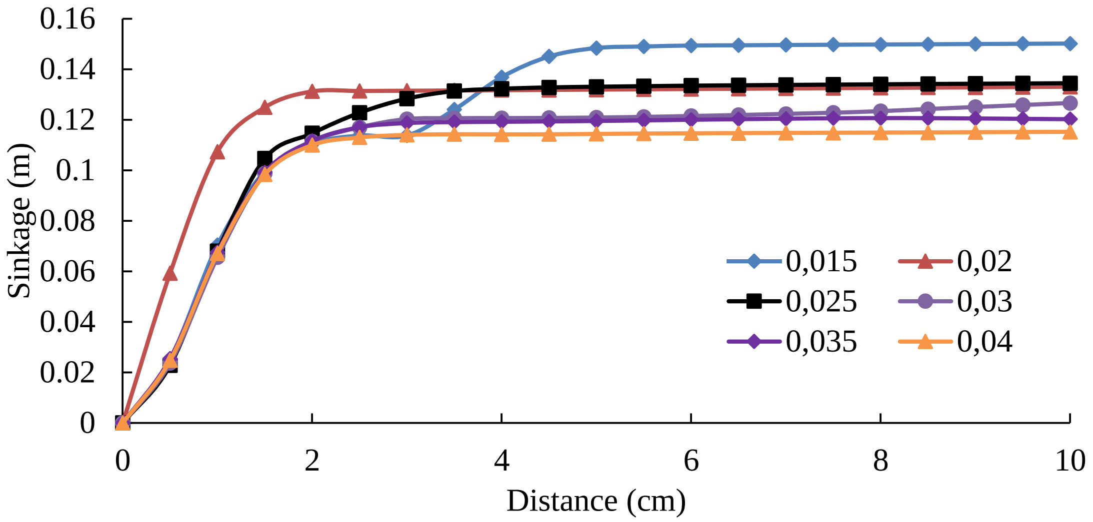

Fig. 4. The variation of tire sinkage on snow for different mesh sizes

Example 2:

In the second example, the values of shear stress formed on the snow for different mesh sizes are investigated and results were plotted in Fig. 5. Similar to the sinking results on snow, 0.015 m mesh size model showed different results than the others. Here, 0.02 and 0.025 m mesh size models values are similar. In the beginning (up to 3 cm travel), the 0.03 m mesh size model exhibited values close to the 0.04 m mesh size results; however, between 3 and 7 cm of progress the 0.03 m mesh size model showed close values to the 0.02 and 0.025 mesh size models, in the last part (7-10 cm travel), 0.03m mesh size model's shear stress values are between 0.035 and 0.04 m mesh size models. The 0.035 and 0.04 m mesh size models exhibited different results in the first 2 cm of progress, but showed close results in the last 5-10 cm progress. Consequently, considering the previous studies, the 0.02 and 0.025 m mesh size models showed more accurate results than the other models.

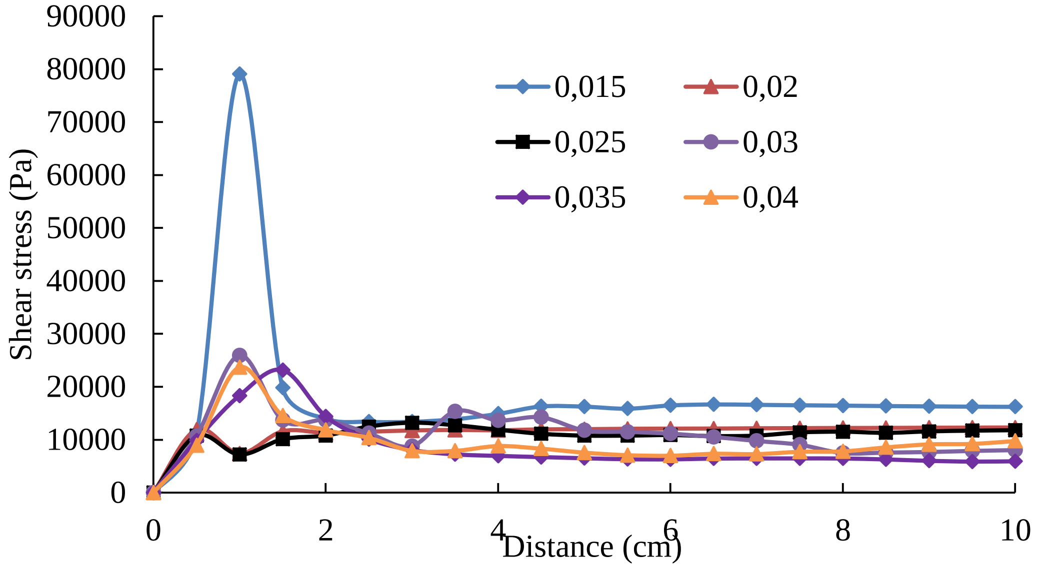

Fig. 5. The variation of shear stress for different mesh sizes

Example 3:

In the third example, the values of normal stress formed on the snow for different mesh sizes are studied and results are given in Fig. 6. In all models except for the 0.015 m mesh size model, first linear increase is observed, then, followed by unregulated change and finally linear decrease observed. 0.020 and 0.025 m mesh size models exhibited nearly equal results to each other. However, the 0.030, 0.035, and 0.040 m mesh size models showed different values in the first 5 cm travel, they showed values close to the 0.02 and 0.025 m mesh size models at the end point.

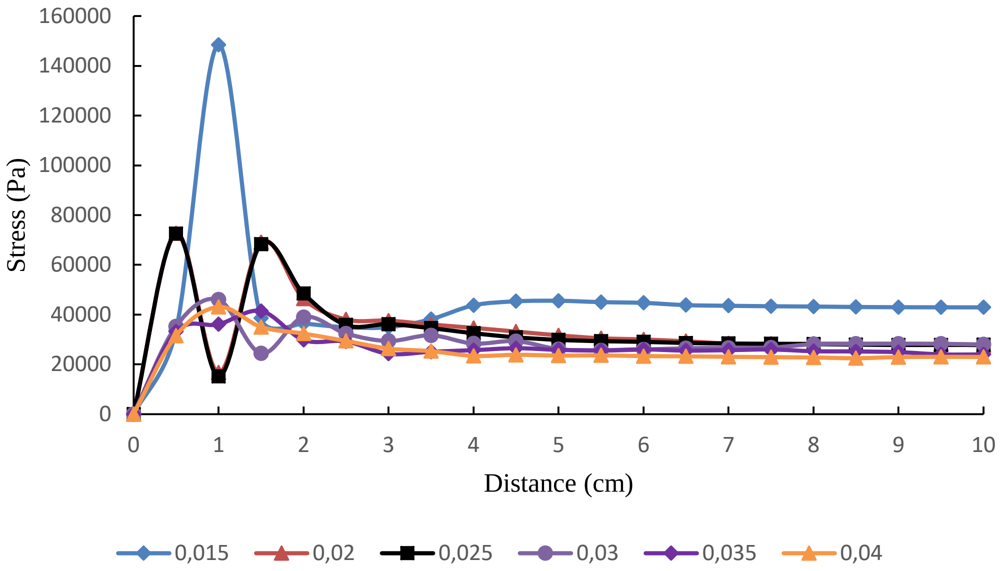

Fig. 6. The variation of normal stress for different mesh sizes

Example 4:

In the fourth example, the values of strain formed on the snow for different mesh sizes are investigated and results were plotted in Fig. 7. First, when the 0.015 m mesh size model is examined, two intense changes are observed in the snow deformation curve of this model and it is found that it has higher value than the other models. As it can be seen in this graph, 0.02 and 0.025 m mesh size models displayed close behavior in the last 6 cm progress, but the 0.02 m mesh size model at the first 4 cm showed a strong increase compared to the 0.025 model. When the other models were compared, itis observed that, although they showed similar results at the first 0.5 cm progression, they had different values in the following sections.

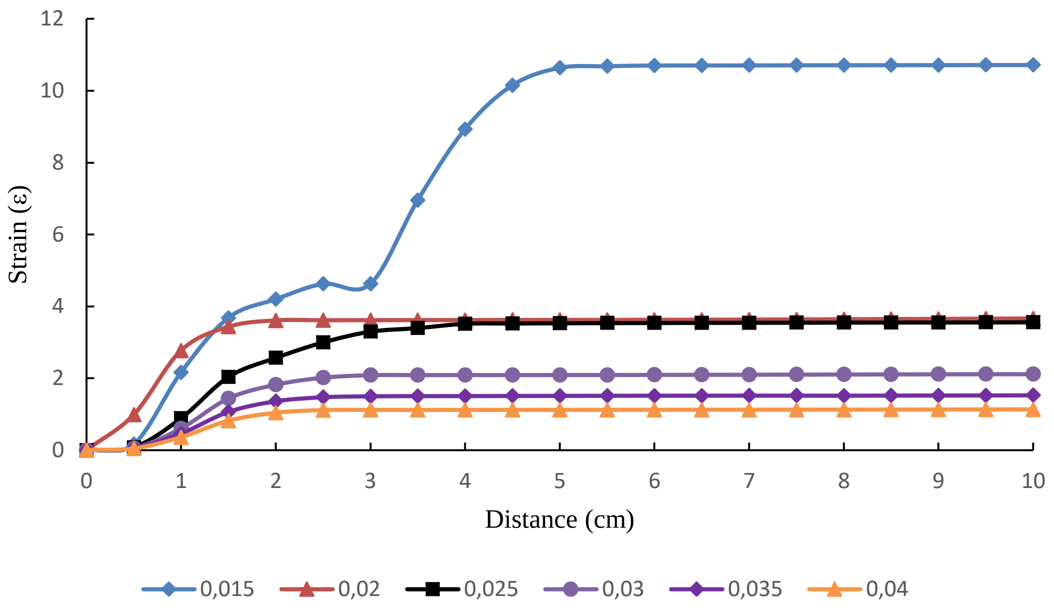

Fig. 5. The variation of strain for different mesh sizes

Example 5:

In the fifth example, the relation between mesh size and solution time is studied and results are presented in Fig. 8. It is found that, there is a strong linear relationship between exponential of the mesh size and the solution time, i.e., the solution time increases as the mesh size gets exponentially smaller.

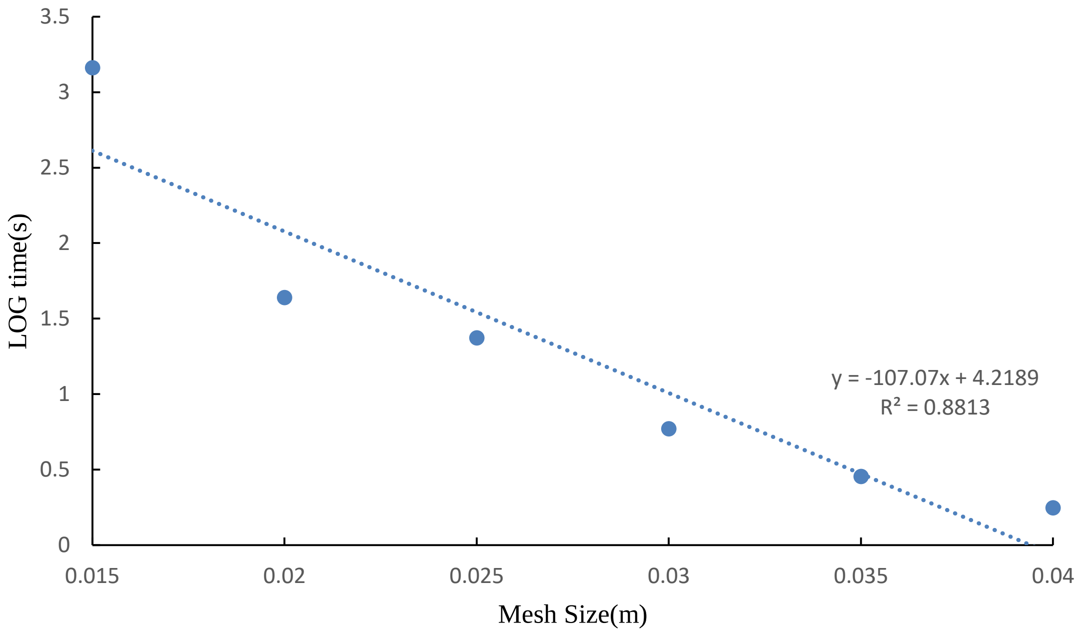

Fig. 6. The variation of time logarithm versus mesh size

Example 6:

In the last example, the relationship between mesh size and number of iteration was discussed and results are plotted in Fig. 9. It is concluded that, there is a strong linear proportion between the number of solution iteration and the exponential mesh size i.e., the mesh size exponentially increases as the number of cycles decreases.

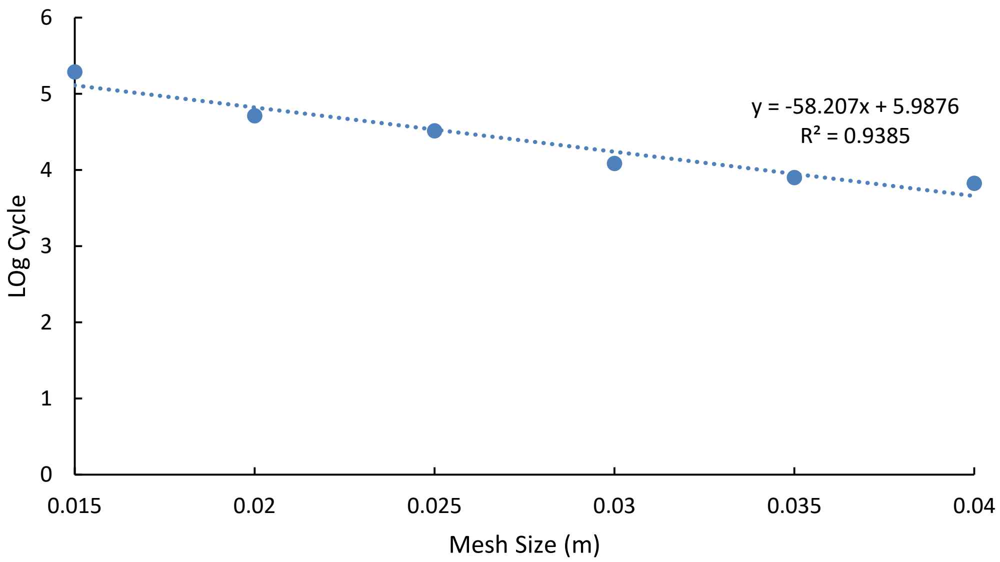

Fig. 9. The variation of number of iteration versus mesh size

4. Conclusion

In the present study, a numerical model is developed for wheel-snow interaction using finite element method based software. For this aim, the model of tire is designed using SolidWorks and ANSYS Design modeler. The analyses of the prepared models are performed using ANSYS Explicit Dynamics considering Mooney- Rivilin tire model. Frictional relationship between wheel and snow ground is established considering snow erosion as linear, in the analyses. Six different mesh sizes are considered, the effect of mesh size and number on the accuracy of the obtained results and solution time is discussed. Briefly, it was found that for sinking, shear stress, normal stress and strain of the snow 0.025 and 0.02 m mesh size models show more accurate results than the other models as well as there is a strong linear proportion between the number of solution iteration and the mesh size i.e., the mesh increases as the number of cycles decreases.

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