Editor

Based upon reviewers' comments, the manuscript needs major revision. Please take into due account all comments and suggestions by the reviewers when preparing your revised manuscript. We look forward to receiving it.

Response: Dear editor, many thanks for your advice. The revised manuscript has been prepared according to all the comments and suggestions by the reviewers. All the modifications are marked in red in the revised manuscript.

Reviewer 1

The paper is addressed to study the dynamic response and the failure of trees subject to a landslide-induced air blast. The study is developed into a framework that includes the eigenfrequency prediction method, tree motion equations and breakage conditions.

The tree is modeled as a flexible variable cross-section beam hinged at ground using elastic support. The air blast loading is calculated considering the large tree deformations.

Two failure modes (bending and overturning) and the associated failure criteria are defined.

The paper address relevant scientific questions within the scope of NHESS, that is the potential forest destruction of the air blasts.

The paper applies known methods on a specific framework.

The scientific methods and assumptions are outlined clearly and the results are sufficient to support the conclusions. The conclusions present the definition and the evaluation of the dynamic magnification effect of an air blast travelling at 20 m/s and the influence of anchorage properties on the tree eigenfrequency.

Some calculations need to be better explained to allow their reproduction by fellow scientists. For example:

(1) in eqs. 4 and 5, what is “B” ? please define it;

Response: We apologize for the mistake. Same to A_1-A_4, B_1-B_4 are also coefficients of the tree deflection equation that need to be determined based on the boundary and continuity conditions. We have added the definition in the revised manuscript (Line 116-117).

(2) in eq 7, what is “F”? please define it and explicit its determinant;

Response: According to Eqs. 5 and 6, $u_1(z)$ and $u_2(z)$ can be written as:

$$u_2(z)=\frac{1}{z}\left[B_1J_2\left(2\sqrt{\lambda_2 z}\right)+B_2Y_2\left(2\sqrt{\lambda_2 z}\right)+B_3J_2\left(2i\sqrt{\lambda_2 z}\right)+B_4Y_2\left(2i\sqrt{\lambda_2 z}\right)\right] \quad l\leqslant z\leqslant h \quad (5)$$

$$u_1(z)=\frac{1}{z}\left[A_1J_2\left(2\sqrt{\lambda_1 z}\right)+A_3J_2\left(2i\sqrt{\lambda_1 z}\right)\right] \quad 0\le z< l \quad (6)$$

Constrained by the continuity conditions of two segments at the splitting point and the boundary condition at the tree base, Eqs. 5 and 6 must satisfy $u_1(l)=u_2(l)$, $u_1'(l)=u_2'(l)$, $u_1''(l)=u_2''(l)$, $u_1'''(l)=u_2'''(l)$, $u_2(h)=0$, and $Ku_2'(h)+EI(h)u_2''(h)=0$ (Lines 121-123). Therefore, a total of six equations are determined here. These six equations can be written as a matrix format:

$$[\mathbf{F}(\lambda_1,\lambda_2)]_{6\times 6}\,[A_1 \quad A_3 \quad B_1 \quad B_2 \quad B_3 \quad B_4]^T=0 \quad (7)$$

where $[\mathbf{F}(\lambda_1,\lambda_2)]_{6\times 6}$ is a matrix that is composed of λ_1 and λ_2. The eigenfrequency and the corresponding vibration mode can be obtained by solving the equation: the determinant of matric $|F(\lambda_1,\lambda_2)|=0$. Notably, the derivatives of $u_1(z)$ and $u_2(z)$ have very complicated expressions but could be easily calculated using Matlab. Therefore we did not provide the complete expression here. The definition of "*F*" has been added in Lines 122-128.

(3) maybe there is some mistakes in the equations of boundary condition in line 128 (the first one);

Response: Dear reviewer, the first boundary condition "$u_1(l)= u_2(l)$" is correct here. As shown in Fig. 2 and described in Line 97, for the Eigenfrequency calculation, the original point (z=0) is set at the treetop and the maximum value of *z* is at the tree base. Therefore, $z=l$ corresponds to the crown base, which is the splitting point of two segments (Fig. 2). Continuity conditions must be satisfied at the point: $u_1(l)= u_2(l)$, $u_1'(l)= u_2'(l)$, $u_1''(l)= u_2''(l)$ and $u_1'''(l)= u_2'''(l)$.

(4) line 158 presents the "w" symbol that is not defined (or is it a typo?);

Response: "*w*" is the first eigenfrequency and we have provided the definition in Line 152.

(5) please make the velocity and displacement symbols explicit.

Response: We apologize for the chaotic use of symbols. To make readers have a better understand, we use symbol "*v*" to represent the velocity and symbol "*u*" to represent the displacement.

About the title, I suggest deleting the sentence after the colon.

Response: Following your advice, we have deleted the sentence after the colon (Line 1).

The abstract provides a concise, complete and unambiguous summary of the work done and the results obtained. The title and the abstract pertinent, and easy to understand to a wide and diversified audience. About the figures, I do not really like the graphics of the fig.s 4, 5, 6 (the histograms). In Fig. 2.b, I suggest to put into evidence the "z" and "u" with vertical and horizontal axis, respectively.

Response: Many thanks for your comments on our manuscript. For Figs. 4, 5 and 7 (Fig. 6 in the initial draft), we have modified them as line charts to make readers have a better understand. Also, we have put into evidence the "*z*" and "*u*" with vertical and horizontal axis in Fig. 2.

The authors give proper credit to previous work, and they indicate clearly their own contribution. The number and quality of the references are appropriate, although not all references are easily accessible by fellow scientists.

The overall presentation is well structured, clear but not so easy to understand by a wide and general audience. The length of the paper is too long: thank you if you can shorten it by removing the various repeated concepts.

Response: Many thanks for your comments on our manuscript. According to your advice, we have removed the repeated concepts to shorten the manuscript.

The English language is fluent, simple and easy to read and understand by a wide and diversified audience and the technical language is precise and understandable by fellow scientists.

Response: Thank you for your recognition of our English writing.

I would ask the authors to make these concepts more explicit in the text:

(1) Are the authors really sure they can use the large deformation hypothesis in this specific case? If so, why? This hypothesis is usually used to study the deformation of hyper-elastic materials, rubbers, etc.

“Large deformations” = Theory of large deformations (I am referring to the non-linear Cauchy model)or Large-displacement or large-rotation theory?

Response: We totally agree with the reviewer’s comment and apologize for the incorrect term. According to the definition by Pivato et al. (2014), our work accounts for the “large deflection” not “large deformation”. The geometric non-linearities related to the tree curvature are accounted for in the expression of the wind load on the tree structure (Eq. 9). Pivato et al. (2014) have tested the ability of using the multi-degree-of-freedom tree swaying model to simulate large deflections and shows good performance (Line 164). We have made the corresponding modifications (change the term to “large deflection”) in the revised manuscript to make readers have a better understand.

Pivato, D., Dupont, S., and Brunet, Y.: A simple tree swaying model for forest motion in windstorm conditions, Trees, 28, 281-293, 2014.

(2) About the boundary condition at the tree base (continuity conditions, lines 126 - 128), I believe the authors use elastic line theory (i.e. Euler-Bernoulli beam theory), i.e. they refer to a linear model of the beam. If this were true, this passage would go against the hypothesis of large deformations. please explain why you can use these equations.

Response: We apologize for the incorrect term in the manuscript. Our work accounts for the “large deflection” (Pivato et al. 2014) rather than “large deformation” you mentioned. The eigenfrequency is calculated using a Euler-Bernoulli beam theory and a linear modal analysis is used to model the tree motion under air blast load. The geometric nonlinearities related to the tree curvature are accounted for in the expression of the wind load on the tree structure. Therefore, our work does not against the “large deflection”. This method could account for the large tree deflection and has been tested by Pivato et al. (2014).

Pivato, D., Dupont, S., and Brunet, Y.: A simple tree swaying model for forest motion in windstorm conditions, Trees, 28, 281-293, 2014.

(3) it is not clear to me why (in lines 271-274) “to investigate the impact of these factors, we conducted a comparative analysis by simplifying the tree motion model of eq.8 WITHOUT involving the impact of large tree deformation”. so the starting hypothesis is no longer taken into account? we return to the hypothesis of small deformations? Thank you if you can explain this better.

Response: Many thanks for your valuable comment. As we stated in Lines 274-279, our proposed model accounts for the impacts of large tree deflection (Sorry, not large deformation): eccentric gravity and modeling of air blast force regarding the wind-tree relative motion and geometric nonlinearities. To investigate the impacts of these factors and confirm the necessity of considering large deflection, a comparative analysis is needed to make readers have a better understand. Therefore, we designed a comparative analysis in the absence of the hypothesis of large tree deflection. The comparative analysis in the absence of large tree deflection provides two main contributions here: (1) highlight the impact of large tree deflection to the air blast assessment (most important contribution); (2) validate the proposed model (both analyses show high agreement in the case of a very low air blast loading, as shown in Fig. 7). We have added the explanation in the revised manuscript (Lines 275-277).

Reviewer 2

The paper tests tree motion equations and breakage conditions under air blasts triggered by large landslides by modeling a tree as a flexible variable cross-section beam hinged at the ground using elastic support. They assess bending and overturning forces.

I like the way the authors approach the problem of impact forces in air blasts. But the question remains unclear-how realistic are the numbers you obtained from your model? A comparison/plot of field observed results vs your model results would potentially benefit the readership of this paper. I saw not only trees but even reinforced concrete pillars being pulled out from the ground by the air blast during field trips in the Langtang avalanche. The pullout forces are very important, probably references from tree pullout tests could be helpful – check with as many cases as you can to know how realistic are those numbers in your model. A case validation on any of the large avalanches would be great!

Response: Many thanks for your valuable comments. I totally agree with your suggestion that a comparison of field tests with our modeling results would benefit the readership. For the eigenfrequency prediction method (Section 2.1), we used parameters provided by Jonsson et al. (2006) and compared the calculated results with their measurements (Lines 200-203). Good consistency checks the validity of our model. As for the tree motion model (Section 2.2), Pivato et al. (2014) and Zhuang et al. (2022a) have validated the model through comparing with test results (mentioned in Line 164). We further checked the model through comparing it with analytical solutions performed by Bartelt et al. (2018) in the case of a weak air blast (Line 293-295). Therefore, we suggest that our model could represent the essential characteristics of trees subjected to a powerful wind load.

We also agree with your comments that pullout forces are very important. We have indeed investigated the air blast triggered by Langtang avalanche (Zhuang et al. 2022b). The pullout of trees you mentioned corresponds to the overturning failure mode we defined in section 2.3. Notably, previous research proved that pressures required for uprooting are in the same range or higher than for stem breakage (Bartelt and Stöckli, 2001; Feistl et al. 2015). Therefore, both bending and anchorage resistance are very important, and the occurred failure mode depends heavily on the biometric characteristics of trees (discussed in Lines 244-247, 314-320). In lines 241-247, we performed simulations on the air blast induced-tree breakage. Modeling results were compared with bending strength and anchorage resistance measured by Peltola et al. (2000) and Lundström et al. (2007).

Actually, most research about landslide-air blasts just describes the tree-breakage phenomenon. Very few studies tested the geometric and mechanical properties of damaged trees. Our previous work on the Wenjia valley avalanche-induced air blast indicated that the damaged trees are primarily tall spruces (Zhuang et al. 2019), similar to the tree parameters presented in Table 1. According to your advice, we have performed a brief case validation using the Wenjia valley avalanche (Lines 248-258).

Bartelt, P. and Stöckli, V.: The influence of tree and branch fracture, overturning and debris on snow avalanche flow, Ann. Glaciol., 32, 209-216, 2001.

Bartelt, P., Bebi, P., Feistl, T., Buser, O., and Caviezel, A.: Dynamic magnification factors for tree blow-down by powder snow avalanche air blasts, Natural Hazards Earth System Sciences, 18, 759-764, 2018.

Feistl, T., Bebi, P., Christen, M., Margreth, S., Diefenbach, L., and Bartelt, P.: Forest damage and snow avalanche flow regime, Natural Hazards and Earth System Sciences, 15, 1275-1288, 2015.

Jonsson, M. J., Foetzki, A., Kalberer, M., Lundström, T., Ammann, W., and Stöckli, V.: Root-soil rotation stiffness of norway spruce (Picea abies (L.) Karst) growing on subalpine forested slopes, Plant Soil, 285, 267-277, 2006.

Lundström, T., Jonsson, M. J., and Kalberer, M. The root-soil system of Norway spruce subjected to turning moment: resistance as a function of rotation, Plant Soil, 300, 35-49, 2007.

Peltola, H., Kellomäki, S., Hassinen, A., and Granander, M.: Mechanical stability of Scots pine, Norway spruce and birch: an analysis of tree-pulling experiments in Finland, Forest Ecology and Management, 135, 143-153, 2000.

Pivato, D., Dupont, S., and Brunet, Y.: A simple tree swaying model for forest motion in windstorm conditions, Trees, 28, 281-293, 2014.

Zhuang, Y., Xu, Q., and Xing, A. G.: Numerical investigation of the air blast generated by the Wenjia valley rock avalanche in Mianzhu, Sichuan, China, Landslides, 16, 2499-2508, 2019.

Zhuang, Y., Xing, A. G., Jiang, Y. H., Sun, Q., Yan, J. K., and Zhang, Y. B.: Typhoon, rainfall and trees jointly cause landslides in coastal regions. Engineering Geology, 298, 106561, 2022a.

Zhuang, Y., Xu, Q., Xing, A. G., Bilal, M., Gnyawali, K. R.: Catastrophic air blasts triggered by large ice/rock avalanches. Landslide, 2022b. Doi: 10.1007/s10346-022-01967-8.

L224 -. What do Feistl et al. 2015 say about assuming density=5 kg/m3?

Response: As described in the manuscript (Lines 216-217), the landslide-induced air blast is a multi-medium fluid that contains numerous dusts, leading to a higher density than air (1.225 kg/m^3). Researchers (e.g., Feistl et al. 2015) in WSL Institute for Snow and Avalanche Research SLF (Switzerland) have done great work on air blast dynamics through experiments and numerical modeling, and suggest a density of 5kg/m^3 for the air blast. Therefore, this value is selected in our work. We have added the explanation in the revised manuscript (Lines 217-218).

Feistl, T., Bebi, P., Christen, M., Margreth, S., Diefenbach, L., and Bartelt, P.: Forest damage and snow avalanche flow regime, Natural Hazards and Earth System Sciences, 15, 1275-1288, 2015.

L330 -> short-duration impulses and can intensify the destruction of vegetation and structures far beyond …

Response: Measurements of air-blast duration reported by Russian and Swiss researchers (Grigoryan et al., 1982; Sukhanov, 1982; Caviezel et al., 2021) indicated that the air blast is intermittent and of short duration, lasting only a few seconds (Lines 73-75). Additionally, the generated air blast has been known to be capable of causing fatalities and destruction far beyond the runout of the movement mass (Zhuang et al. 2022b). Therefore, we made the statement in the manuscript (Line 332).

Caviezel, A., Margreth, S., Ivanova, K., Sovilla, B., and Bartelt, P.: Powder snow impact of tall vibrating structures. In: Papadrakakis M, Fragiadakis M, editors. Compdyn 2021 Proceedings. Institute of Research & Development for Computational Methods in Engineering Sciences. Elsevier, 5318-5330, 2021.

Grigoryan, S., Urubayev, N., and Nekrasov, I.: Experimental investigation of an avalanche air blast, Data Glaciology Student, 44, 87-93, 1982.

Sukhanov, G.: The mechanism of avalanche air blast formation as derived from field measurements, Data Glaciology Student, 44, 94-98, 1982.

Zhuang, Y., Xu, Q., Xing, A. G., Bilal, M., Gnyawali, K. R.: Catastrophic air blasts triggered by large ice/rock avalanches. Landslide, 2022b. Doi: 10.1007/s10346-022-01967-8.

Community comment:

This paper performed a very interesting work about the air blast risk assessment. It proposed an applicable method to estimate the hazard associated with air blasts using the tree breakage. The analytical technique is feasible and the results appear reasonable. Though the writing is smooth and clear, some modifications will make the paper more understandable.

(1) Symbols in some equations are not well defined (Eq. 7), pleas define it.

Response: Following your valuable comment, we have made the corresponding modifications in the revised manuscript (Lines 125-128).

(2) In lines 267-278, authors performed a new comparative simulation. Some hypothesis appears to have changed. Please make a clearer statement to make readers have a better understand here.

Response: Many thanks for your valuable comment. As we stated in Lines 274-275, our proposed model accounts for the impacts of large tree deflection (Sorry, not large deformation): eccentric gravity and modeling of air blast force regarding the wind-tree relative motion and geometric nonlinearities.

To investigate the impacts of these factors and confirm the necessity of considering large deflection, a comparative analysis is needed to make readers have a better understand. Therefore, we performed a comparative analysis without accounting for the hypothesis of large tree deflection. The comparative analysis in the absence of large tree deflection provides two main contributions here: (1) highlight the impact of large tree deflection on the air blast assessment; (2) validate the proposed model (both analyses show high agreement in the case of a very low air blast loading, as shown in Fig. 7). We have added the extra explanation in the revised manuscript (Lines 275-277).