COMPARISON OF TWO NUMERICAL MODELS BY USING A CASE STUDY OF 2014 DEBRIS FLOW DISASTER IN HIROSHIMA.

Alessandro Gustavo Franck [1] & Masato Kobiyama [2]

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INTRODUCTION

Debris flows are common in mountain regions, being severe natural hazards due to their high velocity, travel distance and huge destructive energy. These phenomena cause significant morphological changes along rivers and mountain slopes, and frequently extensive property damage and human loss. Numerical simulation has been widely applied to assess debris flow hazards, there are various numerical models, among which the Hyper KANAKO – HK (Nakatani *et al*. 2012) and the Morpho 2DH – M2DH (Takebayashi, Egashira, Fujita 2014) can be considered widely applied.

Several authors have already proposed comparative analyses between debris flow models, for examples, Cesca and D'Agostino (2008), and Wu, Liu, Chen (2013). Such studies are important to recognize the limits of each model application. Thus, a particular model can be applied preferably in particular situations for each event.

Therefore, the objective of the present study was to compare the performances of two models HK and M2DH by using the debris flow disaster which occurred in Hiroshima Prefecture in 2014 and was reported by Tsuchida *et al*. (2019).

METHODOLOGY

Study area

Asa-Kita ward in Hiroshima city, Hiroshima Prefecture has a humid subtropical climate (Köppen climate classification Cfa). In this ward, the mean annual rainfall is 1,678.3 mm with July as the wettest month. In this place, in August 2014, several mass movements were triggered after a torrential rainfall recorded at some of the areas in Hiroshima that exceeded 100 mm/h. As a result of that in Asa-Minami and Asa-Kita wards in Hiroshima City, a large number of debris flows (at 107 locations) and slope failures (at 59 locations) occurred simultaneously from 03:30 am to 04:00 am. The debris flow occurred in this event caused 74 dead and 44 injured, 132 completely-destroyed houses, and 122 partially-destroyed houses (Tsuchida *et al.* 2019). Then, to perform our analysis we focused on one of these debris' flows (Figure 1). Takebayashi and Fujita (2020) also studied and described this event with M2DH, showing its good potential to represent the occurrence of this phenomenon. After several events that occurred in this region, a bunch of structural measures to contain sediments related disasters were implemented at the site (Figure 1).

Models' theory

Nakatani *et al*. (2012) modified the Kanako-2D, creating Hyper KANAKO (HK) as its second version. The HK uses the dilatant fluid theory adapted for debris flows by Takahashi (1991). In this theory, the repulsive forces caused by collisions between particles are considered responsible for maintaining the flow. There are four fundamental equations in this model (Franck and Kobiyama, submitted). HK simulates the flow from its entrance into the channel in the initiation zone with equations in 1-D scheme and the flow propagation in the transport and deposition zones on the alluvial plain in 2-D. The model uses the finite difference method to perform numerical simulations,

1) Federal University of Rio Grande do Sul - Hydraulic Research Institute, alessandro.franck@ufrgs.br
2) Federal University of Rio Grande do Sul - Hydraulic Research Institute, masato.kobiyama@ufrgs.br

scaling the scalars and vectors by $\Delta x/2$ in the flow direction (x-axis) and $\Delta y/2$ in the transverse direction (y-axis). The details about the governing equations can be seen in Nakatani *et al*. (2012).

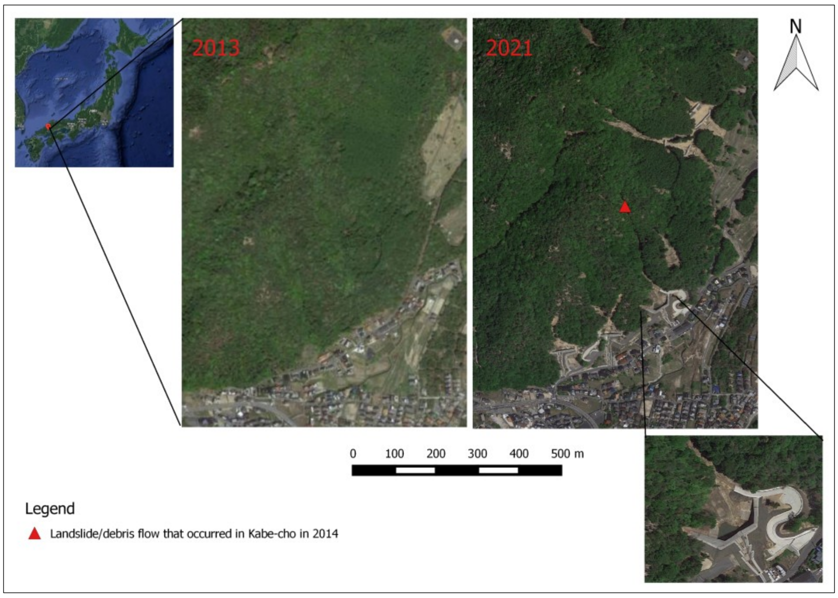

Figure 1. Images of the study area before de event in 2013 and after in 2021. Note that in the detail we can see several SABO dams in the 2021 image.

The M2DH is one of the solvers available on the International River Interface Cooperative (iRIC) software platform, which has a user-friendly interface and is freely available on the internet. This solver was imputed in the iRIC and uses a TVD-MacCormack scheme (2nd order accuracy) for the convection term in the momentum equations as the difference method. The energy dissipation is calculated by the constitutive laws of two layers model. The laminar flow layer near the bed and the turbulence flow layer on the laminar flow are considered in the two-layer model. The model has the following assumptions: (i) movements of the mixtures of water and sediment due to landslides are used as the initial conditions of debris flow; (ii) the horizontal distribution of maximum erosion depth can be considered; (iii) physical structures (ex. SABO dams, weir and so on) can be considered by use of the height data of the non-erosion area; (iv) obstacles (ex. houses and so on) in the calculation domain can be considered; and (v) vegetation can be considered as a drag force acting on the flow. The cover rate and the height of vegetation can be considered to estimate the drag force by introduction of the vegetation cover rate file and the vegetation height file. The detail information about the governing equations can be seen in Takebayashi and Fujita (2020).

Data and simulation parameters

To perform the simulations, we used a DTM (5-m resolution) freely available on the internet, provided by GIAJ (2022). Table 1 shows the other input parameters. The parameters not presented in Table 1 were defined as default.

Table 1 – Parameters used in the simulations

Parameter	Value adopted in both models	Parameter	Value adopted in both models
Computational time step (s)	0.01	**Mean grain diameter (m)**	0.01
Output time interval (s)	1	**Manning coefficient ($s.m^{-1/3}$)**	0.03
Sediment concentration ($m^3.m^{-3}$)	0.4	**Max erosion depth (m)**	0.4
Minimum flow depth (m)	0.01	**Volume of landslide (m^3)**	~ 60
Internal friction angle (deg)	34	**Grid size (m)**	~ 2

RESULTS AND DISCUSSION

To set up simulations, HK has a very linear and intuitive toolbar, which allows users to quickly prepare and change parameters for a new simulation. However, it requires specific formats of input files to be able to perform the simulation, preparing these files may not be very intuitive, demands a certain level of GIS knowledge, and takes some time. M2DH, on the other hand, accepts several formats of input files (all formats accepted by iRIC). Input parameter settings can be quickly changed in the solver menu. Another advantage of M2DH is that a preview of the result can be seen during the simulation. However, the M2DH is highly sensitivity to the Courant–Friedrichs–Lewy condition, presenting numerical instabilities frequently until the parameters are adjusted. Regarding the simulation parameters, the priority was to ensure that both models had as many equal parameters as possible, so that the comparison was fairer. Even so, due to the different equations and theories used in both the models, there were some parameters that could not be equal.

The simulation results show significant differences between the models. The main difference is the maximum depth in the front of debris flow during each simulation step presented by the two models, where this depth in the HK is much smaller than in the M2DH during most of the time (Figure 2a). HK has a fixed discretization interval in the results visualization, and does not permit to edit it for a better view. During the period when the flow depth was greater in HK, we cannot affirm if this maximum depth actually occurred. In other words, the only information we have is that this value was between 100 and 300 cm. Thus, this value could be higher than that presented by M2DH or not.

In general, the possibility of better discretizing the range of results on the *z*-axis (max depth, max erosion, flow velocity, etc.) and the practicality of extracting them gives M2DH an advantage in functionality. This allows the user to conduct a more detailed analysis of variations in the flow during its progression.

Analyzing Figure 2b, we notice a divergence in the travel distance at certain times of the simulation. With HK, there was an acceleration of the flow after 15 seconds and a deceleration after 25 seconds, meanwhile with M2DH, the progression remained more constant until the flow reach the houses (60 s), when the flow decelerates until the end of simulation, due to abrupt slope reduction. It is also noted that the simulation with the HK took 10 seconds longer for the debris front to reach the first inhabited regions. In this small-scale event, this is not very significant, but for larger scale events this time could become minutes, presenting a longer or shorter time for evacuation. This difference needs further investigation in order to present a more conclusive result.

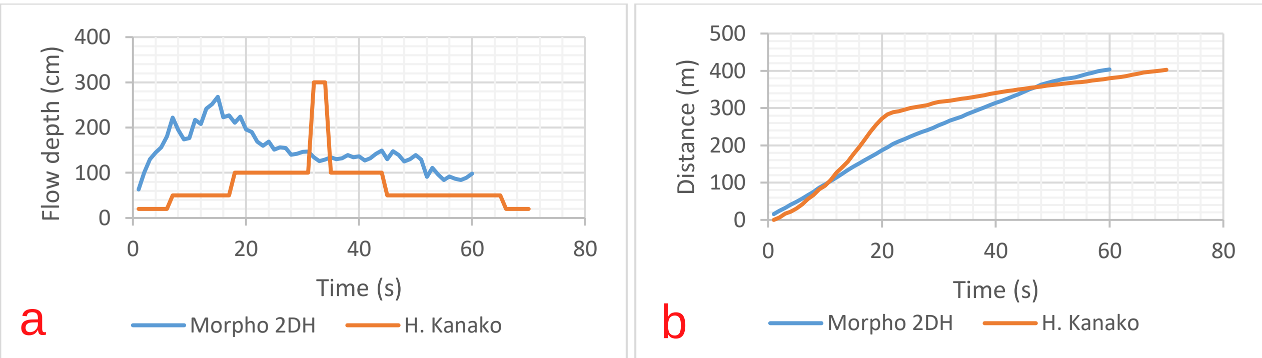

Figure 2. Comparison of both models: (a) flow depth variation; (b) distance in time.

Figure 3 presents the results in 3 different times of interest (25 s; 60 s or 70 s; and 120 s). In the first time, as we can see in Figure 2b, is the time when the flows were further apart, in the second time, they reached the residential area at 70 seconds in HK and 60 seconds in M2DH, and finally, the third time, is approximately when the flow ends for both models.

Despite the differences during the flow progression, the affected area in the simulation presented very similar results for both models. This indicates that for mapping areas susceptible to debris flows, both models can be good options, although there is a significant difference in the maximum depth of the flow that must be investigated, as this parameter demonstrates the destructive potential of the event.

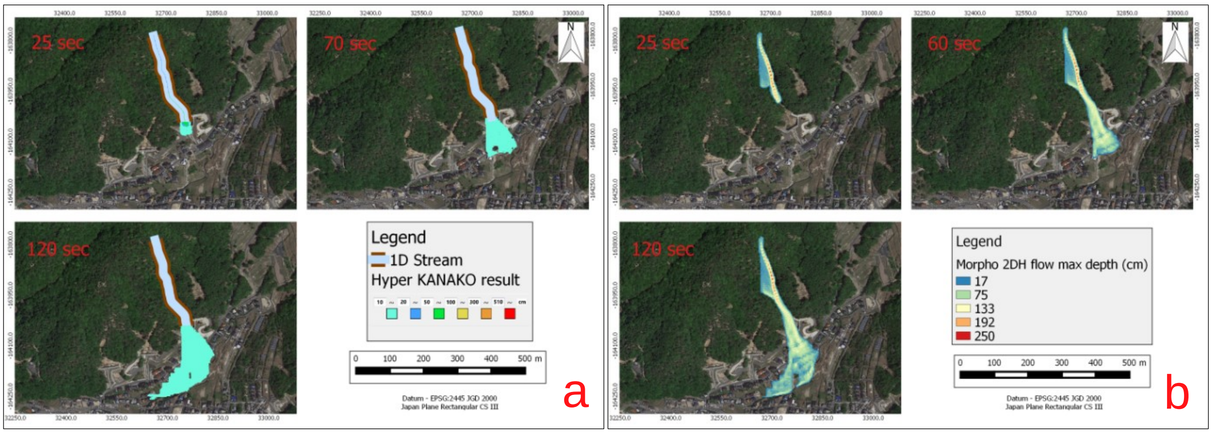

Figure 3. Debris flow propagation at three different times: (a) Hyper KANAKO, and (b) Morpho 2DH.

CONCLUSIONS

In general, Morpho 2DH presented some advantages over Hyper KANAKO, mainly in relation to the geoprocessing interface and results visualization. However, there was also a certain difference between the results presented by the two models. To better assess these differences and the limitations of each model, further investigations are needed, with model calibration and simulations for events of different magnitudes.

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