Brief communication: simple-INSYDE, development of a new tool for flood damage evaluation from an existing synthetic model

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Abstract

INSYDE is a multi-variable, synthetic model for flood damage assessment to dwellings. The analysis and use of this model highlighted some weaknesses, linked to its complexity, that can undermine its usability and correct implementation. This study proposes a simplified version of INSYDE which maintains its multi-variable and synthetic nature, but has simpler
10 mathematical formulations permitting an easier use and a direct analysis of the relation between damage and its explanatory variables.

1 Introduction

INSYDE (IN-depth SYnthetic Model for Flood Damage Estimation, Dottori et al., 2016) is a synthetic model for the estimation of flood damage to residential buildings at the micro scale (i.e. building level), developed and tested in Italian case studies
15 (Amadio et al., 2019, Molinari and Scorzini, 2017, Molinari et al., 2020). The monetary damage to a dwelling is computed in the model as the sum of 33 different components, referring to the costs of repair, removal and replacement of the damaged elements, which are functions of several damage explicative variables, related both to the hazard and to the vulnerability of the affected item (Table 1). Since the same explicative variable may directly or indirectly influence more than one damage component, it is difficult to understand the weight that each explicative variable has on the overall damage estimate. Moreover,
20 the complex and articulate structure of INSYDE could dissuade less expert users to use the model and discourage its implementation with platform and calculation tools others from the original one. This study proposes an alternative version of the model, named simple-INSYDE, which aims at overcoming these limitations. Simple-INSYDE preserves the multi-variable nature of the model, but aggregates damage components in a smaller set of functions, which clearly describe the role of each explicative variable on the total damage figure and can be easily implemented, even by non-expert users. Such functions are
25 calibrated for low-velocity floods, with building characteristics typical of Northern Italy. The method and the assumptions implemented to obtain the simplified version of the model are described in the following sections.

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Table 1. Input variables considered in INSYDE (Dottori et al., 2016) and selected variables in simple-INSYDE. "x" refers to the variables chosen in simple-INSYDE as independent variables**.**

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Event features and building characteristics variables in INSYDE		Default values in INSYDE	Independent variables chosen in simple-INSYDE
h_e	water depth outside the building [m]	[0;5] Incremental step: 0.01m	x
h	water depth inside the building [m]	$h = f(h_e, GL)$	Fixed at default value
v	maximum velocity of the water perpendicular to the building [ms^{-1}]	0.5	Fixed at default value
s	sediment load [% on the water volume]	0.05	Fixed at default value
du	duration of the flood event [h]	24	x
q	water quality (presence of pollutants)	Yes	x
FA	Footprint Area [m^2]	100	x (renamed A in simple-INSDYE)
IA	Internal Area [m^2]	0.9 FA	Fixed at default value
BA	Basement Area [m^2]	0.5 FA	x
EP	External Perimeter [m]	4√FA	Fixed at default value
IP	Internal Perimeter [m]	2.5 EP	Fixed at default value
BP	Basement Perimeter [m]	4√BA	Fixed at default value
NF	Number of floors	2	Functions for one storey
IH	Interfloor height [m]	3.5	Fixed at default value
BH	Basement height [m]	3.2	Fixed at default value
GL	Ground floor level [m]	0.1	Fixed at default value
BL	Basement level [m]	– GL – BH – 0.3	Fixed at default value
BT	Building type (1 detached house, 2 semi-detached, 3 apartment)	1	Fixed at default value
BS	Building structure (1 reinforced concrete, 2 masonry)	2	x
FL	Finishing level (1.2 high, 1 medium, 0.8 low)	1.2	x
LM	Level of maintenance (1.1 high, 1 medium, 0.9 low)	1	x
YY	Year of construction	1994	Fixed at default value
PD	Heating system distribution (1 centralized, 2 distributed)	1 if YY≤1990, 2 otherwise	Fixed as 1 (centralized)
PT	Heating system type (1 radiator, 2 pavement)	2 if YY>2000 and FL>1, 1 otherwise	Fixed as 1 (radiator)

2   Method

40   The first step to provide a simpler structure of the model was to aggregate the original damage functions into four components:

- Damage to basement: in case of flood, basement is assumed totally inundated and damage does not depend on water level.

- Damage to floor: in case of water level higher than the level of floor, the damage to floor is counted as independent from water level.

45   - Damage to storey: it considers damage to the elements over the floor (e.g., walls and systems) that depends on water level.

- Damage to boiler: it depends on water level only if the basement is not present, otherwise, the boiler is considered located in the basement which is completely inundated.

In order to support model transferability (Merz et al., 2010), the simplified model computes damage in relative terms, as the
50   ratio of the absolute damage to a reference value. The reference value is set as the cost of reconstruction of the storeys exposed to the flood, which is evaluated as the product of the replacement value RV [€/m^2] and the footprint area A of each storey [m^2]. Equation (1) represents the conceptual formula of the simplified model, where D is the building damage in absolute term [€], d in relative term, n is the number of flood exposed storeys.

$$D = RV_{basem} \cdot A_{basem} \cdot d_{basem} + RV_{storey} \cdot A \cdot \left(\sum_{i=1}^{n} (d_{storey_i} + d_{floor_i}) + d_{boiler} \right) \qquad (1)$$

55   The second step was the choice of the independent variables to be included in the model, among those of the original INSYDE (Table 1). The variables that were not included in simple-INSYDE were not effectively neglected, but implicitly assumed at the default values according to the assumptions made in INSYDE, for the geographical context and the flood type of interest (Wagenaar et al., 2016). We fixed as default value the variables considered constant in the geographical context, or that are generally not known, or that are functions of other variables or that do not influence significantly damage simulation. Among
60   the variables describing the event, we preserved the water level, the duration of the flood and the presence of pollutants. Indeed, the sensitivity analysis performed in Dottori et al. (2016) highlighted that, in case of slow riverine flood events, water velocity and sediment load have a minor influence on damage, compared to the chosen variables. The selection of the vulnerability variables followed different criteria. We considered the interfloor height and the basement height fixed at their default values because they do not vary significantly in Northern Italy. We kept the default value also for the ground floor level and the
65   heating system variables (PD and PT), because information on them is difficult to retrieve, without a detailed field survey. The internal area, the external perimeter, the internal perimeter, the basement perimeter and the basement level are fixed as functions of other variables in INSYDE, and we maintained the same functions. However, this implies limiting the use of the model for the estimation of damage to single housing units, and not to condominiums; indeed, the functions to estimate perimeters in INSYDE were established considering the typical configuration of a 100 m^2 detached Italian house; this
70   configuration is kept constant in the model, thus not considering a variation in the number of rooms or a multiplication of housing units in case the building area increases. The remaining vulnerability variables were the object of a one-at-a-time sensitivity analysis, which revealed that the variation of the values of the year of construction and of the building type causes

a change of the mean relative damage smaller than 2%, compared to the caused by the other variables which is between 12% and 38%. On the other hand, the building type, in Italy, is important to evaluate the replacement value. Table 1 shows the variables that were finally considered in simple-INSYDE.

The last step was the development of the simplified functions. For the four damage components, a set of reference values was defined for each variable that influences the component under investigation, e.g. A=100 m^2 and FL=low. Then, damage to each component was calculated by varying the value of one variable at a time (e.g. f(A) or f(FL)) and keeping the others at their reference value. The resulting functions are simple interpolating functions suitable for representing the role of each variable in the estimation of a specific damage component: for variables that assume only two values, as BS or FL, the only identification of multiplicative coefficients was required, for variables with a wide range of values, as d or A, the functions that approximate the role of the variables in the final damage figure are more complex. Then, the interpolating functions were calibrated comparing the damage simulated by the simplified model and the original model for a sample of 10000 buildings, whose features (i.e. input variables values) were partly randomly selected from probability distributions assumed representative of Northern Italy (Table 2) and partly set at default values. In particular, the parameters of the probability distributions were chosen on the basis of data supplied by Istat (the Italian institute of statistics), the real estate market observatory of the revenue agency (Agenzia delle Entrate) and some provincial databases that refer to built environment in the regions Emilia Romagna, Lombardia, Piemonte and Veneto.

The final result of the process is expressed by equations 2-5, which represent the simple-INSYDE model:

$$d_{basement} = f(A_{basem})f(du) \rightarrow \begin{cases} f(A_{basem}) = 0.02 + \frac{0.35}{\sqrt{A_{basem}}} \\ f(du) = 1 + 0.3\arctan(du - 36) \end{cases} \tag{2}$$

$$d_{storey} = f(h)f(A)f(LM,du)f(BS)f(FL)f(q) \rightarrow \begin{cases} f(h) = \left(0.17h - 0.02h^2\right) \\ f(A) = \left(0.2 + \frac{7}{\sqrt{A}}\right) \\ f(LM,du) = \begin{cases} 1 + 0.15 \cdot \arctan(du - 36) & \text{if LM low} \\ 0.8 + 0.2 \cdot \arctan(du - 36) & \text{if LM high} \end{cases} \\ f(BS) = \begin{cases} 1.35, & \text{if BS masonry} \\ 1, & \text{elsewhere} \end{cases} \\ f(FL) = \begin{cases} 1.5, & \text{if FL high} \\ 1, & \text{elsewhere} \end{cases} \\ f(q) = \begin{cases} 1.2, & \text{if q} = 1, \text{presence of pollutants} \\ 1, & \text{elsewhere} \end{cases} \end{cases} \tag{3}$$

$$d_{floor} = f(h, FL) = \begin{cases} 0.04, & \text{if h>0 and FL high} \\ 0, & \text{elsewhere} \end{cases} \tag{4}$$

$$d_{boiler} = f(A_{basem}, h) = \begin{cases} 0.015, & \text{if } A_{basem} \neq 0 \text{ or } A_{basem} = 0 \text{ and } h > 1.6 \text{ m} \\ 0, & \text{elsewhere} \end{cases} \tag{5}$$

where the units of measures of the variables are m^2 for the area (A), hours for duration (du), and m for water depth (h).

Table 2. Probability distributions and respective parameters of the explicative variables.

Variable	Distribution		Notes
A	Log-Normal	Lognormal(5.10, 0.49)	
FL	Bernoulli	B(1, 0.02)	0.02 probability FL high
BS	Bernoulli	B(1, 0.64)	0.64 probability BS masonry
LM	Bernoulli	B(1, 0.86)	0.86 probability LM high
NF	Discrete Uniform	U{1, 10}	
Basement	Discrete Uniform	U{0, 1}	0 absent, 1 present
BT	Discrete Uniform	U{1, 3}	1 detached house, 2 semi-detached, 3 apartment
du	Discrete Uniform	U{10, 60}	unit of measure: hour
h	Continuous Uniform	U(0, 3.5)	unit of measure: meters
q	Discrete Uniform	U{0, 1}	0 absent, 1 present

The comparison of the simulated damage by the original and the simplified model, showed a mean relative error equal to 0.24, with a ratio to the mean absolute damage equal to 1.07. The application of the model INSYDE in real case studies (Dottori et al., 2016, Molinari and Scorzini, 2017, Amadio et al., 2019, Molinari et al., 2020) showed good performance of the model, with a mean ratio between the total damage simulated and the observed damage equal to 1.26. On the other hand, literature shows that the performance of flood damage models can be affected by high uncertainty, with relative errors vary from 20% to exceed 1000% (Scorzini and Frank, 2017, Thieken et al., 2008). Thus, we consider that the additional error caused by the use of simple-INSYDE is acceptable, and that the estimation of the overall damage is comparable with that supplied by INSYDE.

3 Discussion

This study led to the main objective of developing a new tool for flood damage estimation to dwellings from the simplification of the model INSYDE. The new model is based on a sensible number of available input data and allows investigating the relation between damage and its explanatory variables by means of a simple set of functions. For instance, Figure 1 shows the relative damage computed by simple-INSYDE as a function of water depth, for the different damage components of the model. The figure highlights that the storey component gives the biggest contribution to the damage and it is the only one depending on water level. The other components are independent on water level and have a lower weight on the final damage figure; still, they assume a non-negligible role, especially in case of shallow waters.
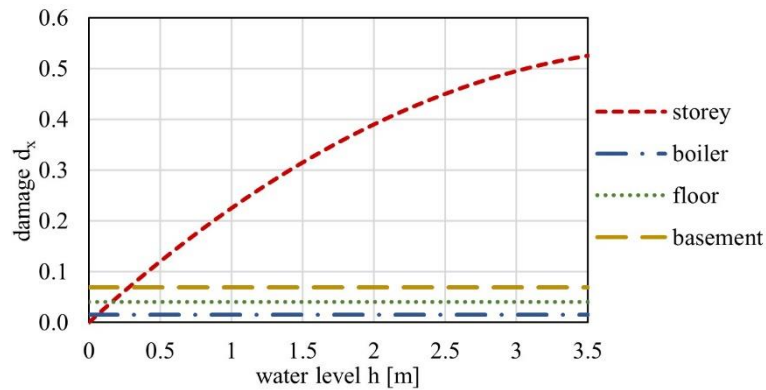
Figure 1 - Comparison of the simple-INSYDE damage components as functions of water depth. Damage values in the figure refer to the case of a 100 m² building, with cellar, in reinforced concrete, with high finishing level and low maintenance level, affected by a flood of 36 hours, in absence of pollution.

Moreover, the study allowed to deeply investigate the behaviour of the original model and to highlight shortcomings that could be further improved in the future. For example, assumptions made in the model on building configuration, which limit its use to single housing units and not condominiums, is not directly reported in the paper of Dottori et al. (2016), but it is important for a correct implementation of the model and a better understanding of estimation errors.

The study demonstrates that the use of a simplified model, which is consistent with the assumption of the original one, can lead to comparable results and does not decrease considerably the accuracy of damage forecast.

Compared to the original model, the simplified model requires fewer input variables, facilitating the model implementation, but hampering the control on the variables that are implicitly considered. For this reason, simple-INSYDE is less adaptable to contexts different from the calibration one than INSYDE. In this regard, it is worth recalling that simple-INSYDE is addressed to evaluate damage in case of low-velocity floods and built environments typical of Northern Italy. It is recommended not to use it for other types of inundation (Kreibich and Dimitrova, 2010) or for other types of building and/or geographical contexts. In these cases, the derivation of new interpolating functions from INSYDE, with the process described in this study is suggested; to this aim, the original model needs be adapted to the context of interest, by modifying the default values of the variables and the unit prices of the building components, and then by implementing the simplification method to obtain new functions with new coefficients.

It is worth noting that the method proposed in this study for the derivation of the model is not limited to INSYDE, but can be repeated and developed also for other multi-variable models to obtain alternative, simpler and more explicit versions.

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