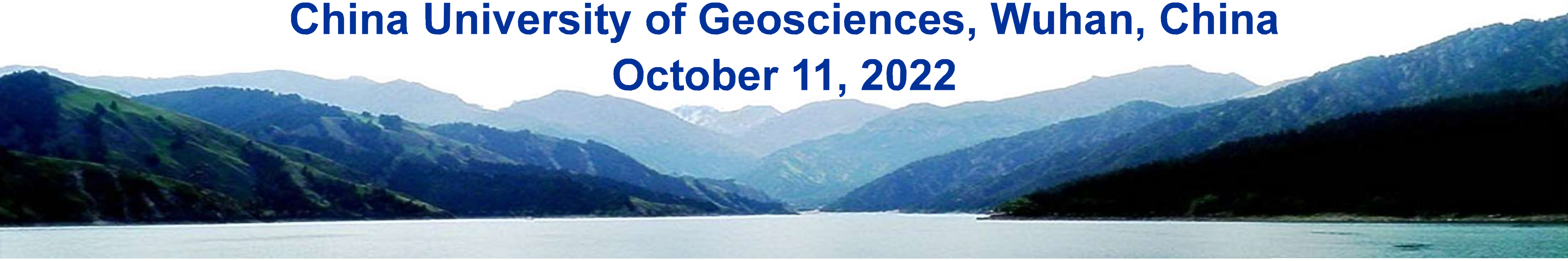
IAEG Richard Wolters Prize Competition

Towards Intelligent Recognition and Risk Assessment of Landslides

Wenping Gong, Ph.D., Prof.

China University of Geosciences, Wuhan, China

October 11, 2022



About the award candidate

Education

- ☐ 2007.09-2011.07, B.Eng., Civil Engineering, Tongji University (China)
- ☐ 2012.08-2014.12, Ph.D., Civil Engineering, Clemson University (USA) (advisor: Prof. C. Hsein Juang)

Employment

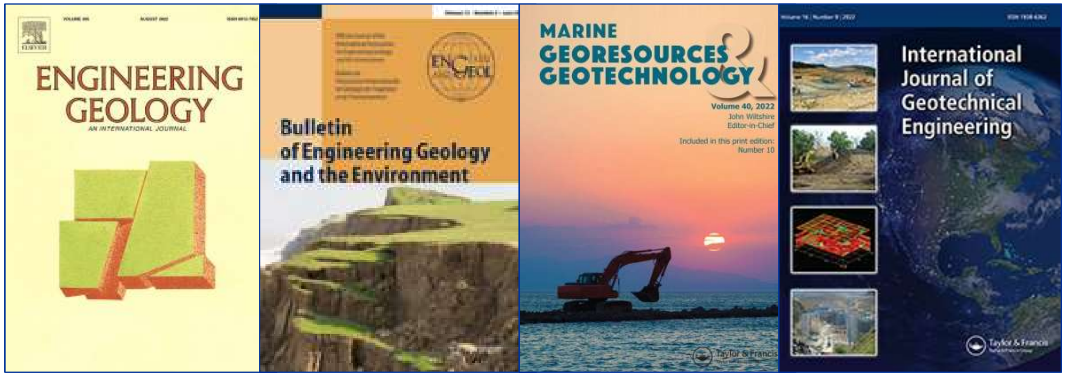
- ☐ 2015.01-2017.06, Research Assistant Professor, Clemson University (USA)
- ☐ 2017.07-present, Professor, China University of Geosciences (China)

2007 — 2012 — 2017 — present

About the awards candidate

Professional service

- 2022.01-present, **Co-Editor-in-Chief, Engineering Geology**
- 2015-present, **Editorial Board Member (EBM), Bulletin of Engineering Geology and the Environment (IAEG)**
- 2016-2021.12, EBM, Assistant Editor, and Managing Editor, Engineering Geology
- 2015-present, EBM, **Marine Georesources & Geotechnology**
- 2015-present, EBM, **International Journal of Geotechnical Engineering**



Reviewer for more than
20 peer-reviewed SCI journals

About the award candidate

Professional service

- Chair of Organization Committee for two national symposiums
- Session Organizer or Chair for over ten international congresses or symposiums, including three organized by IAEG
- Member of IAEG, ISSMGE/TC304, and ASCE/G-I

Research grant

PI or Co-PI of five national projects, including

- State Young Talent Program (5 million RMB, PI)
- Major program on landslide prediction, funded by NSFC (3.7 million RMB, Co-PI)
- Two projects on risk assessment of landslides, funded by NSFC (0.9 million RMB, PI)
- Distinguished Young Scholar Program of Hubei Province, China (0.3 million RMB, PI)

Outline

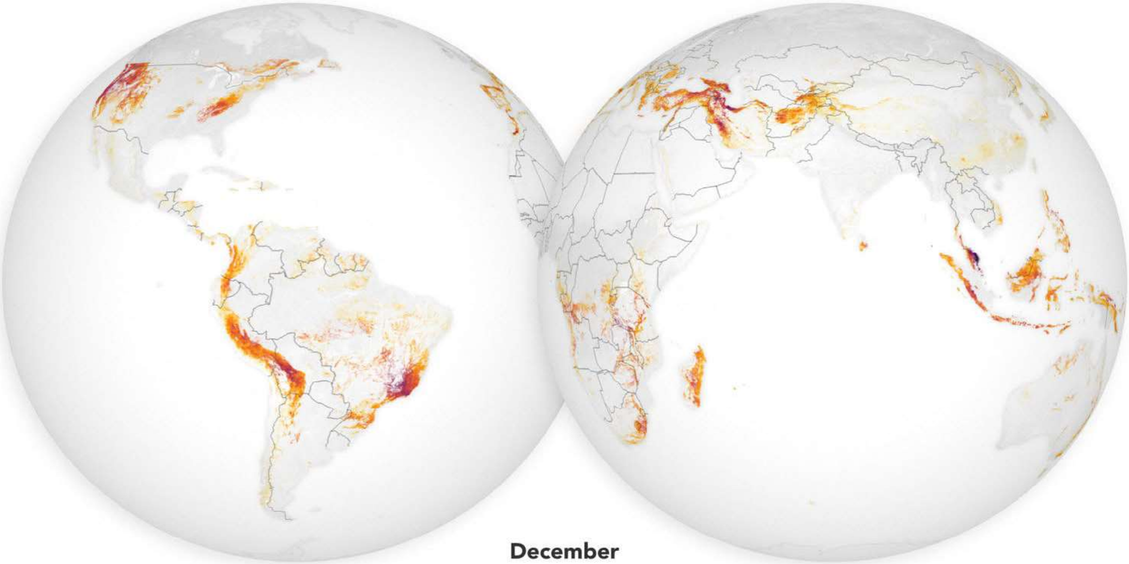
Outline

Motivation

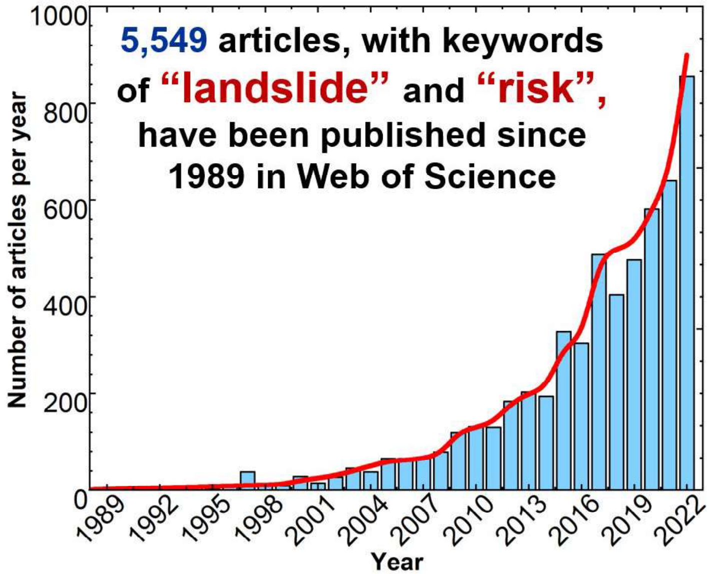
Landslide is one of the most frequent and destructive geohazards around the world, which causes huge economic losses and casualties every year.

Landslides around the world

Landslides occur throughout much of the world, the direct economic loss caused by global landslides from 2000 to 2018 is 45 billion U.S. dollars (CRED, 2020), which threatens over 300 million people (the World Bank, 2018).



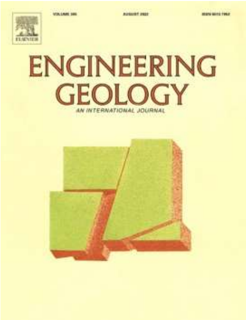
Landslide susceptibility mapping around the world from 2001 to 2018 (NASA)



Number of landslide articles published each year (data from web of science)

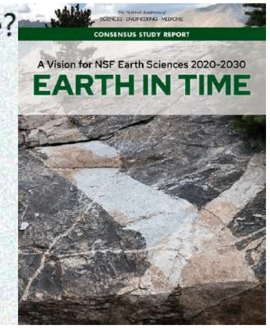
Landslide research around the world

Identification and risk assessment of landslides is one of the emerging priorities summarized by Engineering Geology; and, landslide risk reduction is one of the priority science questions in earth sciences developed by NSF.



- Advance the state of knowledge and practice regarding landslide hazard, vulnerability, and risk in the following topic areas: (1) the temporal probability of landslide occurrence to complement the spatial probability; (2) landslide hazard assessment related to land-use and climate changes; (3) landslide vulnerability; (4) hydrological triggering of landslides; (5) testing and application of new geophysical, geodetic, and remote-sensing monitoring techniques; (6) regional scale assessments of seismic landslide hazard; and (7) long-term monitoring of representative test slopes susceptible to seismic triggering using arrays of sensors.

- How is Earth's internal magnetic field generated?
- How does the critical zone influence climate?
- How do geological processes influence biodiversity?
- How is Earth's water cycle changing?
- What are the causes and consequences of topographic change?
- What drives volcanism?
- When, why, and how did plate tectonics start?
- How do biogeochemical cycles evolve?
- How are critical elements distributed and cycled in the Earth?
- What is an earthquake?
- What does Earth's past reveal about the dynamics of the climate system?
- How can Earth science research reduce the risk and toll of geohazards?



Components of landslide risk assessment

Risk is expressed as a functional **combination** of the **consequences** of an event and the associated **probability** of occurrence (Knight, 1921; Rowe, 1975; Kaplan and Garrick, 1981; Glade et al., 2005; ISO Guide 73, 2009):

Risk = *f*(Probability, Consequences)

Tasks of landslide risk assessment

Task 2: Probability of landslide occurrence

Task 3: Vulnerability of elements at risk under landslide impact

Task 1: Identification of potential landslides and associated elements at risk (e.g., buildings and humans)

Knight, F.H. (1921). Risk, Uncertainty and Profit. Houghton Mifflin.

Rowe, W.D. (1975). An "Anatomy" of risk. Environmental Protection Agency.

Kaplan, S., and Garrick, B.J. (1981). On the quantitative definition of risk. Risk Analysis, 1(1), 11-27.

Glade, T., Anderson, M.G., and Crozier, M.J. (2005). Landslide Hazard and Risk. John Wiley & Sons.

ISO (the International Organization for Standardization) Guide 73: 2009 Risk Management.

Research Objective

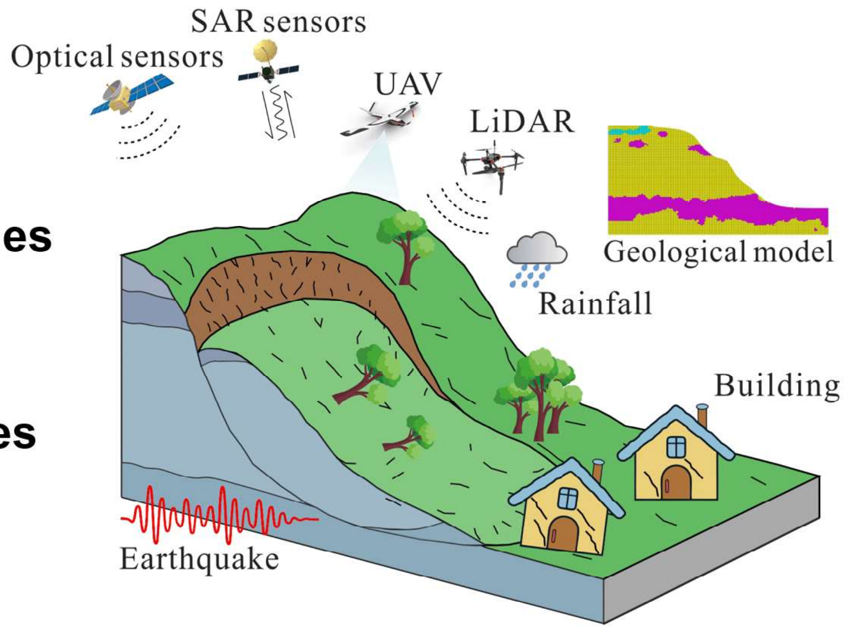
Intelligent recognition and risk assessment of landslides

Accomplishments

- ☐ Remote sensing images-based **intelligent recognition** of landslides
- ☐ Runout behavior analysis of landslides and **vulnerability modelling**
- ☐ Uncertainties quantification and **probabilistic analysis** of landslides

Task 1 Task 3 Task 2

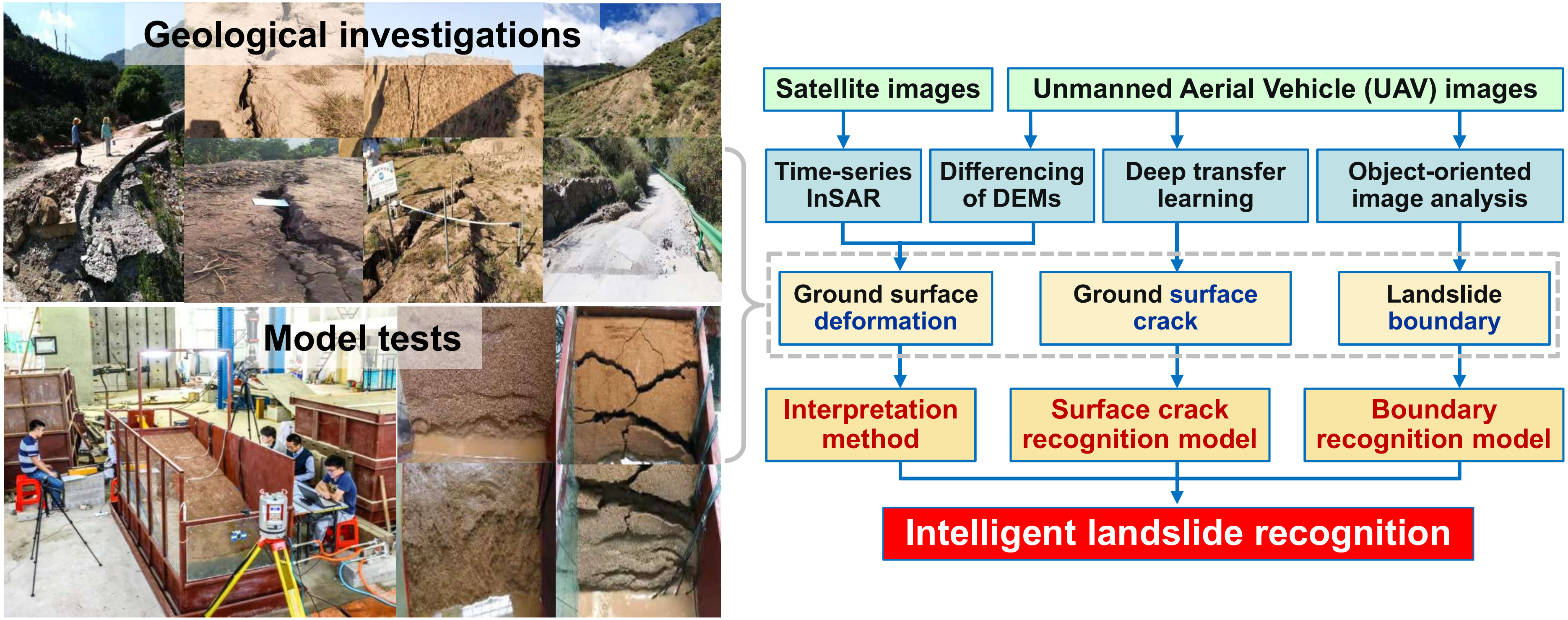
Tasks of landslide risk assessment



Outline

2.1 Remote sensing images-based intelligent recognition of landslides

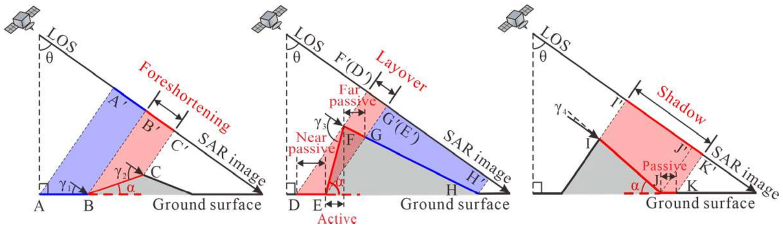
Contribution 1: Developed an **intelligent framework** for recognizing landslides from multi-source remote sensing images



A ground surface deformation interpretation method of satellite SAR images for landslide identification

Component 1: An improved R-index model for SAR visibility analysis

$$R\text{-}index_{(im)} = \sin\{\theta + \arctan[\tan(\alpha) \times \cos(\varphi - \beta)]\} \times Sh \times La \times Fa$$

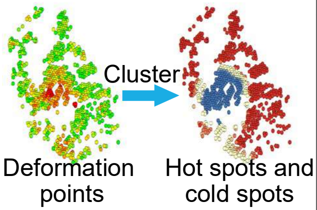


Component 2: Conversion of deformation rate

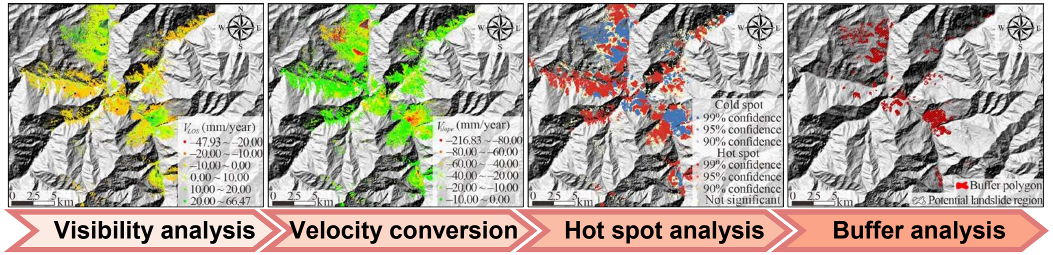
$$V_{slope} = \frac{V_{LOS}}{sin(\theta) \times cos(\alpha) \times cos(\varphi - \beta) + cos(\theta) \times sin(\alpha)}$$

Component 3: Hot spot analysis of ground surface deformation

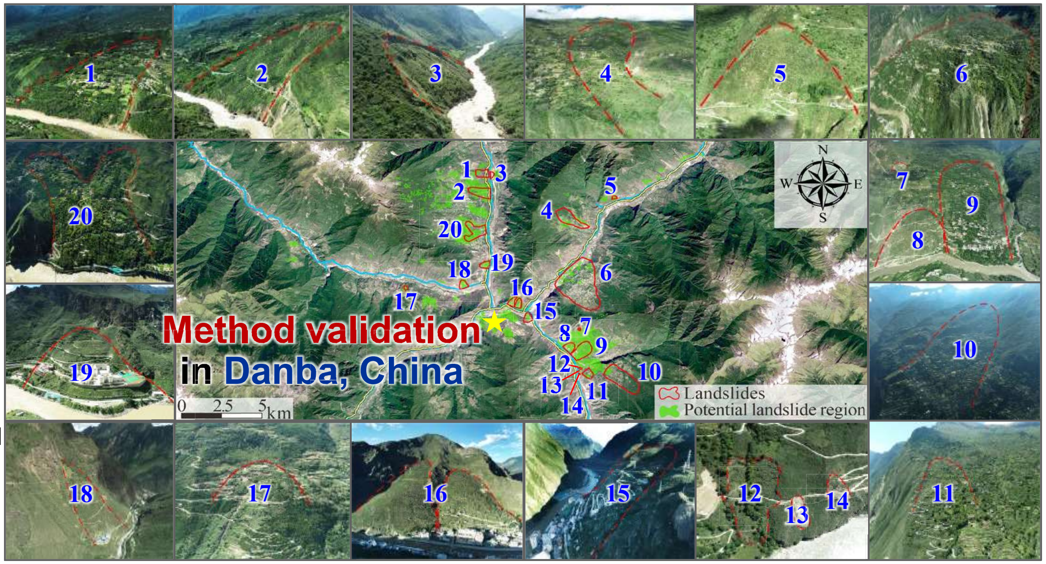
$$G_i^*(d) = \frac{\sum x_j + x_i - n_{ij}\bar{x}}{s^*\left\{\left[(n \times n_{ij}) - n_{ij}^2\right]/(n-1)\right\}^{0.5}}$$



Key components of the proposed interpretation method

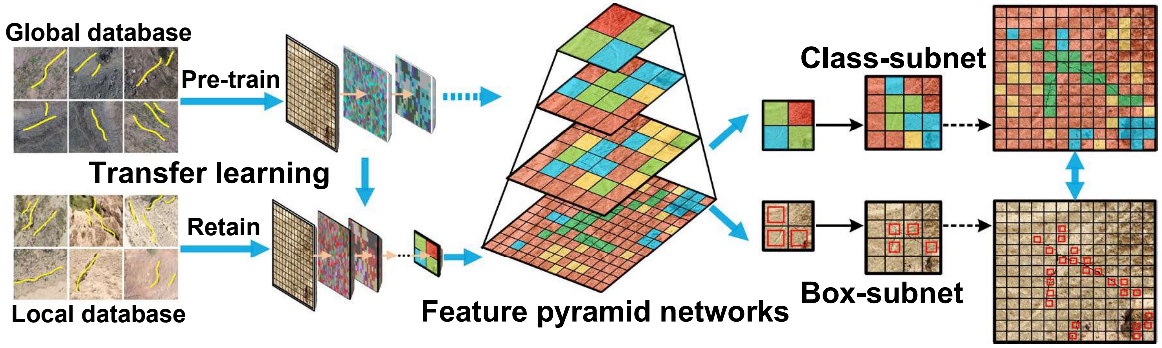


Procedures for implementing proposed method

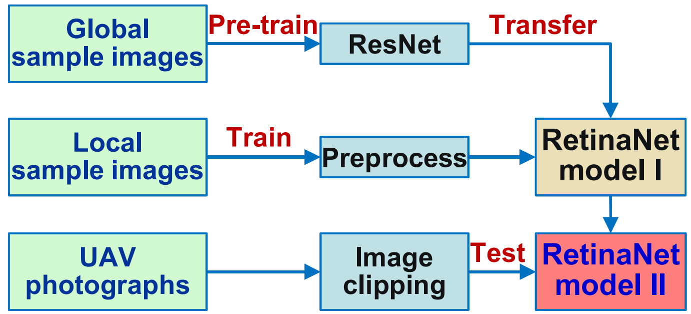


(Ren, Gong* et al., Remote Sensing, 2021&2022)

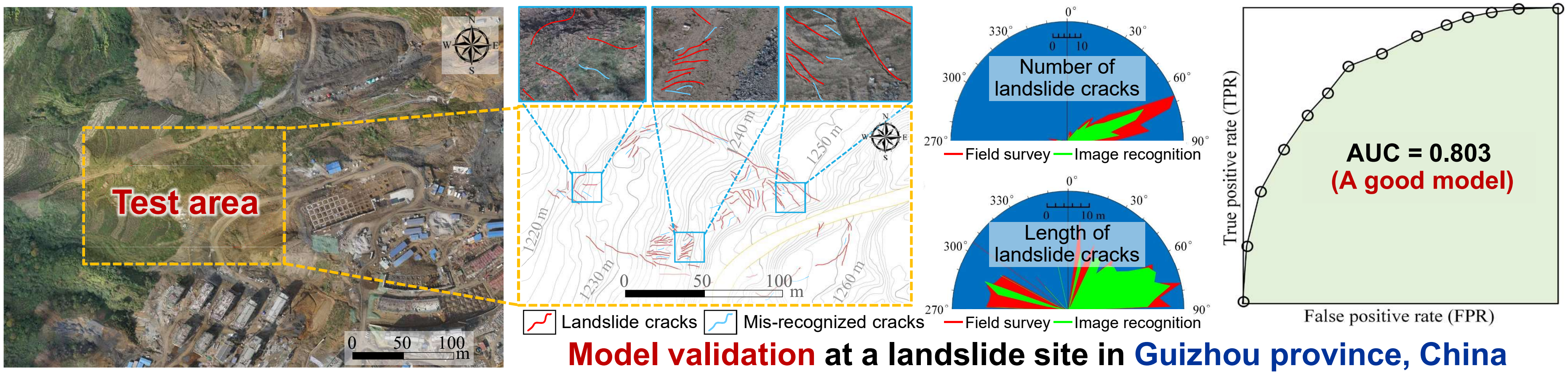
An intelligent algorithm RetinaNet-based automatic landslide surface crack recognition model in UAV photographs



Methodology and key components of RetinaNet



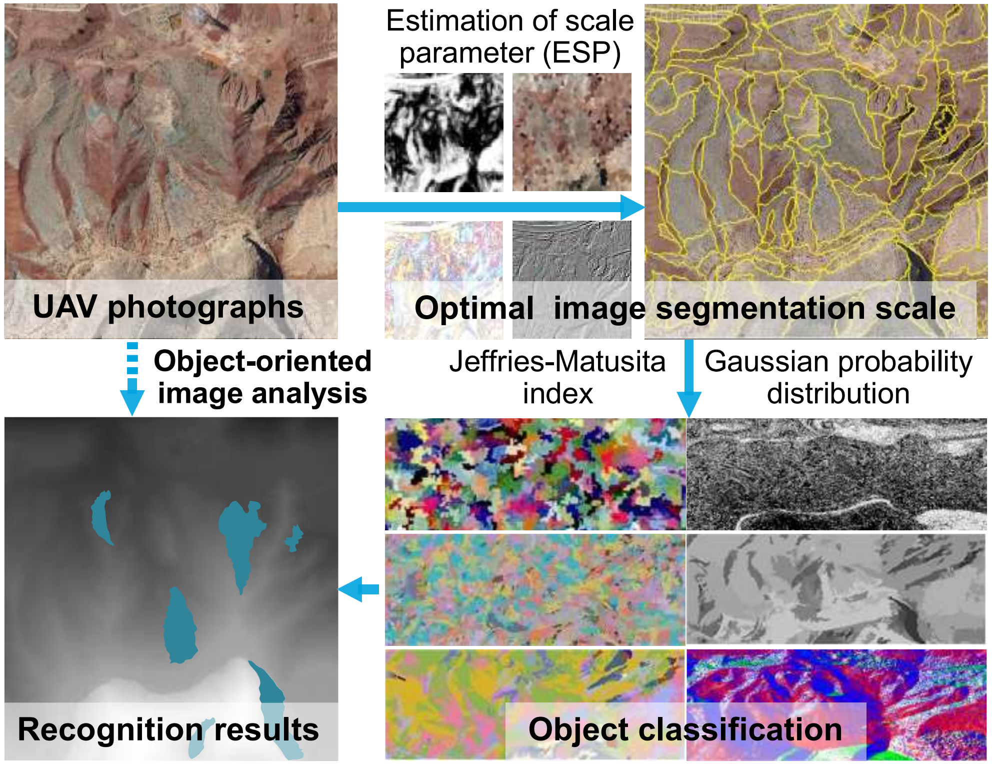
Procedures for model training



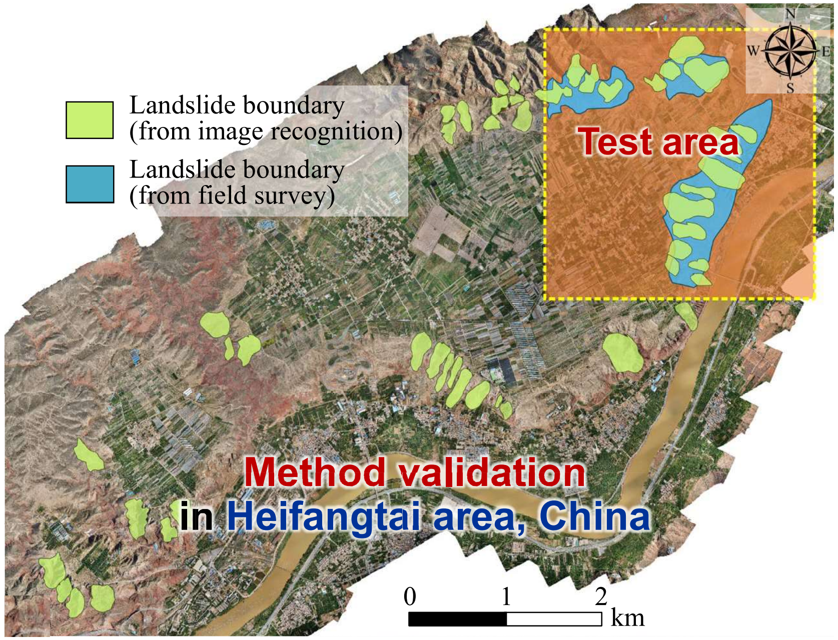
Model validation at a landslide site in Guizhou province, China

(Cheng, Gong* et al., Engineering Geology, 2021)

An object-oriented image analysis-based method for automatic landslide boundary recognition in UAV photographs



Methodology and **implementation procedures** of proposed landslide boundary recognition method

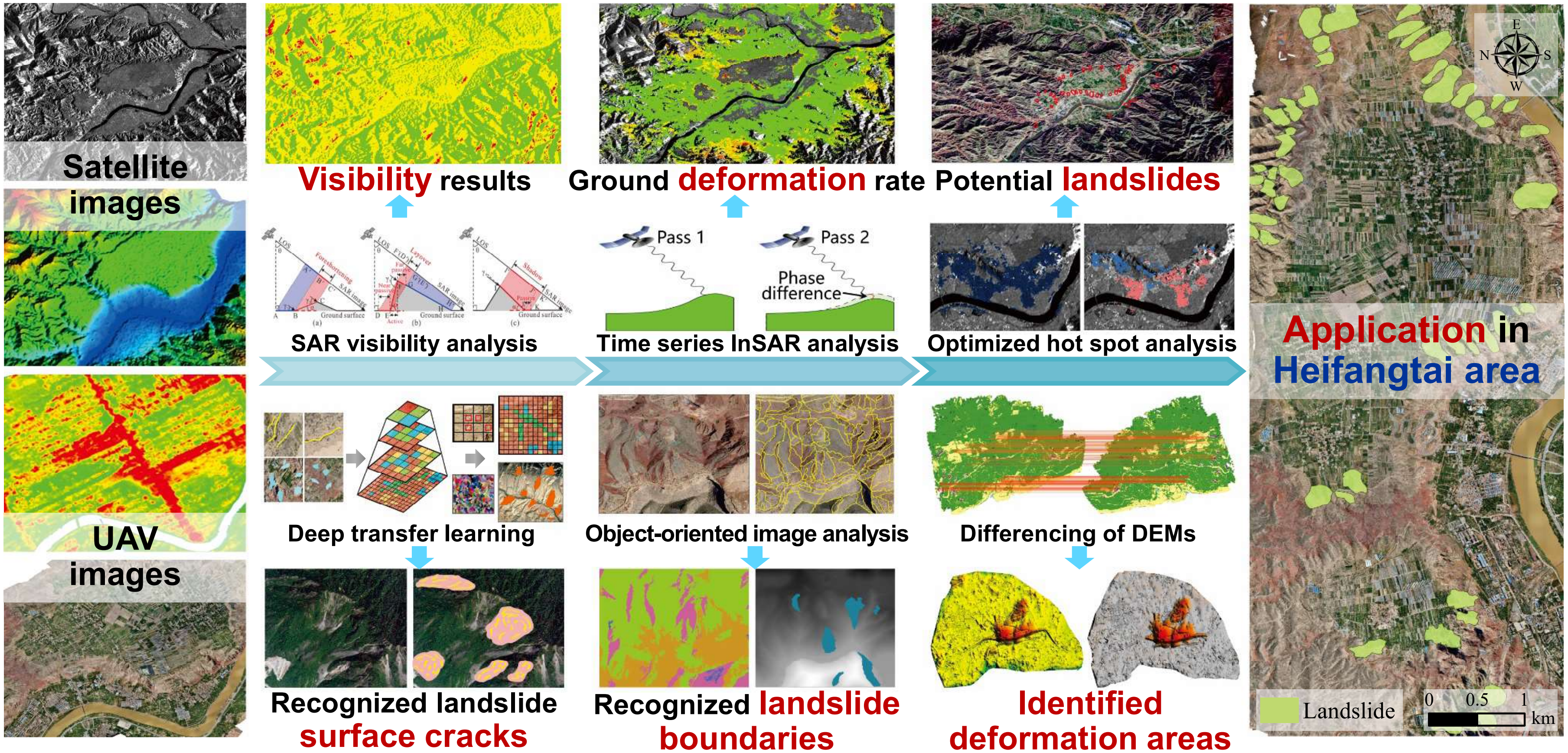


Field survey / Recognition	Landslide area (km²)	Non-landslide area (km²)
Landslide area (km²)	1.39	0.33
Non-landslide area (km²)	0.25	4.28

Kappa coefficient = 0.764
(Satisfactory performance)

(Cheng, master thesis, advised by Gong, 2021; Gong presented at MLRA 2021 Wroclaw, Poland)

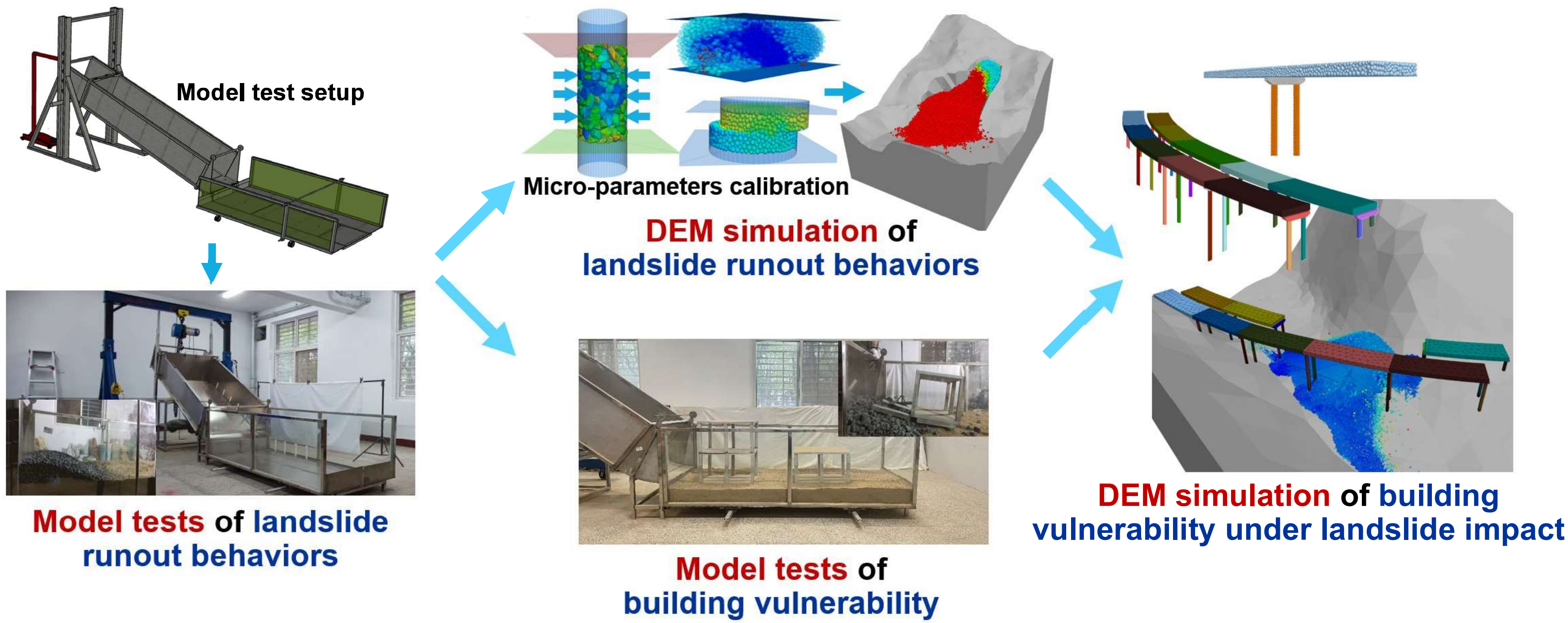
An application of the developed intelligent framework for recognizing landslides in Heifangtai area, China



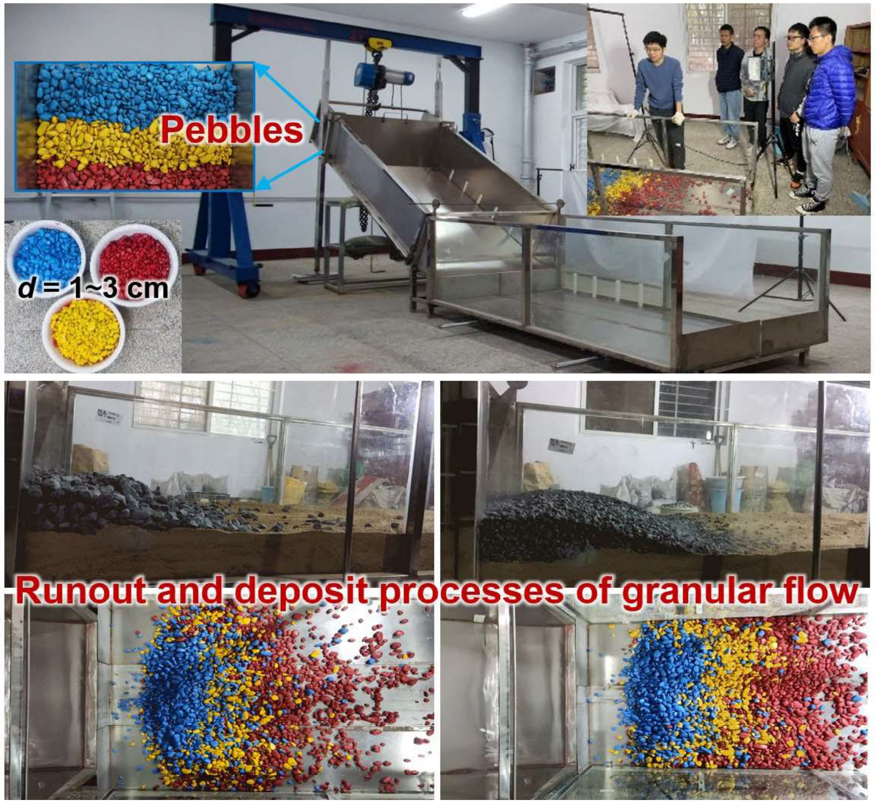
(Ren, master thesis, advised by Gong, 2022; Ding, master thesis, advised by Gong, 2022)

2.2 Runout behavior analysis of landslides and vulnerability modelling

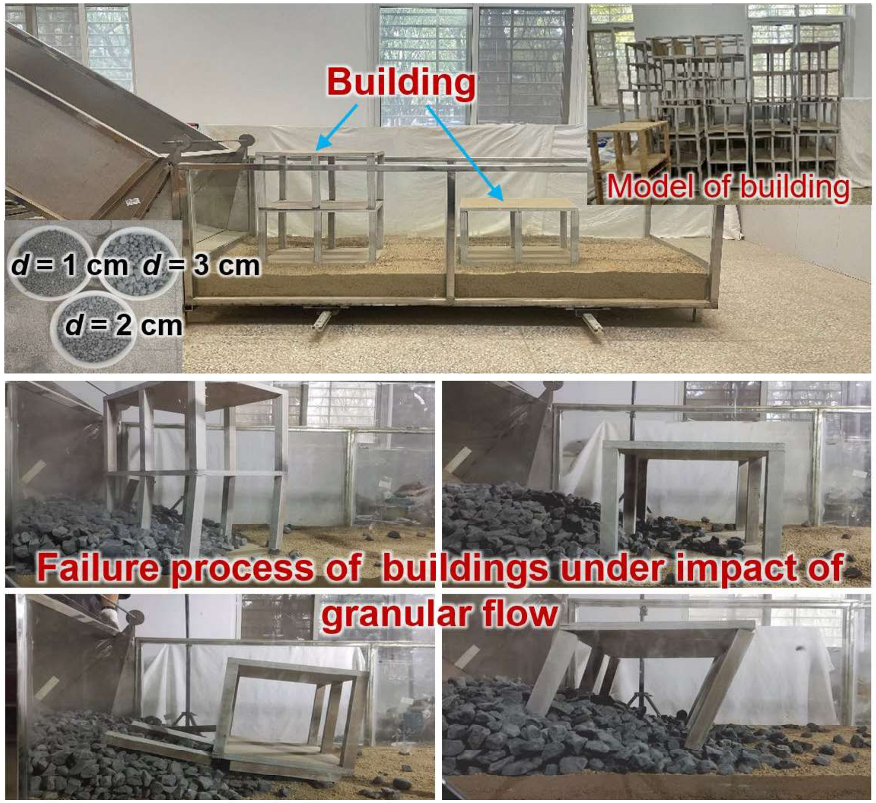
Contribution 2: Established a DEM-based numerical simulation scheme for modelling **building vulnerability** under landslide impact



Model tests of landslide runout behaviors and building vulnerability under landslide impact



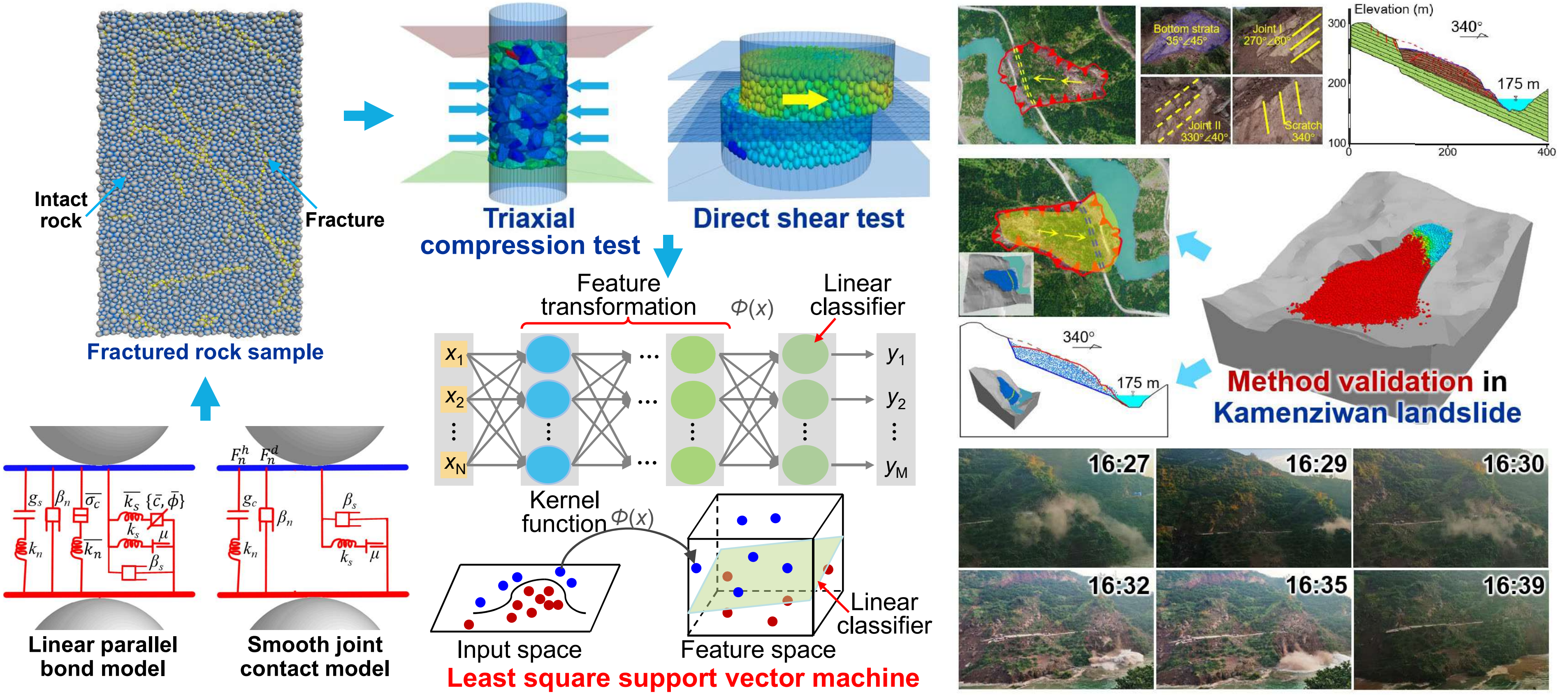
Model tests of landslide runout behaviors



Model tests of building damage under landslide impact

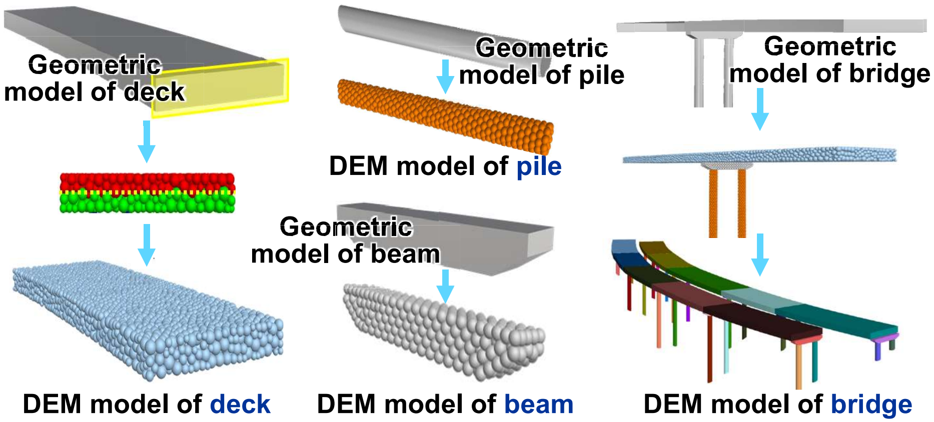
(Quan, master thesis, advised by Gong, 2022)

A least square support vector machine-based method for micro-parameters calibration in landslide runout behaviors modelling

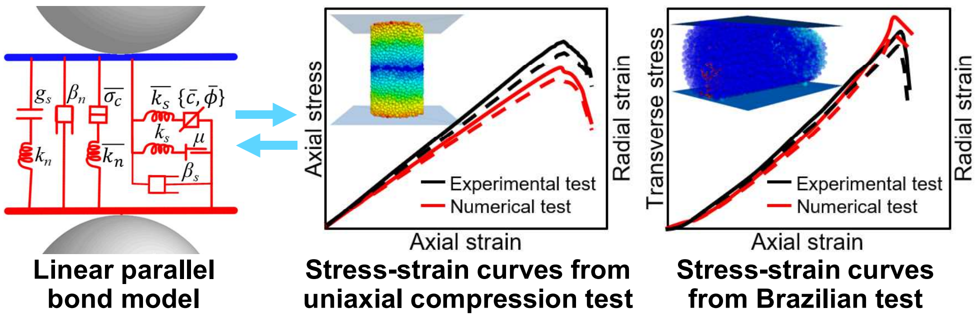


(Li, Gong* et al., Landslides, 2022)

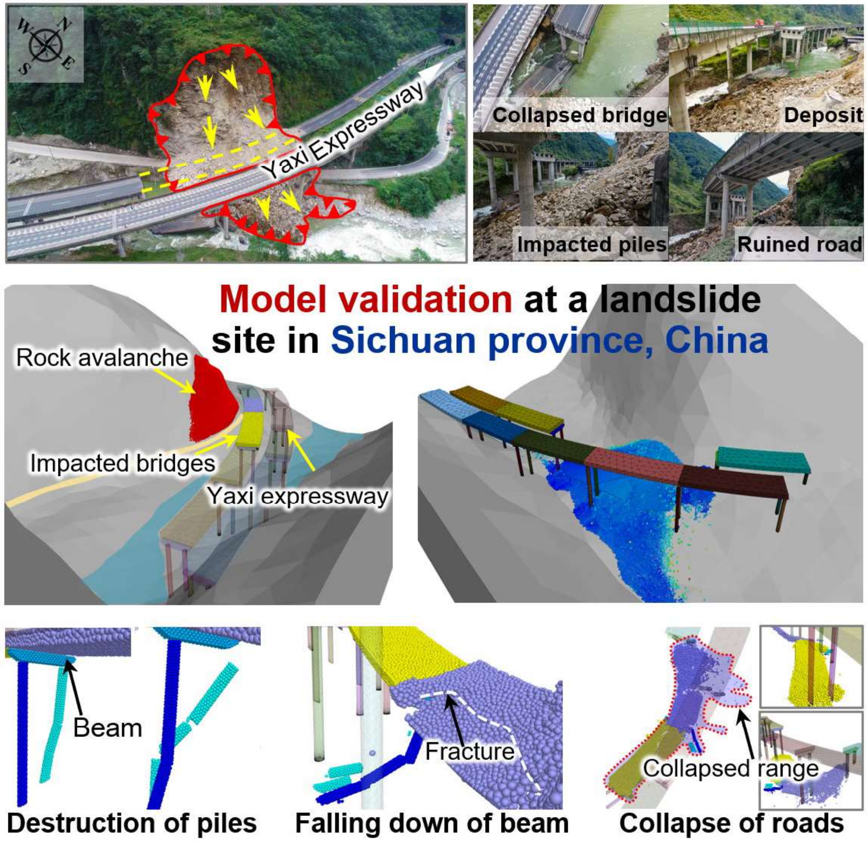
A DEM-based numerical simulation scheme for modelling building vulnerability under landslide impact



DEM modelling of building

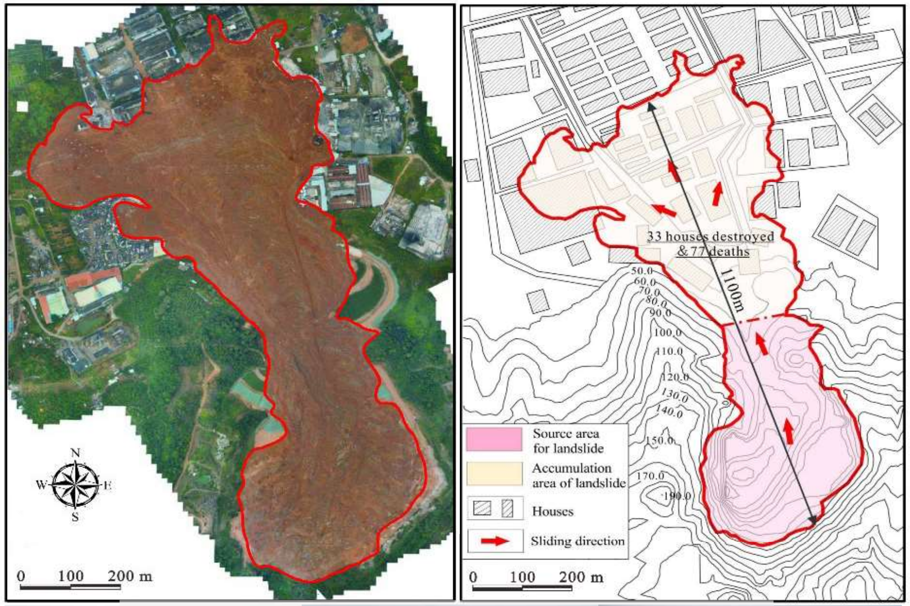


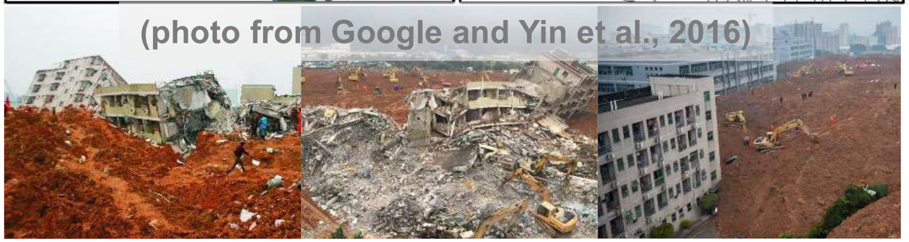
Micro-parameters calibration in building DEM modelling



(Wang, master thesis, advised by Gong, 2022)

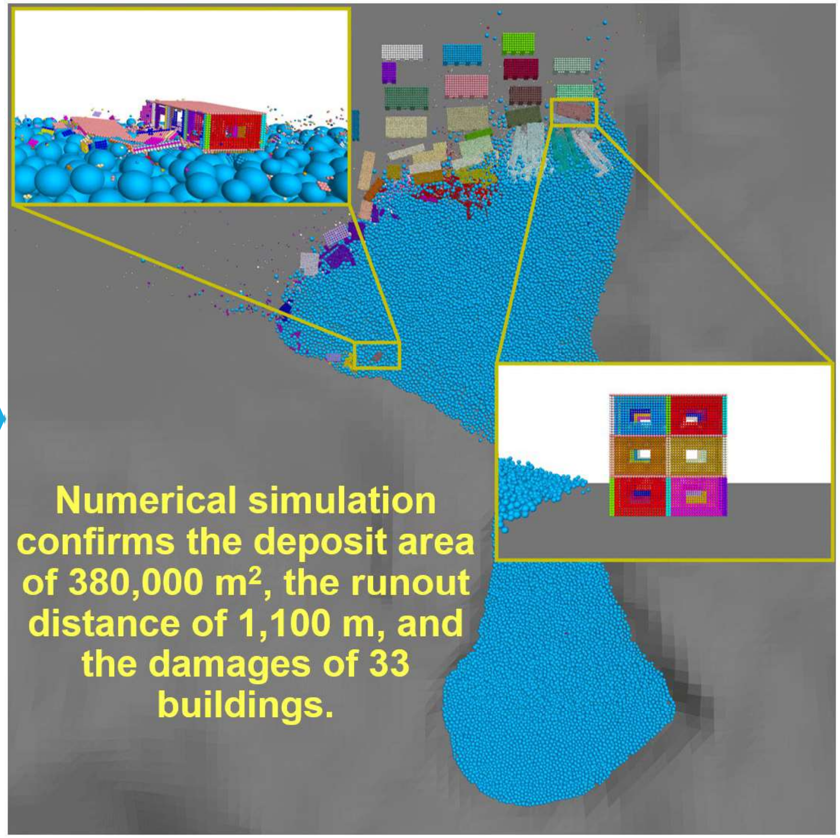
An **application** of the established simulation scheme for modelling buildings damage in the **Shenzhen 12.20 landslide**





(photo from Google and Yin et al., 2016)

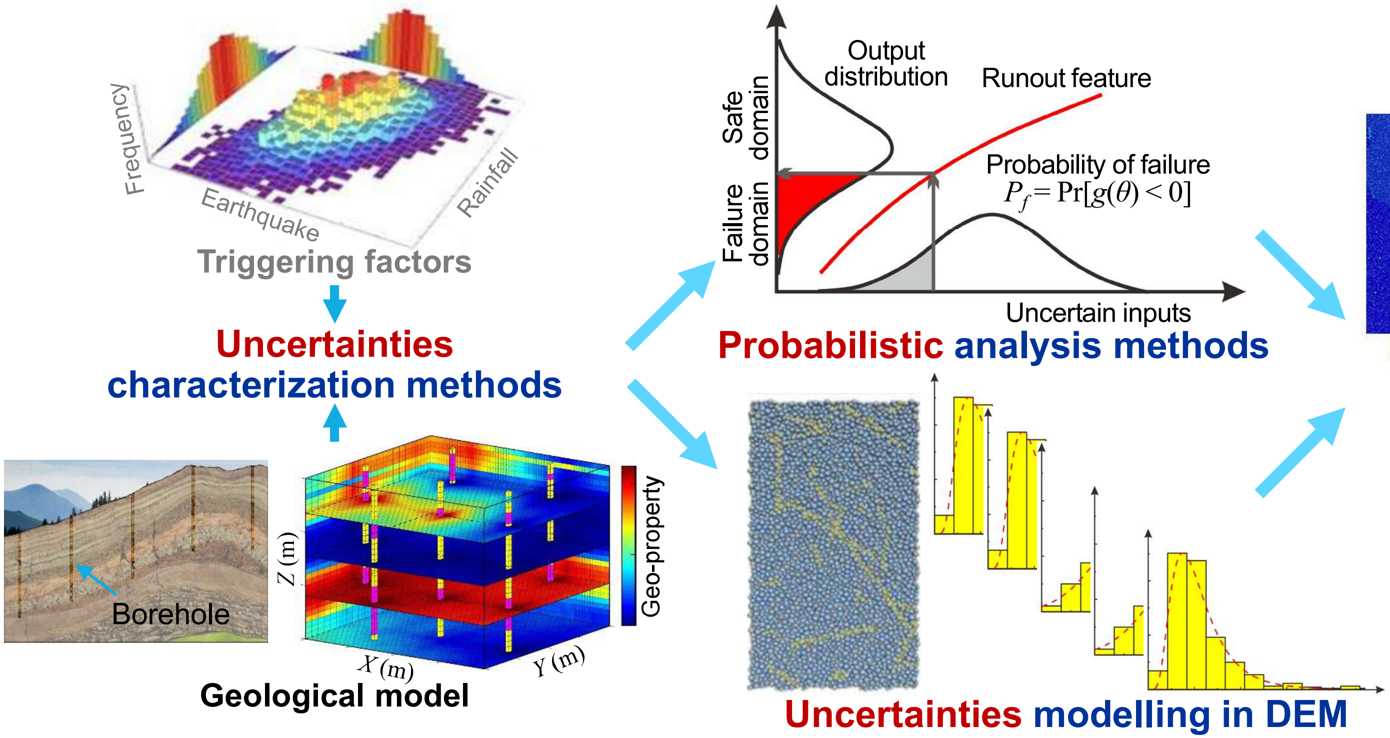
Field surveys of the **Shenzhen 12.20 landslide**



(Wang, master thesis, advised by Gong, 2022; Li, Gong* et al., 7th ISGSR, 2019)

2.3 Uncertainties quantification and probabilistic analysis of landslides

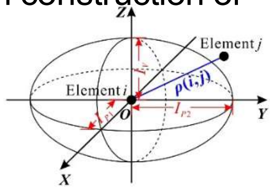
Contribution 3: Developed novel theories for quantifying geological uncertainties and probabilistic analysis of landslide behaviors



A conditional random field-based approach for characterizing the geological model uncertainty at landslide sites

Component 1: Spatial correlation construction of stratum existence

$$\rho_s(i,j)=\exp\left(-\frac{d_{P1}^2}{I_{P1}^{\ 2}}-\frac{d_{P2}^2}{I_{P2}^{\ 2}}-\frac{d_V^2}{I_V^{\ 2}}\right)$$



Component 2: Existence probability estimate of stratum with K-nearest neighbors algorithm

$$P_k(i)=\sum_{l=1}^{l=n_B}\left[\rho_k(i,l)\cdot Index(l,k)\right]\Big/\sum_{h=1}^{h=m}\left\{\sum_{l=1}^{l=n_B}\left[\rho_h(i,l)\cdot Index(l,h)\right]\right\}$$

Stratigraphic uncertainty characterization

Coupled characterization

$$\rho_g'(i,j)=\begin{cases}\rho_g(i,j) & \text{if } s(i)=s(j)\\ 0 & \text{if } s(i)\neq s(j)\end{cases}$$

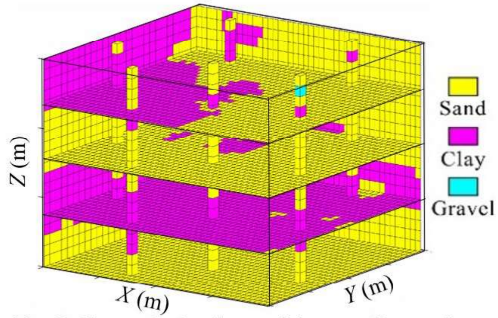
Find: $\boldsymbol{\theta}^{\mathrm{T}}=\{\boldsymbol{\phi},I_P,I_V\}$
Subject to:

Maximum likelihood principle

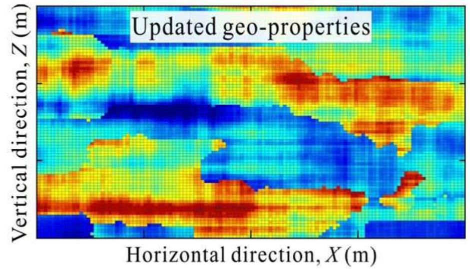
$$L(\mathbf{D}|\boldsymbol{\theta})=\frac{1}{(2\pi)^{n_d/2}|\boldsymbol{C}|^{1/2}}\exp\left[-\frac{1}{2}(\mathbf{D}-\bar{\mathbf{D}})^{\mathrm{T}}\boldsymbol{C}_D^{-1}(\mathbf{D}-\bar{\mathbf{D}})\right]$$

Objective: Maximizing $L(\mathbf{D}|\boldsymbol{\theta})$

Geo-properties uncertainty characterization

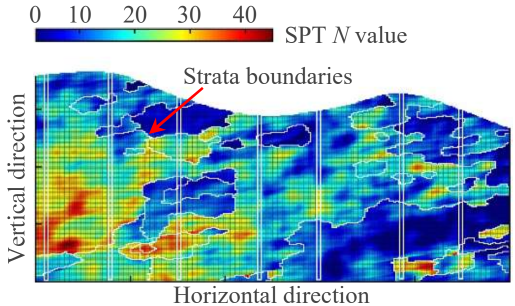


Updating of stratigraphic configuration

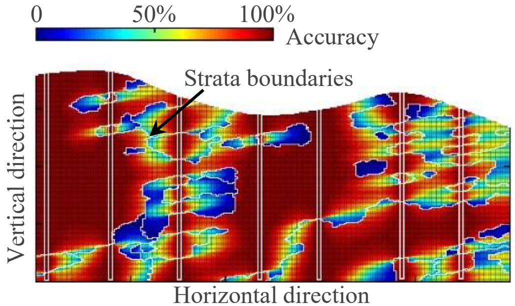


Updating of geo-properties

Illustration application of coupled characterization approach



One realization of geological model

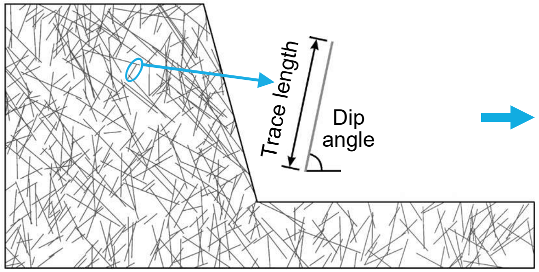


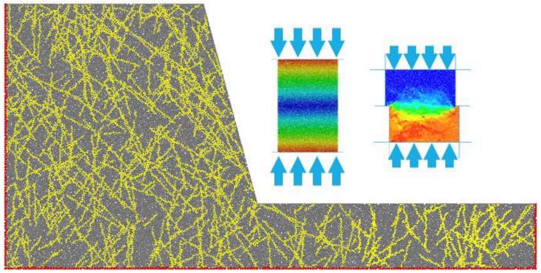
Characterization accuracy

Method validation at a site in Taiwan

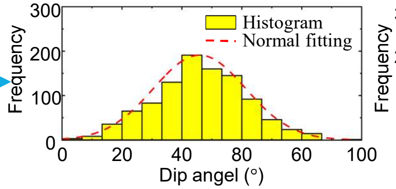
(Gong et al., Comput. Geotech., 2014&2020; Gong et al., Bull. Eng. Geol. Environ., 2017; Gong et al., Géotechnique, 2017; Gong et al., Tunn. Undergr. Space Technol., 2018; Gong et al., Eng. Geol., 2019&2021; Gong et al., Acta Geotech., 2020; Zhao, Gong* et al., Eng. Geol., 2021)

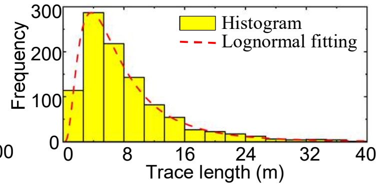
A method for characterizing the uncertainty of micro-parameters in DEM modelling of landslide runout behaviors



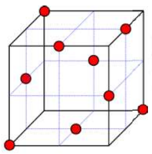


Field survey results

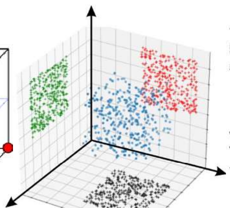




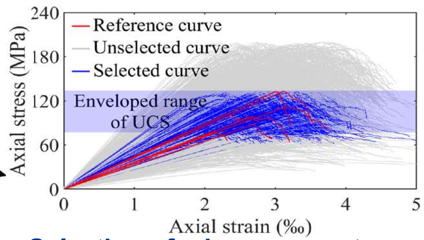
Statistical characterization of fracture geometric parameters



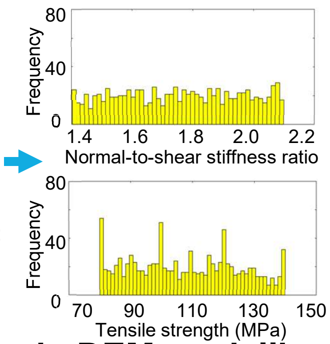
Orthogonal design



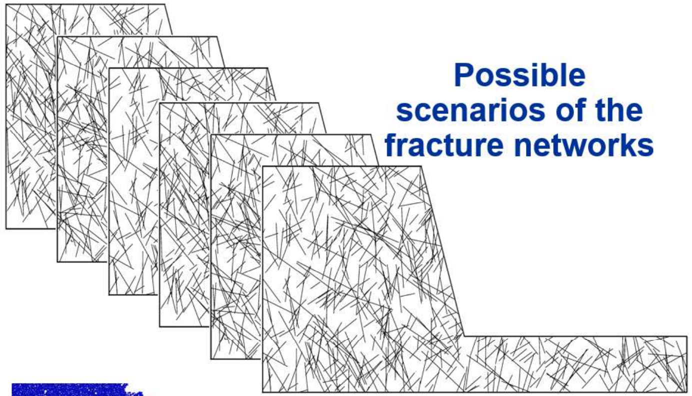
Random sampling



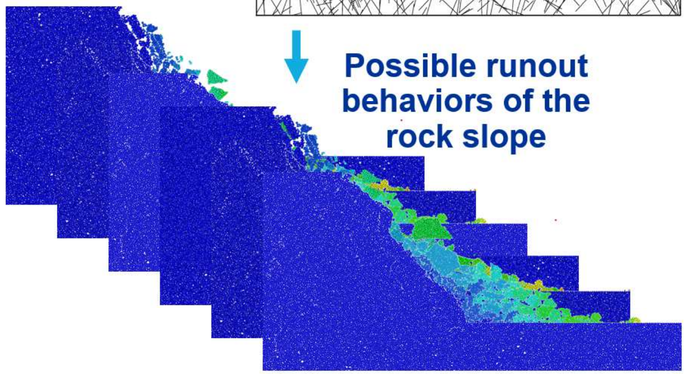
Selection of micro-parameters through numerical sample testing



Uncertainty quantification of micro-parameters in DEM modelling



Possible scenarios of the fracture networks



Possible runout behaviors of the rock slope

Methods validation in a hypothetical rock slope problem

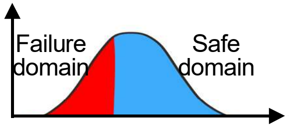
(Li, Gong* et al., Computers and Geotechnics, 2022; Liu, master thesis, advised by Gong, 2022)

Efficient methods for evaluating failure probability and robustness of landslide behaviors in face of uncertainties

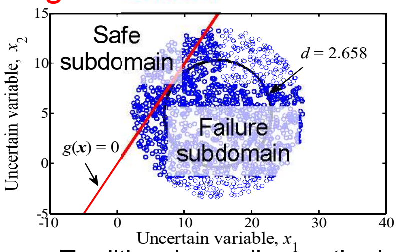
Component 1: Partition possible domain of uncertain variables with Hasofer-Lind index *d*

$$p_{di} = \chi^2_{n_x}(d_i^2) - \chi^2_{n_x}(d_{i-1}^2)$$

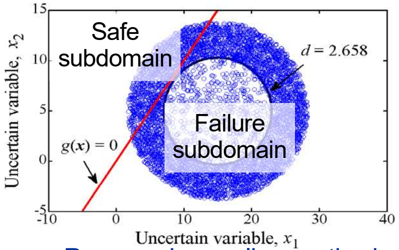
$$d = \sqrt{[\boldsymbol{n}]^{\mathrm{T}}[\boldsymbol{R}]^{-1}[\boldsymbol{n}]},\ \chi^2_{n_x}(d_{\max}^2) = \varepsilon$$



Component 2: Generate samples of uncertain variables in significant subdomains



Traditional sampling method



Proposed sampling method

Component 3: Estimate conditional failure probability in each subdomain and total failure probability

$$P_f = \sum_{i=1}^{i=n_s}\left(p_{di}\cdot p_{fi}\right) \qquad \delta_{P_f} = \sqrt{\sum_{i=1}^{i=n_s}\left[p_{di}^{\ 2}\cdot(p_{fi}\cdot\delta_{p_{fi}})^2\right]} \Bigg/ \sum_{i=1}^{i=n_s}\left(p_{di}\cdot p_{fi}\right)$$

Key components of proposed subdomain sampling methods

Measure 1: Variation-based robustness

$$\sigma[g] = \sqrt{\boldsymbol{G}\mathbf{C}_{\boldsymbol{\theta}}\boldsymbol{G}^T}$$

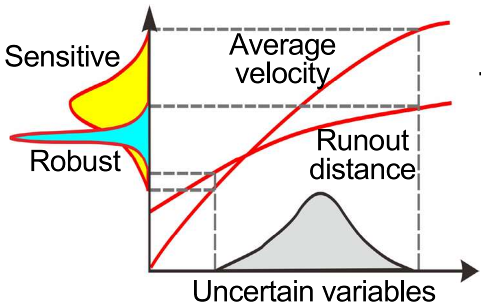
Measure 2: Feasibility-based robustness

$$\beta_{\mathrm{p}} = \Phi^{-1}\left\{\Pr\left[(\mathrm{P}_f - \mathrm{P}_T) < 0\right]\right\}$$

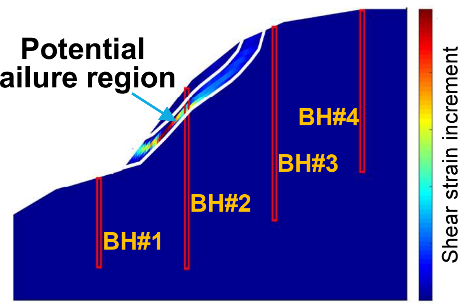
Measure 3: Sensitivity-based robustness

$$\boldsymbol{J} = \left\{ \frac{\mu_{\theta_1}}{f(\boldsymbol{d},\boldsymbol{\mu_\theta})}\frac{\partial f(\boldsymbol{d},\boldsymbol{\theta})}{\partial\theta_1}\bigg|_{\boldsymbol{\theta}=\boldsymbol{\theta}'}, \frac{\mu_{\theta_2}}{f(\boldsymbol{d},\boldsymbol{\mu_\theta})}\frac{\partial f(\boldsymbol{d},\boldsymbol{\theta})}{\partial\theta_2}\bigg|_{\boldsymbol{\theta}=\boldsymbol{\theta}'}, \cdots, \frac{\mu_{\theta_n}}{f(\boldsymbol{d},\boldsymbol{\mu_\theta})}\frac{\partial f(\boldsymbol{d},\boldsymbol{\theta})}{\partial\theta_n}\bigg|_{\boldsymbol{\theta}=\boldsymbol{\theta}'} \right\}$$

Formulations of developed robustness measures



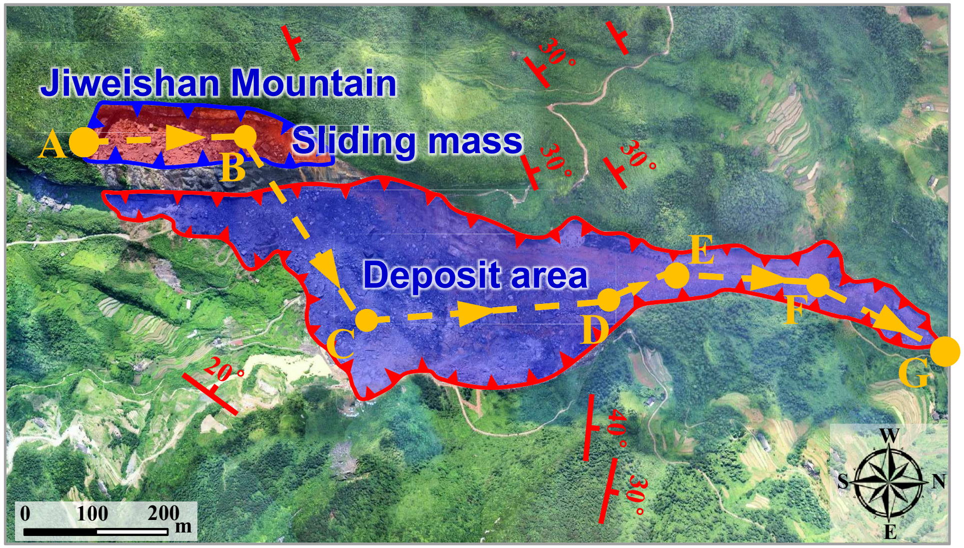
Schematic diagram of robustness concept

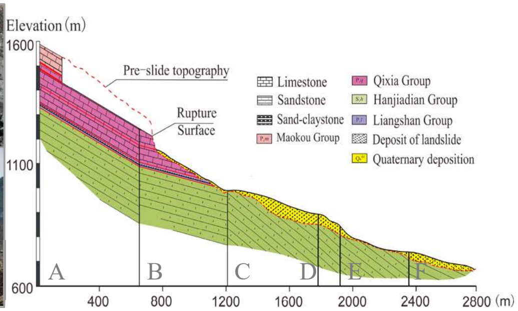


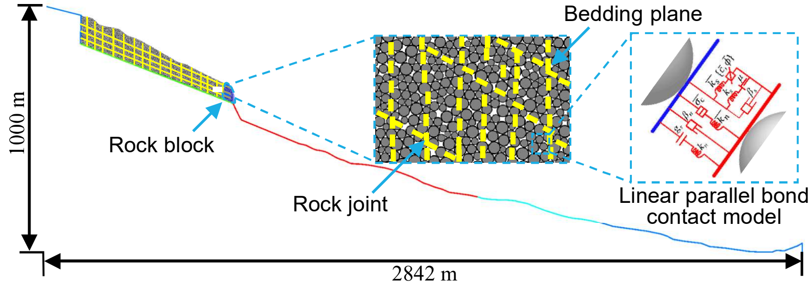
Methods validation in hypothetical slope problems

(Gong et al., Can. Geotech. J., 2014&2015; Gong et al., J. Geotech. Geoenviron. Eng., 2015; Gong et al., Comput. Geotech., 2014&2016; Gong et al., Géotechnique, 2017; Gong et al., Bull. Eng. Geol. Environ., 2017; Juang, Gong* et al., Struct. Saf., 2017; Gong et al., Tunn. Undergr. Space Technol., 2018 ...)

An application of developed theories to probabilistic analysis of runout behaviors of the Jiweishan landslide

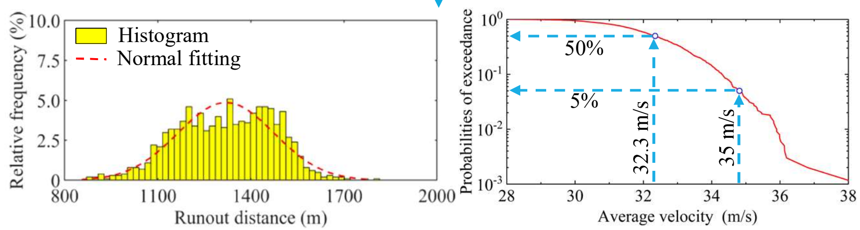






Built **PFC model** of the Jiweishan landslide

Possible deposits of the landslide in face of uncertainties



Statistical analysis of the landslide runout behaviors

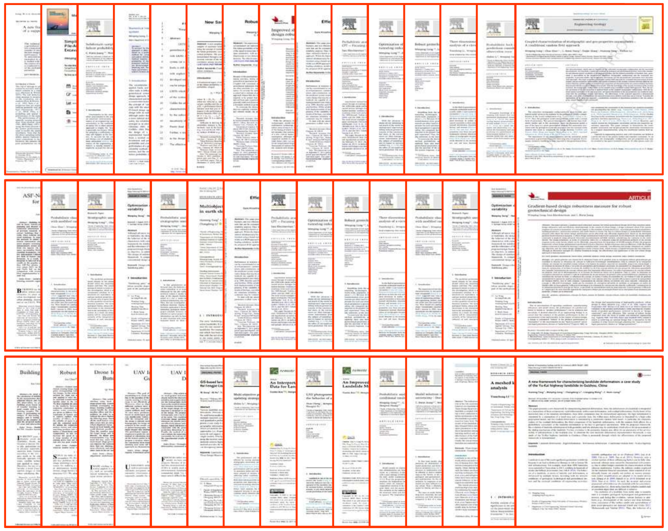
(Li, Gong* et al., Int. J. Numer. Anal. Meth. Geomech., 2021)

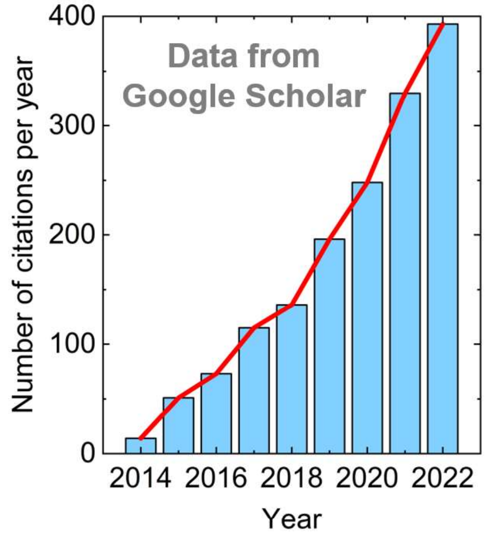
Outline

Publications

Published 74 research journal papers and 28 peer-reviewed conference papers, and co-authored one book chapter.

- **Be first and/or corresponding author of 45 journal papers (indexed by SCI), among which 33 are JCR Q1 papers, 11 are JCR Q2 papers, and one is JCR Q3 paper**
- **Google Scholar lists the H-index at 25 with 1567 citations**

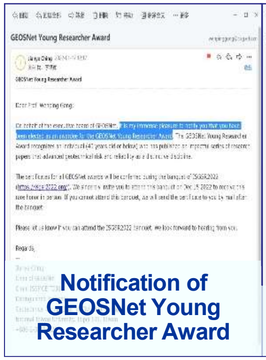




Honors and Awards

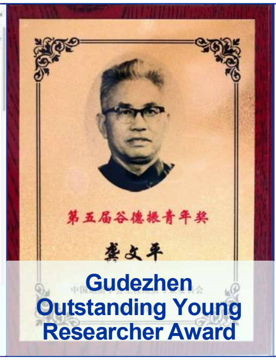
The achievements made have been well recognized by some international associations and journals.

- **GEOSNet Young Researcher Award,** GEOSNet, 2022
- **Bright Spark lecture,** International Society for Soil Mechanics and Geotechnical Engineering (ISSMGE), 2022
- **Gudezhen Outstanding Young Researcher Award,** Engineering Geology Branch of China Geological Society, 2020
- **Excellent Paper Award,** Journal of GeoEngineering, 2015
- **Best Paper Award,** GeoShanghai 2014 International Conference, 2014
- **Nominations for the Best Paper Awards** by ASCE/G-I Risk Assessment Committee (2015), Georisk journal (2015), and APSSRA6 international conference (2016)
- **Positive and Kind-hearted Young People,** Hubei Province, China, 2022

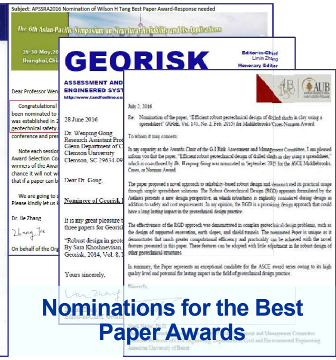


Notification of GEOSNet Young Researcher Award

Invitation for Bright Spark lecture



Gudezhen Outstanding Young Researcher Award



Nominations for the Best Paper Awards

Outline

1 Motivation and research objective

2 Accomplishments

2.1 Remote sensing images-based intelligent recognition of landslides

2.2 Runout behavior analysis of landslides and vulnerability modelling

2.3 Uncertainties quantification and probabilistic analysis of landslides

3 Publications and honors

4 Future works

Future Works

Research work

- Develop intelligent recognition techniques for landslides
- Establish models for evaluating building vulnerability under landslide impact
- Develop quantitative risk assessment methods for landslides

Professional service

- Organize international symposiums on geohazards
- Promote international collaborations on reduction and mitigation of landslide risk
- Invite scholars and geologists to organize special issues in Engineering Geology and join the editorial board

Acknowledgments

- **Institutes: China University of Geosciences, Clemson University, Tongji University, and National Science Foundation of China**
- **Advisors: Profs. C. Hsein Juang, Huiming Tang, and Hongwei Huang**
- **Collaborators: Profs. Abdul Shakoor, Janusz Wasowski, Vicki Moon, Carlos Carranza-Torres, Michel Jaboyedoff, Limin Zhang, Farrokh Nadim, Jia-Jyun Dong, Shengwen Qi …**
- **IAEG and Richard Wolters Prize jury**

Thank You for Your Attention!

Welcome to XIV Congress of International Association for Engineering Geology and the Environment!