Engineering Geology 201 (2016) 67–70

Contents lists available at ScienceDirect

Engineering Geology

journal homepage: www.elsevier.com/locate/enggeo

Short communication

Engineering geology — A fifty year perspective

Charng Hsein Juang [a,*], Carlos Carranza-Torres [b], Giovanni Crosta [c], Jia-Jyun Dong [d], Candan Gokceoglu [e], Randall W. Jibson [f], Abdul Shakoor [g], Huiming Tang [h], Theo W.J. van Asch [i], Janusz Wasowski [j]

[a] Department of Civil Engineering, 214 Lowry Hall, Clemson University, Clemson, SC 29634, USA
[b] Department of Civil Engineering, 260 Swenson Civil Engineering, University of Minnesota, Duluth, MN 55812, USA
[c] Department of Earth and Environmental Sciences, University of Milano-Bicocca, Milano, Italy
[d] Graduate Institute of Applied Geology, National Central University, Taoyuan, Taiwan
[e] Department of Geological Engineering, Hacettepe University, 06800 Beytepe, Ankara, Turkey
[f] U.S. Geological Survey, Box 25046, MS 966, Denver Federal Center, Denver, CO 80225, USA
[g] Department of Geology, Kent State University, Kent, OH 44242, USA
[h] Faculty of Engineering, China University of Geosciences, Wuhan 430074, PR China
[i] Faculty of Geosciences, Utrecht University, P.O. Box 80115, 3508 TC Utrecht, The Netherlands
[j] National Research Council, Institute for Geo-hydrological Protection, via Amendola 122 I, 70126 Bari, Italy

ARTICLE INFO

Available online 22 December 2015

1. Introduction

Recently, the Journal, *Engineering Geology*, celebrated its 50th anniversary. *Engineering Geology* (referred to hereinafter as "the Journal") was founded in 1965 with the inaugural issue published in August of that year. More than 3400 papers have been published in the Journal since then. To help celebrate the 50th anniversary of the Journal, a virtual special issue (VSI) that consists of thirty selected papers was published in 2015 (http://www.journals.elsevier.com/engineering-geology/). These papers were selected by the two Chief Editors, Carlos Carranza-Torres and Charng Hsein Juang, with the assistance from the publisher, Kate Hibbert. The selection criteria included citations, the balance of the subjects, and contributions of individuals to the Journal. The preface of the VSI was written by Charng Hsein Juang with contributions from selected members of the Editorial Board of the Journal. This short communication, an enlarged version of the preface of the VSI, aims to summarize the history of the Journal, to discuss the future challenges faced by the engineering geology communities, and to provide new horizons for the young practitioners and researchers in this field.

2. Background and evolution of engineering geology

Engineering geology is a multidisciplinary subject of study at the intersection of earth sciences and engineering (particularly geological, civil, and mining engineering). Engineering geologists generally are trained as geologists, and they commonly have a background focused on the geologic and environmental factors that affect engineering design and construction. Their expertise also requires knowledge in soil and rock mechanics, groundwater, and surface water hydrology. The role of an engineering geologist is to understand the complexities of natural phenomena and geologic materials, and to describe them in a way that is readily usable in an engineering project.

Engineering Geology is an international research journal that is dedicated to serve the researchers and professionals working in the broad field of engineering geology. Indeed, the editorial of that inaugural issue clearly stated that the aim of the Journal was "to approach engineering from the geological angle, and to fill the gap between engineering and geology and to stimulate the publication of papers containing a significant content of both fields". The Journal published more than 3400 papers during the period of 1965–2015. The number of published papers steadily increased for the past 50 years (Fig. 1). The early theme of the Journal to emphasize "the need for engineers and geologists to communicate with each other" has greatly expanded over the past five decades to cover emerging technological and socioeconomic issues such as natural hazards, environmental concerns, and safety.

The papers published during the past 50 years can be classified into seven subject categories, as summarized in Table 1.

1) Physical and mechanical properties of soil, rock and rock masses (PMPSR); topics on treated soils, permafrost, and loess are also included in this category.
2) Engineering geology for engineering projects (EGEP); topics on hydropower stations, dams, and tunnels are also included in this category.

* Corresponding author.

http://dx.doi.org/10.1016/j.enggeo.2015.12.020

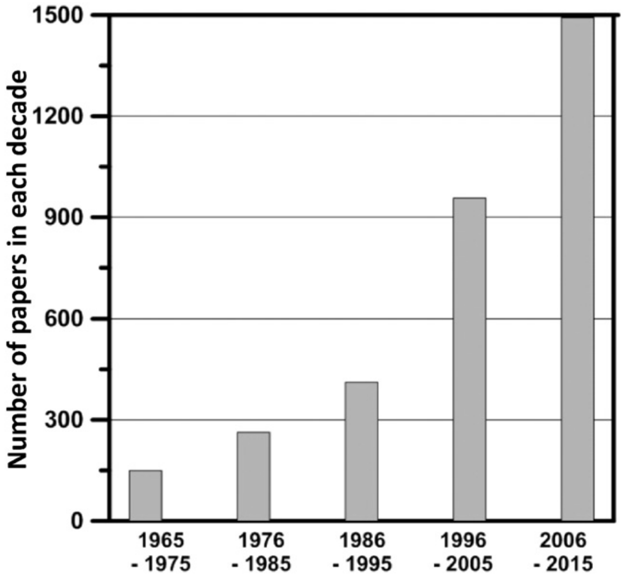

Fig. 1. Number of papers published in the Journal over the past 50 years.

3) Geological engineering and geotechnical engineering (GEGE); topics on empirical or theoretical design of foundations, slopes, tunnels and related technologies are included in this category.
4) Site characterization (SC); topics on geophysical prospecting and remote sensing applications are also included in this category.
5) Landslides (LS); slope stability and slope erosion are also included in this category.
6) Geohazards other than landslides (GH); fault and earthquake, liquefaction, karst and sinkhole, and land subsidence are included in this category.
7) Geo-environment and geo-resources (GEGR); topics on radioactive wastes disposal, carbon dioxide capture and sequestration, waste landfilling, groundwater pollution, and development of groundwater resources are included in this category.

PMPSR is the most dominant category of papers published in the Journal; almost half of the papers published between 1965 and 1975 fall in this category. Over the past 50 years, the average of PMPSR has remained quite steady and accounts for approximately 30% of all papers (Fig. 2). The papers categorized into EGEP account for approximately 14%. In 1995, the EGEP proportion reached the peak (30%) but has dropped quickly since then. After reaching a peak of approximately 20% in 1985, the GEGE category decreased significantly and averaged approximately 10% over the past 50 years. Site characterization (SC) is generally a part of the engineering project and thus this category can be difficult to differentiate from the aforementioned categories. However, this category has an increasing trend, reaching approximately 10% in the last 10 years. The Journal published numerous papers in the fields of the geo-hazard, geo-resources, and geo-environment. The landslide (LS) category is separated from the geo-hazard (GH) category because of its large proportion in the database. The long-term average proportion of LS papers is approximately 20%, but in the last ten years we have more than 400 LS papers, a substantial increase in both numbers and proportion of published papers. LS papers account for nearly one-third of all papers published in the Journal from 2006 to 2015. The number of geo-hazards (GH) papers was quite substantial, averaging approximately 10%. The papers in the geo-resources and geo-environment category (GRGE) also accounted for approximately 10%, with about half of the papers in this category being related to the subject of nuclear waste disposal.

Table 1
Number of papers published in each subject category during the past 50 years.

	1965–1975	1976–1985	1986–1995	1996–2005	2006–2015
PMPSR	74	87	131	226	473
EGEP	28	54	120	140	121
GEGE	18	54	26	119	91
SC	2	9	10	58	177
LS	13	24	44	165	425
GH	11	24	36	95	123
GEGR	4	11	45	155	82
Total	150	263	412	958	1492
Unclassified	18	23	32	52	75

2.1. Analysis of the subject preference of the published papers in each decade

1965–1975: In the early 1960's, numerous papers focused on the engineering behavior of problematic soils, such as quick clay or loess. Half of the papers published during this decade belonged to PMPSR category (Fig. 3). New methods were developed to improve the properties of these problematic soils. The first paper using remote sensing technology also appeared in this period, which used aerial photography to investigate the occurrence of laterites in northern Nigeria. It is interesting to note that induced seismicity was discussed extensively in the Journal during the middle of 1970's, and this is becoming a hot topic again now because of anomalous seismic activity recorded at some sites that could be related to the intense production of oil and gas shale, CO_2 sequestration, or geothermal energy extraction from hot dry rocks.

1976–1985: The papers belonging to PMPSR category dropped to less than one-third of the papers published in the Journal, whereas the papers related to EGEP and GEGE categories increased quickly during this period. Many papers in EGEP and GEGE from this decade were related to seismicity and reservoir projects. At the same time, the number of studies focusing on frost heave and ground freezing increased. Studies related to waste repositories first appeared in this decade.

1986–1995: During this period, the number of papers related to EGEP category reached a peak (~30%). This was probably related to the increasing budget for infrastructure development all around the world. Meanwhile, many other papers focused on the investigation of dam failures. The study of waste repositories also increased quickly in this decade, as researchers devoted much effort to environmental issues. As a result, the number of papers in the GEGR category increased significantly (greater than 10%).

1996–2005: In this decade the seven subject categories attracted similar attention from the researchers although the number of papers categorized into PMPSR was still greater than others and those categorized into SC was slightly less. The number of papers focusing on geo-environment and geo-resource issues reached a peak during this decade. Many LS papers appeared after 2000, which became a hot topic as reflected by the high citation counts. The number of papers related to earthquakes and active faults also increased in this decade.

2006–2015: The number of papers in the LS and SC categories increased quickly in this decade. In particular, the large magnitude 1999 Chi-Chi and 2008 Wenchuan earthquakes were two key events, which resulted in the extensive research on seismically induced landsliding and post-seismic slope hazards. However, the papers related to geo-environment and geo-resource (GEGR) issues dropped during this period. Interestingly, the number of papers in the PMPSR category increased in this decade but those in EGEP and GEGE categories declined. The world-wide economic recession from 2008 might have contributed to the decline of infrastructure development and thus the number of papers in these two subject categories.

The interests of the engineering geology communities will undoubtedly continue to evolve to address the emerging needs in a changing world. Accordingly, the Journal will continue to adapt to better serve the professionals and researchers working in the broad field of engineering geology.

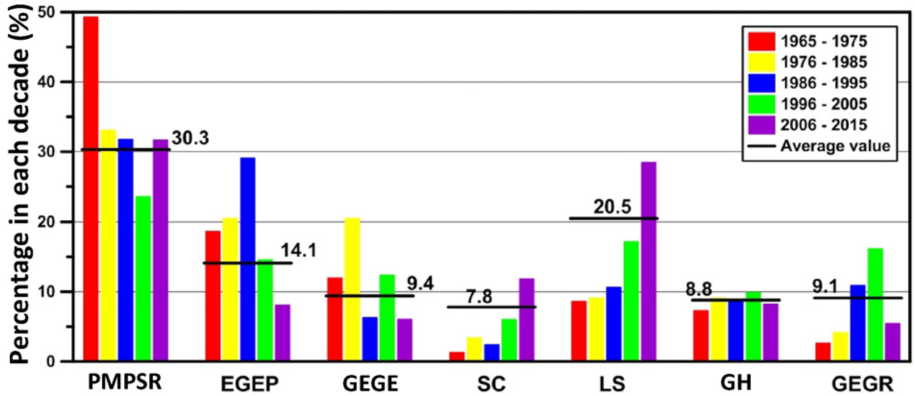

Fig. 2. Variation of different subject categories published in the past five decades. PMPSR: Physical and mechanical properties of soil, rock and rock masses; EGEP: Engineering geology for engineering projects; GEGE: Geological engineering and geotechnical engineering; SC: Site characterization; LS: Landslides; GH: Geohazards; GEGR: Geo-environment and geo-resources.

3. Opportunities and concerns in engineering geology

Three concepts clearly make engineering geology relevant in a changing world. First, burgeoning population growth clearly requires the construction of more infrastructure such as buildings, roads, airports, ports, and dams, which, in turn, will increase the demand for finding suitable sites or routes to meet these needs. These infrastructure needs will demand increasingly more quality services (e.g., site selection, environmental studies, and design) from the engineering geology professionals and more advanced research tools. Second, the increased need for industrial raw materials and ore minerals for building infrastructure and other uses (e.g., mining-related) will also enhance the important role of engineering geology. Third, the increase of losses from natural disasters, some of which could be exacerbated by land use and climate changes, will place a renewed focus on the relevance of engineering geology. Consequently, the future of engineering geology is very bright indeed, as opportunities are abundant for engineering geologists to be great contributors in making the world a better and safer place to live.

Two serious concerns affect this vision, however. First, the decrease in research revenues to fund new engineering geology research, coupled with the decrease in the number of engineering geology programs in higher education in the Western world, is detrimental to the scientific and technological advances of this discipline, which, in turn, adversely affects the education of young professionals. Second, the decrease in opportunity and quality of education and research will eventually affect the quality of engineering geology solutions in critical projects. Both problems can lead to a decrease in the relevance of engineering geology. To this end, engineering geology communities must reach out to policymakers and lawmakers because the ultimate funding to meet these future engineering geology challenges will come from them.

4. Emerging priorities and new frontiers in engineering geology

We have compiled a list of emerging priorities in the field of engineering geology that merit further discussion, research, and action in order to continue to make engineering geology a field of relevance to the changing world.

- Improve the characterization of the mechanical properties (especially shear strength) of geologic materials within a geologic formation to facilitate more quantitative regional hazard assessment and mapping.
- Develop models of complex natural phenomena and processes using hydro-chemo-thermo-mechanical approaches to improve our basic understanding of these processes. This includes an understanding of the microscopic properties of materials and the consequences on meso- and macroscopic behavior.
- Improve standards for data collection and analysis, quantify uncertainty, and validate models in order to provide more quantitative and reliable results of engineering geologic analyses.
- Apply engineering geologic expertise to address emerging issues of particular socioeconomic relevance, including the following: (1) disaster resilience of civil infrastructure in which geology is

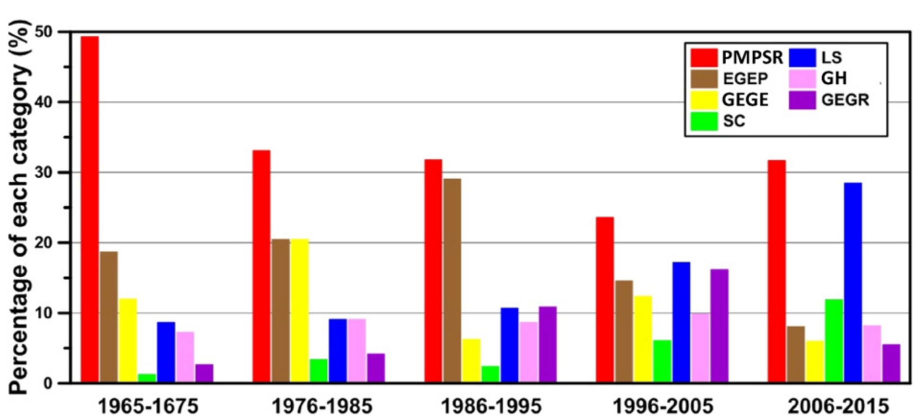

Fig. 3. Distribution of subject categories (i.e., percentage of each category) in each decade. PMPSR: Physical and mechanical properties of soil, rock and rock masses; EGEP: Engineering geology for engineering projects; GEGE: Geological engineering and geotechnical engineering; SC: Site characterization; LS: Landslides; GH: Geohazards; GEGR: Geo-environment and geo-resources.

integrated into infrastructure rating systems; (2) climate and land-use changes, the effect of which should be considered in the design, construction, and rehabilitation of water resources and infrastructures; (3) developing surface and groundwater resources in developing countries where availability of drinking and irrigation water is still a major challenge; (4) local and global response to increase sustainable development of communities worldwide; (5) development of alternative energy resources minimizing dependency on fossil fuels; (6) the role of engineering geology in CO_2 sequestration and stability of underground caves for storage; and (7) integrated design of stabilization works at regional scale departing from the more classical local design approach.
- Improve engineering geologic knowledge and tools as they apply to (1) nuclear-waste storage; (2) enhancing geothermal systems; (3) major construction projects such as long tunnels and large dams; and (4) solving engineering problems in active tectonic regions, tropical regions, Arctic regions, coastal and marine environments, problematic soil deposits, and urban environments.
- Develop new tools for multi-variable data collection for engineering geologic applications: (1) remote-sensing tools and techniques (e.g. Light Detection and Ranging, Synthetic Aperture Radar Multi-temporal Interferometry, Unmanned Aerial Vehicles), (2) Geographic Information System and interoperable user friendly tools and expert systems, (3) geostatistical methods, (4) advanced site-investigation techniques.
- 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.

In all of these emerging subjects a major advancement will be possible only through interdisciplinary approaches requiring a closer cooperation among the various disciplines. In what follows we use landsliding as an example to discuss how the new technologies can affect the research and/or practice of engineering geology.

Slope instability or landsliding is one of the most important, widely encountered problems in the field of engineering geology and is an example of a field where a multi-disciplinary approach is fundamental. The increasing impact of humans on the environment, urbanization of areas susceptible to slope failures, and ongoing changes in climate patterns will require a shift in our approaches to landslide hazard assessment and reduction. Indeed, evidence shows that landslide-related socio-economic losses have been increasing worldwide, particularly in developing countries. It follows that the protection of pre-existing and newly developed landslide areas using traditional engineering stabilization works and field monitoring is no longer considered sufficient or economically feasible. Furthermore, even where available, ground-control systems are typically installed only ex-post and for short term monitoring, and hence their role in preventing disasters is limited. Considering the global dimension of the slope instability problem, a reasonable way to reduce landslide hazards seems to be through increased use of affordable remote-sensing systems, with focus on early detection, long-term monitoring, and possibly early warning. Among a number of emerging space- and air-based remote-sensing techniques, Synthetic Aperture Radar Multi-temporal Interferometry and Airborn Laser Scanner are the most promising for important innovation in landslide hazard assessment and monitoring. These methods provide frequent and rapid measurements, both at local and regional scales, to support the understanding of landslide triggering processes as well as the development of early warning systems. We expect that by taking full advantage of the strengths of new space- and airborne technologies, remote sensing can help improve our methods of slope hazard assessment and make landslide monitoring more effective and affordable in more situations than in the past. However, much more effort is needed to better integrate ground-space information.

Furthermore, new developments in geophysical and geodetic techniques have enormously improved the accuracy and spatial resolution of the landslide geometry and the kinematic development. It will open new ways in visualizing, modeling and interpreting these processes. Geophysical investigations can also bring additional information on subsurface processes and movements which are essential for monitoring and early-warning techniques.

5. Remarks for future developments of engineering geology

Databases that document the details of engineering geology applications and case histories (successful or unsuccessful) are essential. Engineering geology remains a young discipline that continues to encounter new problems and innovative techniques as well as experiencing incredible research specialization. A standardized set of approaches for engineering geologic investigation, analysis, and evaluation are still lacking and must be established. Innovative applications of techniques such as geostatistics, geographic information systems, and expert systems to the field of engineering geology could be increased, but the fundamental relevance of data quality should be stressed to take advantage of these advanced tools. Again, attention must be directed toward fundamental understanding and analysis more than the simple application of techniques. The same caution should be applied to the use of the advanced equipment.

Improved datasets and appropriate techniques for collecting data are required. In many cases models that we use today are still based on little or poor quality data, or on very simple empirical approaches. Data and model validations are still rare or performed merely as a requirement and not as a fundamental investigation step. Furthermore, engineering geologists deal with nature in its intrinsic variability and complexity; geologic uncertainties should be recognized and quantified, and considered in the engineering design and construction.

Availability of drinking and irrigation water is still a major challenge in many parts of the world. For this reason, developing surface and groundwater resources is essential and requires cooperation within the broad field of engineering geology. High energy demand is also a pressing issue. As society tries to reduce dependency on fossil fuels, identifying alternative energy resources is a major issue that engineering geology has a role in addressing. Changing climate can potentially affect our approaches to landslide-hazard mitigation as well as the design, construction, and rehabilitation of structures and infrastructure. This is a new horizon with very little information, and establishing a baseline of reliable approaches to identify and address climate-related problems is essential.