

Enhancing Liquefaction Hazard Forecasting on Regional Scale

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Abstract: Soil liquefaction is an earthquake-induced phenomenon that is frequently reported on alluvial plains and coastal areas. Though the fact that liquefaction is considered as a low-level hazard compared to other relevant coseismic phenomena, can cause severe damage to lifelines, critical facilities and other structures constructed upon loose and saturated Quaternary deposits. Today, two approaches are followed for assessing liquefaction susceptibility and hazard of a site: the local scale and the regional one. The former is based on in-situ tests conducted on the selected site, while the latter is based on qualitative criteria combined by considering post-earthquake reports and the spatial distribution of geological features. This study investigated the correlation between geological/geomorphological features and the density of liquefaction occurrences aiming to propose a new quantitative classification of liquefaction potential of geomorphological features. As an outcome, it was clearly shown that the deposits of the inner part of meanders, characterized as point bar formations, are characterized by the highest weight values followed by the areas mapped as abandoned river channels.

Keywords: *Geomorphology, Liquefaction, Failures.*

Introduction

Studying the liquefaction susceptibility of deposits and being able to forecast the liquefaction occurrence is a task that requires numerous studies. Starting from the collection of information regarding the existing geological status to the reconstruction of paleogeomorphology on regional scale, this type of research aims to highlight the areas showing the highest susceptibility and to inform the authorities and stakeholders to reinforce existing structures and to avoid designing the construction of new ones on these areas.

The consequences of the generation of soil liquefaction can be the major cause of severe economic losses affecting the resilience of the community. It is also important to point out that rapid estimates of the effects of an earthquake and its secondary phenomena can help improve emergency response and recovery activities.

As has been shown by detailed studies in the last 15 years, the occurrence of liquefaction phenomena is

strongly related to geomorphology. It was well known and validated by the earthquakes occurred in New Zealand (2010-2011) (Wotherspoon et al., 2012; Bastin et al., 2015), Italy (2012) (Papathanassiou et al., 2015), Greece (2021) (Papathanassiou et al., 2022; Valkaniotis et al., 2024), Turkey (2023) (Taftsoglou et al., 2023) and recently Myanmar (2025) that the liquefaction manifestations are mainly reported on specific types of deposits.

However, the scientific community has not yet proposed a quantitative correlation between the geomorphological features and the relevant liquefaction hazard and risk, and this is a major gap in the current literature and practice. Having established this correlation, it would be possible to quantify in advance the liquefaction potential on a regional scale in a more reliable and accurate way. Consequently, this can facilitate the quantitative risk analysis of the exposed areas and critical infrastructure, in a rapid manner.

This study aims to address this issue by quantifying the performance of specific geomorphological features regarding the liquefaction occurrences by estimating weight values per type. To achieve this, liquefaction case studies from Damasi, Greece 2021, Christchurch, New Zealand 2010-2011 and Turkey, 2023 events were taken into account.

Methodology

The correlation between the spatial distribution of liquefaction phenomena with the geomorphological formations of the Piniada plain (Greece) and the Amik (Turkey) and Canterbury (New Zealand) valleys was based on the application of an equation proposed by Taftsoglou et al. (2025). This relationship considers the density of liquefaction phenomena within each geomorphological formation, as well as the overall occurrences across the study area, leading to the calculation of weight factors for each formation. The equation is expressed as:

$$LWF \text{ (Liquefaction Weight Factor)} = \ln \left[\frac{DenseUNIT}{DenseMAP} \right] \quad (1)$$

Where:

- The parameter *DenseUNIT (%)* refers to the density of liquefaction phenomena within each geomorphological formation and is calculated as the percentage of the area of liquefaction occurrences (km²) relative to the corresponding area of the geomorphological unit (km²).
- The parameter *DenseMAP (%)* refers to the density of liquefaction phenomena across the entire study area and is calculated as the percentage of the total area of liquefaction occurrences (SumLiq) (km²) relative to the total area of the mapped geomorphological formations (SumUnit) (km²).

Having collected the data of liquefaction phenomena and the corresponding maps of surficial geology for the three areas, the extent of the formations of abandoned meanders, floodplains, and point bar deposits was estimated in relation to the extent of liquefaction occurrences within each one of them. Moreover, the total extent of each study area with their respective liquefaction manifestations was measured. Consequently, density values were derived for each geomorphological formation (*DenseUNIT*), which were then compared with the overall liquefaction density of each study area (*DenseMAP*), leading to the estimation of corresponding weight factors for the geomorphological features.

Result and conclusion

According to the case study of Piniada plain, the highest weight values were attributed to point bar formations (0.93), followed by the type of abandoned meanders (0.57). A similar ranking is observed for the weight factors assigned to the formations of the Orontes River valley, with the lowest values calculated for the floodplain formations.

Regarding the weight factors of the geomorphological formations in the Avon River valley, based on the observed liquefaction phenomena resulting from the Darfield earthquake (2010), the highest values were estimated for the point bar formations (0.90), followed by the younger floodplain deposits (0.83). Similarly, based on the spatial distribution of liquefaction phenomena induced from the Christchurch earthquake (February 2011), the ranking of weight factors for the geomorphological formations follows the same pattern as observed in the case studies of Piniada plain and Orontes valley.

Finally, considering the extents of the geomorphological formations in the three study areas and the corresponding total areas of liquefaction manifestations, application of the suggested equation led to the estimation of weight factors for the geomorphological units of point bars, abandoned meanders, and floodplains, with the highest values assigned to the former.

Table 1, Final Liquefaction Weight Factors for the geomorphological formations of point bars, abandoned meanders and floodplains.

Geomorphological features	Liquefaction Weight Factors for each earthquake				Final Liquefaction Weight Factors
	Damasi (2021)	Turkey (2023)	Darfield (2010)	Christchurch (Feb-2011)	
Point bars	0.93	0.67	0.90	0.18	0.57
Abandoned meanders	0.57	0.62	-1.01	0.05	0.05
Floodplain deposits (younger)	-1.03	-0.48	0.83	0.08	-0.25
Floodplain deposits (older)	-1.11	---	-0.64	-0.06	-0.22

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