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Beyond Visible Earthquake Damage: Integrating Ground Failure Assessment into Disaster Response Following the 2026 M7.7 Flores Earthquake

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ABSTRACT

Post-earthquake disaster response commonly prioritizes casualties, structural damage, accessibility, and other visible impacts, while earthquake-triggered ground failure may receive less operational attention despite its implications for settlement safety, infrastructure, and recovery. Following the M7.7 Flores earthquake of 15 August 2026, this study examines the potential integration of near-real-time ground failure information into disaster response, focusing on the two principal mechanisms represented in the U.S. Geological Survey (USGS) Ground Failure product: liquefaction and earthquake-triggered landslides. Spatial outputs generated following the earthquake are examined to identify areas where ground-failure susceptibility may warrant prioritized attention and field verification. Rather than treating probabilistic model outputs as confirmation of ground failure at specific locations, the study proposes their use as an initial screening layer within a tiered post-earthquake framework. This framework links near-real-time geospatial hazard information with spatial prioritization, targeted field verification, settlement and infrastructure screening, and decisions concerning further geotechnical investigation. The analysis emphasizes that visible structural damage alone may not adequately represent post-earthquake ground conditions; apparently limited surface damage may coexist with underlying instability requiring assessment before repair, reconstruction, or continued occupation. The Flores earthquake illustrates how rapidly available ground failure information can bridge the critical interval between earthquake occurrence and comprehensive field investigation. Integrating such information into disaster response could strengthen risk-informed decision-making and reduce the likelihood that potentially unstable ground conditions are overlooked during recovery.

Keywords: *Ground Failure, Liquefaction, Earthquake-Triggered Landslides, Rapid Assessment, Disaster Response, Flores Earthquake*

1. INTRODUCTION

Earthquake impacts are commonly recognized through their most immediately observable consequences: casualties, collapsed or damaged buildings, disrupted roads and bridges, interrupted utilities, and population displacement. These impacts appropriately dominate the initial priorities of emergency response. However, earthquakes can also alter the physical condition of the ground on which settlements and infrastructure depend. Earthquake-triggered landslides and liquefaction, collectively referred to as ground failure, can contribute substantially to earthquake losses and may create hazards that are not adequately represented by observations of structural damage alone (Allstadt et al., 2022; Marano et al., 2010). This distinction is particularly important for post-earthquake decision-making because the apparent condition of a structure does not necessarily establish the stability of the ground beneath or around it.

The consequences of ground failure can extend beyond the earthquake. Liquefaction may result in loss of soil strength, settlement, lateral spreading, and other forms of ground deformation, with consequent effects on buildings, foundations, roads, lifelines, and other infrastructure. Earthquake-triggered landslides can directly affect settlements and infrastructure while also obstructing transportation corridors and constraining access to affected communities. Ground failure therefore represents not only a geotechnical phenomenon but also an operational concern for emergency response and subsequent recovery (Bird & Bommer, 2004). Its potential consequences were demonstrated dramatically during the 2018 Central Sulawesi earthquake, when extensive liquefaction-related ground deformation and large-scale lateral movement devastated several communities (Miyajima et al., 2019; Watkinson & Hall, 2019). Such events illustrate that earthquake losses cannot always be understood solely through conventional descriptions of shaking intensity and visible structural damage.

A major practical challenge is that comprehensive geotechnical field investigation requires time, specialized expertise, site access, and resources that are often limited during the early stages of a disaster (Jibson, 2007). Conversely, scientific information relevant to ground instability can now become available shortly after an earthquake. Since late 2018, the U.S. Geological Survey (USGS) Ground Failure (GF) earthquake product has provided publicly available, near-real-time spatial estimates of earthquake-triggered landslide and liquefaction hazard worldwide (Allstadt et al., 2022). The product is triggered by a USGS ShakeMap when an earthquake reaches M6.0 or greater, or for an event of at least M4.5 when maximum peak ground acceleration reaches 0.1 g. It combines ShakeMap ground-motion estimates with globally available proxies for ground-failure susceptibility to generate regional probabilistic estimates (Worden et al., 2010). In operational implementation, these estimates can become available within approximately 30 minutes of an earthquake, providing situational awareness during the critical period before direct observations are comprehensively available (Allstadt et al., 2022).

The purpose of these outputs is not to confirm individual occurrences of landslides or liquefaction. Rather, the USGS developed the product to provide initial awareness of the possible extent and significance of ground failure and to indicate areas where such processes are more likely to have occurred, thereby helping focus attention and response planning before responders and technical experts can complete field surveys (USGS, 2026). This distinction between prediction and prioritization is fundamental. The underlying models are designed for rapid and consistent regional or global application and necessarily depend on globally available datasets. Consequently, they cannot incorporate every local geological, geomorphological, hydrological, and geotechnical characteristic, nor can they predict specific occurrences at individual sites (Allstadt et al., 2022; USGS, 2026). Nevertheless, this limitation does not diminish their potential operational value. During the interval between earthquake occurrence and comprehensive field investigation, probabilistic ground-failure information can function as a spatial screening layer that directs limited technical and response resources toward locations where verification may be most consequential.

The M7.7 earthquake that struck the Flores region of East Nusa Tenggara, Indonesia, on 15 August 2026 provides a timely context in which to examine this potential. According to the updated parameters of the Indonesian Agency for Meteorology, Climatology and Geophysics (BMKG), the earthquake occurred at 04:58 WIB with an epicenter at 8.41°S and 121.39°E, approximately 30 km northeast of Mbay, Nagekeo, at a depth of 15 km (BMKG, 2026a). Subsequent BMKG analysis characterized the event as a shallow earthquake generated by thrust faulting associated with the Flores Back-Arc Thrust system (BMKG, 2026b). The earthquake generated strong shaking across Flores and triggered a tsunami warning that extended across parts of East Nusa Tenggara and neighboring regions (BMKG, 2026a). While immediate response appropriately focused on casualties, structural damage, accessibility, tsunami effects, and humanitarian needs, the event also triggered the USGS Ground Failure product, providing spatially variable probabilistic estimates of liquefaction and earthquake-triggered landslides across affected areas.

The geological and geomorphological setting of Flores further reinforces the relevance of ground-failure screening. The island is characterized by pronounced topographic contrasts between mountainous terrain, steep slopes, valleys, and lower-lying coastal and fluvial environments, creating fundamentally different conditions for the two principal forms of earthquake-triggered ground failure. Steep terrain is particularly relevant to slope instability, whereas relatively flat depositional environments may warrant liquefaction screening where loose and saturated materials are present. These contrasting physical settings reinforce the need to consider both mechanisms rather than interpreting earthquake impacts solely through shaking intensity and visible structural damage.

The distinction is also reflected in the structure of the USGS models. The preferred earthquake-triggered landslide model is based on an empirical relationship derived from inventories of landslides triggered by previous earthquakes and incorporates slope, peak ground velocity (PGV), lithology, land cover, and a compound topographic index representing relative wetness (Nowicki Jessee et al., 2018; USGS, 2026). The preferred liquefaction model similarly combines earthquake shaking with globally available proxies for susceptibility, including PGV, near-surface shear-wave velocity (Vs30), precipitation, proximity to coasts and rivers, and groundwater-related conditions (Zhu et al., 2017; USGS, 2026). In general terms, landsliding becomes more likely where shaking is strong and slopes are steep, whereas liquefaction becomes more likely where strong shaking coincides with relatively flat and wet terrain. The resulting outputs therefore provide complementary perspectives on post-earthquake ground instability rather than interchangeable representations of the same hazard.

Despite the increasing availability of such near-real-time geospatial information, an important gap remains between hazard estimation and operational use. Producing a probabilistic map does not by itself ensure that its information becomes part of disaster-response decisions. Indeed, the original development of the USGS Ground Failure system was motivated in part by the need to integrate estimates of secondary earthquake hazards with existing real-time earthquake information products (Allstadt et al., 2017). The practical question is therefore not whether a global model can replace site-specific geotechnical investigation—it cannot—but how its outputs can be translated into decisions about where field verification and subsequent investigation should begin. This is particularly relevant in geographically extensive disasters, where responders must allocate limited personnel, specialist expertise, and logistical resources across numerous affected settlements and infrastructure networks.

Accordingly, this study examines the potential integration of near-real-time ground-failure assessment into disaster response following the 2026 M7.7 Flores earthquake. It analyzes USGS probabilistic outputs for liquefaction and earthquake-triggered landslides as spatial screening information rather than confirmed inventories of ground failure. The study then develops a tiered pathway linking probabilistic hazard information to spatial prioritization, targeted field verification, settlement and infrastructure screening, and decisions concerning further geotechnical investigation. Where appropriate, preliminary field observations from the affected region are incorporated only as contextual evidence and are not treated as systematic validation of the probabilistic models. By positioning ground-failure information between near-real-time hazard science and field-based disaster assessment, this study seeks to broaden post-earthquake response beyond visible damage and toward a more risk-informed understanding of the ground conditions on which emergency operations, continued occupation, and subsequent recovery ultimately depend.

2. LITERATURE REVIEW

2.1 Earthquake-Induced Ground Failure

Ground failure represents an important class of secondary earthquake effects in which seismic shaking produces instability or deformation of the ground itself. The U.S. Geological Survey (USGS) Ground Failure framework focuses on two principal mechanisms: earthquake-triggered landslides and liquefaction (Allstadt et al., 2022). Although both are initiated or intensified by earthquake shaking, their controlling conditions and physical manifestations differ substantially. Their common relevance to disaster response lies in their capacity to generate losses beyond those directly attributable to structural shaking and to modify the physical environment on which settlements, infrastructure, and emergency access depend.

Earthquake-triggered landslides result from the destabilization of slopes under seismic loading. Their occurrence is influenced by the interaction of ground motion with slope geometry, lithology, hydrological conditions, land cover, and other local factors. At regional scale, strong shaking and steep terrain are among the principal controls on the spatial distribution of coseismic landsliding (Nowicki Jessee et al., 2018). Individual failures may range from relatively small rockfalls and shallow slides to large and complex mass movements. Consequently, their operational impacts may extend beyond direct burial or structural damage. Landslides can obstruct roads, isolate settlements, disrupt lifelines, alter drainage, and constrain the movement of emergency personnel and supplies.

Liquefaction involves a substantial reduction in the strength and stiffness of susceptible saturated soils during cyclic seismic loading. Its surface manifestations may include sand or water ejecta, settlement, ground cracking, lateral spreading, and other forms of permanent ground deformation. The susceptibility of a site is strongly conditioned by soil characteristics and saturation, while earthquake shaking provides the triggering demand. At regional scale, liquefaction therefore tends to be associated with combinations of sufficiently strong shaking and geomorphic or hydrological conditions indicative of relatively flat, wet, and potentially susceptible terrain (Zhu et al., 2017).

The distinction between these mechanisms is particularly relevant in an island environment such as Flores. Steep volcanic terrain can favor earthquake-triggered slope instability, whereas lower-lying coastal, riverine, and depositional environments may contain conditions requiring liquefaction screening. Ground-failure assessment following a major earthquake should therefore not treat landsliding and liquefaction as interchangeable hazards. Instead, they represent complementary mechanisms through which seismic shaking may compromise the ground supporting communities and infrastructure.

The importance of this distinction is reinforced by experience from previous Indonesian earthquakes. The 2018 Central Sulawesi earthquake demonstrated how liquefaction and associated large ground deformation can transform earthquake impacts beyond conventional building damage. At the same time, earthquake-triggered landslides repeatedly demonstrate that communities outside the most visibly damaged urban areas can experience severe secondary impacts through slope failure and disruption of transportation networks. Ground failure is consequently relevant not only to geotechnical characterization but also to the spatial organization of emergency response and recovery.

2.2 *Near-Real-Time Ground Failure Modelling*

Rapid field identification of ground failure presents an inherent operational challenge. Comprehensive inventories normally require direct observation, remote sensing interpretation, or dedicated geotechnical investigation. Such information may not be available during the first hours or days following a major earthquake, particularly where the affected region is geographically extensive or access is disrupted (Wald et al., 2008). Near-real-time modelling offers a complementary approach by identifying areas where ground failure is statistically more likely and where subsequent observation may therefore be prioritized.

The USGS Ground Failure (GF) earthquake product was developed specifically to provide this form of situational awareness. It combines ground-motion information from USGS ShakeMap with globally available geospatial proxies for susceptibility and produces regional estimates for both earthquake-triggered landslides and liquefaction (Allstadt et al., 2022; Wald et al., 2022). The system is triggered when an earthquake meets either of two conditions: magnitude M6.0 or greater, or magnitude M4.5 or greater combined with maximum peak ground acceleration (PGA) of at least 0.1 g (USGS, 2026).

The operational significance of the product lies in its timing. Ground-failure estimates can become available shortly after ShakeMap generation and before systematic field surveys have been completed. The product is therefore intended to provide early awareness of the possible overall extent and significance of ground failure and to identify areas in which it is more likely to have occurred. Importantly, the models do not predict individual landslides or liquefaction occurrences. Their appropriate interpretation is regional and probabilistic rather than deterministic (USGS, 2026).

This limitation is intrinsic to globally applicable models. Site-specific ground failure depends on geological, geomorphological, hydrological, and geotechnical characteristics that cannot be represented completely using global datasets. Model performance is also dependent on the quality of the underlying ShakeMap, which can evolve as instrumental observations, macroseismic information, and improved rupture characterization become available. Consequently, early GF outputs should be understood as dynamic spatial estimates rather than definitive inventories.

This distinction is central to their proposed role in disaster response. A probabilistic ground-failure map need not accurately identify every individual occurrence to be operationally useful. Its value may instead lie in reducing a very large affected region into spatial priorities for targeted observation. In this sense, near-real-time modelling functions as a bridge between regional earthquake information and subsequent field-based assessment.

2.3 USGS Earthquake-Triggered Landslide Model

The preferred USGS earthquake-triggered landslide model is based on the global empirical model developed by Nowicki Jessee et al. (2018). The model builds on an earlier globally applicable statistical model developed by Nowicki et al. (2014), which used logistic regression relationships between observed landsliding and globally available predictor variables. The 2018 model expanded the observational database to 23 landslide inventories and incorporated a broader range of earthquake, climatic, and tectonic settings (Nowicki Jessee et al., 2018). Its implementation within the USGS Ground Failure product has an approximate output resolution of 250 m (USGS, 2026). The broader physical relationship between earthquake shaking, geological setting, and earthquake-triggered landsliding has long been established in global observations (Keefer, 1984).

The principal predictor variables include slope, peak ground velocity (PGV), lithology, land cover, and compound topographic index (CTI), which provides a proxy for relative topographic wetness. Slope is derived from global elevation data, PGV is supplied by USGS ShakeMap, lithology is represented using the Global Lithological Map, and land-cover and hydrological proxies are derived from global datasets. For operational implementation, USGS excludes terrain with slopes below 5° and applies modifications to selected lithological coefficients. Probabilities below 0.002 are excluded from aggregate statistics as operationally insignificant (USGS, 2026).

The model therefore represents a physically meaningful but deliberately simplified relationship: earthquake-triggered landsliding becomes more likely where sufficiently strong shaking coincides with terrain and material conditions favorable to slope instability. It does not calculate the conventional factor of safety of individual slopes and does not substitute for site-specific slope-stability analysis (Jibson, 2011). Rather, it estimates regional relative hazard and subsequently converts that output into an estimate of expected areal coverage.

This distinction is important for post-earthquake interpretation. A high model value does not imply that every slope within the corresponding grid cell has failed, nor does it indicate the dimensions, mechanism, or runout of an individual landslide. Conversely, a relatively low regional probability cannot establish the absence of localized failure where site-specific conditions are unfavorable. Field observations remain necessary to establish actual occurrence and characterize individual failures.

2.4 USGS Liquefaction Model

The preferred USGS liquefaction model is the global geospatial model developed by Zhu et al. (2017), building on earlier work by Zhu et al. (2015) on geospatial liquefaction modelling for rapid response and loss estimation. The model is based on 27 inventories of earthquake-triggered liquefaction and combines earthquake shaking with globally available proxies related to site susceptibility. Its principal inputs include PGV from ShakeMap, time-averaged shear-wave velocity in the upper 30 m (Vs30), mean annual precipitation, distance to coast, distance to rivers, and estimated groundwater-table depth (Zhu et al., 2017; USGS, 2026).

Within the USGS implementation, terrain with slopes greater than 5° is excluded and a PGA threshold of 0.1 g is applied. The approximately 1-km original input layers are interpolated to a 500-m grid for implementation. These parameters allow the model to distinguish, at regional scale, areas where strong shaking coincides with environmental conditions more compatible with liquefaction susceptibility.

USGS identified a tendency for the original model to overpredict liquefaction probabilities for some moderate-magnitude earthquakes. A magnitude-dependent scaling factor is therefore applied to PGV before evaluation by the Zhu et al. (2017) model:

$$SF = \frac{1}{1 + e^{-2(M-6)}} \tag{1}$$

where (SF) is the scaling factor and (M) is earthquake magnitude (USGS, 2026). The adjusted PGV is subsequently evaluated within the liquefaction model. For a large event such as the M7.7 Flores earthquake, the scaling factor approaches unity, reflecting the diminishing need to suppress PGV as earthquake magnitude increases.

As with the landslide model, the liquefaction output must not be interpreted as confirmation of liquefaction at a particular site. Local stratigraphy, soil density, grain-size distribution, groundwater conditions, and other geotechnical parameters are important considerations in site-specific liquefaction assessment (Youd et al., 2001). These parameters are not directly represented at site-specific resolution. The model instead provides a regional screening estimate that can identify locations where targeted verification may be warranted.

2.5 *Interpreting Ground Failure Probability and Exposure*

An important characteristic of the preferred USGS models is the meaning of the probability displayed on the Ground Failure maps. Both preferred models are logistic models whose native outputs represent relative hazard. These values are calibrated against mapped inventories to obtain a physically interpretable measure termed areal coverage (A_c), reflecting the importance of observed earthquake-induced landslide inventories in developing and interpreting probabilistic models (Tanyas et al., 2017; Schmitt et al., 2017). Areal coverage represents the expected proportion of a grid cell affected by ground failure rather than the probability that a discrete landslide or liquefaction occurrence will happen at a particular point (USGS, 2026).

This distinction prevents deterministic interpretation of the maps. A grid cell with an areal-coverage value of 0.20, for example, should not be interpreted as indicating a 20% probability that one specific location will fail. It represents an expectation that approximately that proportion of the cell may be affected. USGS notes that an areal-coverage probability of approximately 0.2 already corresponds to severe ground failure, and model values generally do not approach unity (USGS, 2026).

To summarize the regional significance of predicted ground failure, USGS calculates the Estimated Area Exposed to Hazard:

$$H_{tot} = \sum_{i=1}^{m}\sum_{j=1}^{n} P_{i,j}A_{i,j} \text{ for } gm_{i,j} \geq gm_{thresh} \text{ and } P_{i,j} \geq P_{thresh} \tag{2}$$

where $P_{i,j}$ is the estimated ground-failure areal coverage in grid cell i,j, $A_{i,j}$ is the cell area in km², $gm_{i,j}$ is the relevant ground-motion parameter, and gm_{thresh} and P_{thresh} are the applicable ground-motion and probability thresholds. H_{tot} is therefore a model-based estimate or proxy for the total area potentially affected rather than a directly mapped inventory of actual failure (USGS, 2026).

The second summary statistic is Estimated Population Exposure:

$$pop_{exp} = \sum_{i=1}^{m}\sum_{j=1}^{n} L_{i,j}P_{i,j} \text{ for } gm_{i,j} \geq gm_{thresh} \text{ and } P_{i,j} \geq P_{thresh} \quad (3)$$

where $L_{i,j}$ represents the population within each grid cell. The statistic is not an estimate of casualties. It represents the approximate population living near areas modelled as susceptible to earthquake-triggered ground failure and serves as a proxy for potential human impact (USGS, 2026).

These statistics provide useful event-level summaries, but they also reveal an important limitation for operational disaster response. Population exposure does not adequately represent indirect consequences in sparsely populated or remote terrain. A landslide affecting a critical mountain road, for example, may isolate multiple communities even if the modelled population within the landslide grid cell itself is small. USGS explicitly identifies blocked or damaged roads and landslide-dam hazards as examples of indirect remote effects that are not well captured by population exposure alone (USGS, 2026). This limitation is particularly relevant to Flores, where mountainous terrain and road-based connectivity can make localized slope failures operationally significant beyond their immediate footprint.

2.6 From Probabilistic Hazard to Operational Ground-Failure Screening

The availability of near-real-time ground-failure estimates does not by itself ensure their operational use during earthquake response. Such products occupy an intermediate position between regional hazard characterization and direct evidence from affected locations. Their practical value therefore depends on how probabilistic information is translated into decisions concerning where attention should be directed, what conditions require verification, and when more detailed geotechnical investigation becomes necessary. This translation is particularly important during the early response period, when the affected area may be extensive while technical personnel, accessibility, and field information remain limited.

For operational purposes, ground-failure information can be considered across three complementary levels of assessment. The first is regional probabilistic screening, represented in this study by the USGS Ground Failure product. At this level, near-real-time modelling provides an initial indication of the spatial distribution and relative significance of potential liquefaction and earthquake-triggered landsliding. Its principal value is not confirmation of individual failures but the identification of areas that may warrant greater attention.

The second level is targeted field verification. Locations identified through probabilistic outputs can be considered together with observed surface manifestations, community reports, infrastructure disruption, accessibility constraints, and other information emerging during response operations. Field verification provides the critical transition from modelled susceptibility to evidence of actual ground conditions. Depending on the mechanism involved, observations may include slope failure, displaced material, rockfall, ground cracking, settlement, lateral spreading, or liquefaction-related ejecta. Precise geographic coordinates and photographic documentation can further establish the spatial relationship between observed phenomena and modelled hazard patterns. Such observations remain preliminary unless supported by systematic investigation and should not be interpreted as substitutes for geotechnical characterization.

The third level is site-specific geotechnical investigation, undertaken where preliminary evidence indicates that ground conditions may affect safety, infrastructure performance, continued occupation, repair, or reconstruction. This level requires substantially greater technical detail and may involve characterization of slope geometry, geological and soil conditions, groundwater, failure mechanisms, subsurface stratigraphy, and relevant engineering parameters. The distinction between field verification and geotechnical investigation is important: confirming that a slope failure or liquefaction manifestation exists does not, by itself, establish the stability or engineering suitability of the affected site.

These levels are therefore complementary rather than interchangeable. Regional modelling cannot establish site-specific safety, while comprehensive geotechnical investigation cannot realistically be undertaken across every potentially affected location during the initial response period. Targeted verification can bridge this scale gap by directing more intensive investigation toward locations where the consequences of overlooked ground instability may be greatest. Conceptually, this creates a sequential pathway from near-real-time ground-failure information to spatial prioritization, targeted field verification, settlement and infrastructure screening, site-specific geotechnical investigation where required, and ultimately response and recovery decisions.

This distinction is particularly relevant to transportation networks and geographically dispersed settlements. Ground failure in a sparsely populated grid cell may have limited direct population exposure but substantial operational consequences if it affects a road providing access to multiple communities. The USGS Ground Failure methodology itself recognizes that population-exposure estimates do not adequately capture some indirect remote effects, including roads blocked or damaged by landslides and hazards associated with landslide dams (USGS, 2026). Consequently, operational screening should consider not only the probability and spatial extent of ground failure but also the function and connectivity of potentially affected infrastructure.

The 2026 Flores earthquake provides an event-specific context in which to examine this relationship. In addition to the near-real-time probabilistic outputs, preliminary observations obtained during ongoing response activities documented several slope failures at precisely georeferenced locations. These observations do not constitute a systematic landslide inventory and are insufficient for formal validation of the USGS model. Their value in the present study is more limited but operationally relevant: they provide field-based evidence that can be spatially compared with the probabilistic output and used to examine how regional screening information relates to conditions encountered during disaster-response activities.

Accordingly, spatial correspondence between an observed slope failure and an area of elevated modelled probability is treated in this study as supporting evidence rather than model validation. Conversely, an observed failure outside a relatively elevated probability zone would not necessarily demonstrate model failure, because localized geological, topographic, hydrological, and geotechnical conditions may not be adequately represented by globally available datasets. This distinction preserves the intended scale and purpose of the USGS product while allowing field observations to contribute meaningfully to its operational interpretation.

Integrating ground-failure information into disaster response therefore does not require probabilistic models to function as deterministic forecasts, nor does it require emergency responders to perform comprehensive geotechnical investigations. Instead, it requires a structured transition from regional scientific information to progressively more specific forms of evidence and technical assessment. The central operational question shifts from whether a probabilistic map can determine exactly where ground failure has occurred to whether it can help determine where verification should begin and where overlooked ground instability could materially affect response and recovery decisions.

3. METHODS

3.1 Study Design and Analytical Approach

This study employed an event-based geospatial assessment to examine how near-real-time ground-failure information can be integrated into post-earthquake disaster response. The analysis focused on the M7.7 Flores earthquake of 15 August 2026 and considered the two ground-failure mechanisms represented by the USGS Ground Failure product: earthquake-triggered landslides and liquefaction. Rather than conducting a retrospective inventory-based validation of the models, the study evaluated their potential operational use as regional screening information during the interval between earthquake occurrence and comprehensive field investigation.

The analytical approach combined three forms of information: (1) earthquake and ground-motion information describing the triggering event; (2) probabilistic ground-failure outputs providing regional estimates of earthquake-triggered landsliding and liquefaction; and (3) preliminary georeferenced field observations obtained during ongoing disaster-response activities. These information layers were examined at different spatial and evidential scales. The probabilistic outputs were used for regional prioritization, whereas field observations were used as location-specific evidence of actual ground conditions. Their spatial relationship was subsequently interpreted within the tiered screening framework developed in Section 2.6.

3.2 Data Sources

The primary earthquake parameters were obtained from BMKG and USGS earthquake information products. BMKG data were used to characterize the earthquake origin time, epicentral location, depth, magnitude, felt intensity, and tectonic mechanism. USGS ShakeMap provided the regional ground-motion information underlying the Ground Failure product (Wald et al., 1999; Worden et al., 2010).

The principal geospatial datasets consisted of the USGS near-real-time earthquake-triggered landslide and liquefaction outputs generated for the event. These products represent spatially distributed probabilistic estimates derived from the empirical models described in Sections 2.3–2.5. The analysis used the model outputs as released for the Flores earthquake rather than independently recalculating the underlying global models. This distinction is important because the objective was to examine the operational interpretation and application of rapidly available information rather than to reproduce the USGS modelling system.

Supporting geological and geomorphological information was used to provide regional context for interpretation of the spatial patterns. Particular attention was given to the contrast between mountainous and steep terrain relevant to earthquake-triggered landsliding and lower-lying depositional environments potentially relevant to liquefaction susceptibility.

Preliminary field information consisted of photographic observations and geographic coordinates collected during disaster-response activities in affected parts of Flores following the earthquake. At the time of analysis, several precisely georeferenced locations documented observable slope failures. Because these observations were collected opportunistically during ongoing response operations rather than through a systematic landslide-inventory survey, they were treated as field observations for spatial comparison and operational interpretation, not as a statistically representative sample or formal validation dataset.

3.3 Spatial Analysis of Ground-Failure Information

The landslide and liquefaction outputs were examined separately because the two models represent distinct ground-failure mechanisms and employ different predictor variables, spatial resolutions, and applicability conditions. Spatial patterns were interpreted according to the areal-coverage concept used by the USGS Ground Failure product. Accordingly, mapped values were not interpreted as point-specific probabilities of failure but as estimates of the expected proportion of individual grid cells potentially affected by ground failure.

The analysis first examined the regional distribution of modelled ground-failure hazard across Flores and identified areas displaying comparatively elevated landslide or liquefaction estimates. These patterns were considered in relation to earthquake shaking, terrain characteristics, settlement distribution, and transportation connectivity where relevant to disaster-response operations. Particular attention was given to locations where ground failure could have consequences beyond its immediate spatial footprint, including slope failures capable of disrupting road access to geographically dispersed communities.

The spatial analysis was therefore comparative and prioritization-oriented rather than deterministic. Areas of elevated modelled hazard were interpreted as locations warranting greater attention or field verification, while areas of lower modelled probability were not assumed to be free from localized ground failure.

3.4 Field Observations and Spatial Correspondence

Georeferenced field observations were spatially compared with the earthquake-triggered landslide output to examine whether documented slope failures occurred within or near areas identified by the regional model as having elevated ground-failure potential. Each usable observation consisted, where available, of geographic coordinates, photographic documentation, observation date, and a qualitative description of the observed ground condition.

Spatial correspondence was interpreted qualitatively rather than as a conventional model-performance statistic. An observed slope failure located within an area of elevated modelled landslide probability was considered supporting field evidence of correspondence between regional screening information and actual post-earthquake conditions. It was not classified as a model "success" in a formal validation sense. Similarly, observations occurring in areas of lower modelled probability were retained rather than treated automatically as model errors, because localized geological, topographic, hydrological, and geotechnical conditions may not be represented adequately by the global model inputs.

No equivalent field validation was assumed for liquefaction unless observable manifestations could be documented with sufficient location information. Consequently, the absence of reported liquefaction observations was not interpreted as evidence of the absence of liquefaction, particularly in areas that had not been systematically inspected.

3.5 Integration of Ground Failure Information into Post-Earthquake Disaster Response

The resulting interpretation followed a sequential pathway from near-real-time ground-failure information to spatial prioritization, targeted field verification, settlement and infrastructure screening, site-specific geotechnical investigation where required, and ultimately response and recovery decisions. This pathway is intended to connect rapidly available regional hazard information with progressively more localized forms of assessment rather than to replace field-based investigation.

The first stage involves the interpretation of near-real-time USGS Ground Failure outputs as an initial spatial screening layer. Areas showing relatively higher modeled ground-failure exposure can be identified shortly after an earthquake and considered for further attention. At this stage, the outputs are not interpreted as confirmed occurrences of liquefaction or landslides. Their primary operational function is to provide an early indication of where ground-failure-related impacts may warrant additional consideration, particularly when comprehensive field information is not yet available.

The second stage is spatial prioritization. Because post-earthquake response resources are inherently limited, the entire affected region cannot necessarily be investigated simultaneously. Ground-failure information can therefore be combined with the distribution of settlements, roads, bridges, public facilities, lifelines, and other critical infrastructure to identify locations where potential ground instability may have greater consequences. This approach shifts the use of probabilistic hazard information from simply describing hazard distribution toward supporting decisions about where technical attention should initially be directed.

The third stage consists of targeted field verification. Locations prioritized through the spatial screening process should be examined through field observation where access and operational conditions permit. Field verification may include identification of landslide scarps and displaced materials, slope instability, ground cracking, settlement, lateral deformation, sand ejecta, surface water or mud emergence, and other observable indicators consistent with earthquake-triggered ground failure. Precise geographic coordinates and photographic documentation can strengthen the evidentiary value of these observations. In this study, preliminary field observations from affected areas are used as contextual evidence of ground-failure occurrence and spatial correspondence, rather than as a statistically representative validation dataset for the USGS models.

The fourth stage is settlement and infrastructure screening. Where field observations indicate ground deformation or where potentially exposed locations coincide with settlements and critical infrastructure, the condition of the ground should be considered alongside the visible condition of structures. A building that appears to have limited structural damage does not necessarily indicate that the underlying site is suitable for immediate repair, reconstruction, or continued occupation. Similarly, roads and other infrastructure may remain superficially functional while being affected by slope instability, settlement, lateral spreading, or other ground deformation. Ground-failure screening can therefore provide an additional layer of information for post-earthquake damage and safety assessment.

The fifth stage involves site-specific geotechnical investigation where required. Locations exhibiting significant ground deformation, confirmed or strongly suspected liquefaction, substantial slope instability, or important infrastructure exposure may require investigation beyond regional probabilistic assessment and field reconnaissance. Such investigation may include characterization of subsurface materials, groundwater conditions, slope geometry, soil strength, density, stratigraphy, and other parameters appropriate to the suspected failure mechanism. The purpose of this stage is to establish site-specific engineering conditions that cannot be reliably determined from regional probabilistic models alone.

The final stage concerns response and recovery decisions. Information accumulated through the preceding stages can support decisions regarding access restrictions, temporary safety measures, repair, reconstruction, continued occupation, relocation, stabilization measures, and the need for more detailed engineering assessment. The framework therefore treats ground-failure information as an input to decision-making rather than as a standalone determination of safety or unsafety.

Overall, the framework establishes a practical progression from regional, rapidly available hazard information toward increasingly localized evidence and engineering assessment. Its principal value lies in reducing the likelihood that potential ground instability is overlooked during the early transition from emergency response to recovery, particularly in geographically extensive disasters where field resources cannot immediately cover all affected areas.

3.6 Methodological Scope and Limitations

This study is designed as a rapid, hazard-informed assessment of the potential operational use of near-real-time ground-failure information following the 2026 M7.7 Flores earthquake. The analysis focuses specifically on earthquake-triggered liquefaction and landslides represented by the USGS Ground Failure product and does not attempt to provide a complete post-earthquake inventory of all ground failures across Flores. The study consequently emphasizes the interpretation and operational application of available probabilistic information rather than exhaustive field mapping.

Several limitations should be recognized. First, the USGS Ground Failure models are designed for regional and global applicability and necessarily simplify local geological, geomorphological, hydrological, and geotechnical conditions. Model outputs therefore represent probabilistic estimates and should not be interpreted as confirmation that a particular grid cell has experienced ground failure. Local variations in soil properties, groundwater conditions, slope geometry, land use, drainage, and geological structure may produce conditions that differ substantially from those represented by the model.

Second, the spatial resolution and input datasets of the probabilistic products impose limitations on site-level interpretation. A relatively high modeled value does not establish that a specific building, road segment, or parcel has failed, while a relatively low value does not guarantee the absence of ground deformation. Accordingly, the products are most appropriately used for screening and prioritization before field verification and, where necessary, site-specific investigation.

Third, preliminary field observations available during the study period are geographically limited. The observations provide direct evidence of ground conditions at specific locations and may help illustrate the practical relevance of the modeled hazards, but they do not constitute a systematic validation survey. The absence of field observations in a particular area should therefore not be interpreted as evidence that ground failure did not occur there. Conversely, an observed landslide or other ground-failure feature cannot by itself establish that the corresponding probabilistic model correctly predicted that specific event without a structured validation analysis.

Fourth, the study does not attempt to establish deterministic thresholds for declaring settlements or infrastructure unsafe. Decisions concerning repair, reconstruction, continued occupation, stabilization, or relocation require site-specific engineering and institutional assessment beyond the scope of a regional probabilistic screening framework. The proposed pathway is therefore intended to support the allocation and sequencing of technical attention rather than to replace professional engineering judgment or established disaster-management procedures.

Finally, the operational value of near-real-time ground-failure information depends not only on the quality of the underlying models but also on whether the information reaches actors capable of interpreting and acting upon it. A probabilistic map that remains isolated from disaster-response workflows has limited practical value. The principal contribution proposed here is therefore the integration of available ground-failure information into a structured assessment sequence, connecting rapid hazard screening with spatial prioritization, field verification, settlement and infrastructure screening, and subsequent geotechnical investigation where warranted. Within these methodological boundaries, the Flores earthquake provides a timely case through which the potential contribution of ground-failure information to risk-informed disaster response can be examined.

4. RESULTS AND DISCUSSION

4.1 Near-Real-Time Ground-Failure Assessment Following the Flores Earthquake

The near-real-time USGS Ground Failure product generated following the 15 August 2026 Flores earthquake provides separate spatial estimates for earthquake-triggered landslides and liquefaction. The two outputs reveal substantially different spatial patterns, reflecting the distinct physical controls incorporated into their respective models. Rather than representing a uniform extension of earthquake shaking, the ground-failure products indicate that potential post-earthquake ground instability is spatially heterogeneous across Flores.

The availability of these outputs shortly after the earthquake is particularly relevant to the early response period. The USGS Ground Failure system is designed to provide initial awareness of the potential extent and significance of earthquake-triggered ground failure while comprehensive field surveys are still developing. The maps therefore provide an opportunity to identify areas that may warrant additional attention before systematic field investigation becomes possible.

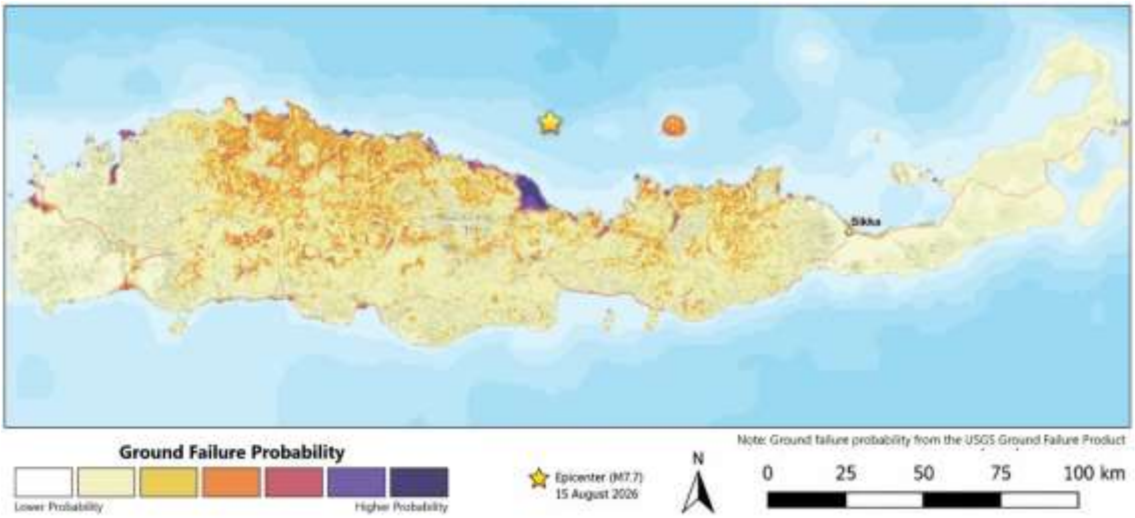

Figure 1. Earthquake-triggered ground failure hazard following the 15 August 2026 M7.7 Flores earthquake

The spatial distribution of modeled ground failure should nevertheless be interpreted at the regional scale. High-value areas indicate greater modeled areal coverage of potential ground failure rather than deterministic predictions that a particular settlement, road, or structure has failed. This distinction is especially important when translating the maps into operational decisions.

The contrasting patterns of landslide and liquefaction estimates also demonstrate why the two mechanisms should be considered separately during post-earthquake assessment. Landslide-related hazard is more closely associated with steep and mountainous terrain, whereas liquefaction-related hazard may occur in areas where ground shaking interacts with susceptible near-surface materials and groundwater conditions. Consequently, the combined regional visualization provides an initial overview, while subsequent interpretation should consider the mechanisms independently.

4.2 Spatial Distribution of Earthquake-Triggered Landslide Hazard

The spatial distribution of modeled earthquake-triggered landslide hazard shows a pronounced concentration across the mountainous and relatively steep terrain of Flores. Higher modeled probabilities are distributed across numerous slope zones, particularly in the central and western portions of the island, while lower probabilities generally occur across flatter and less rugged areas. This pattern is consistent with the strong influence of terrain and ground-motion conditions on earthquake-triggered slope instability.

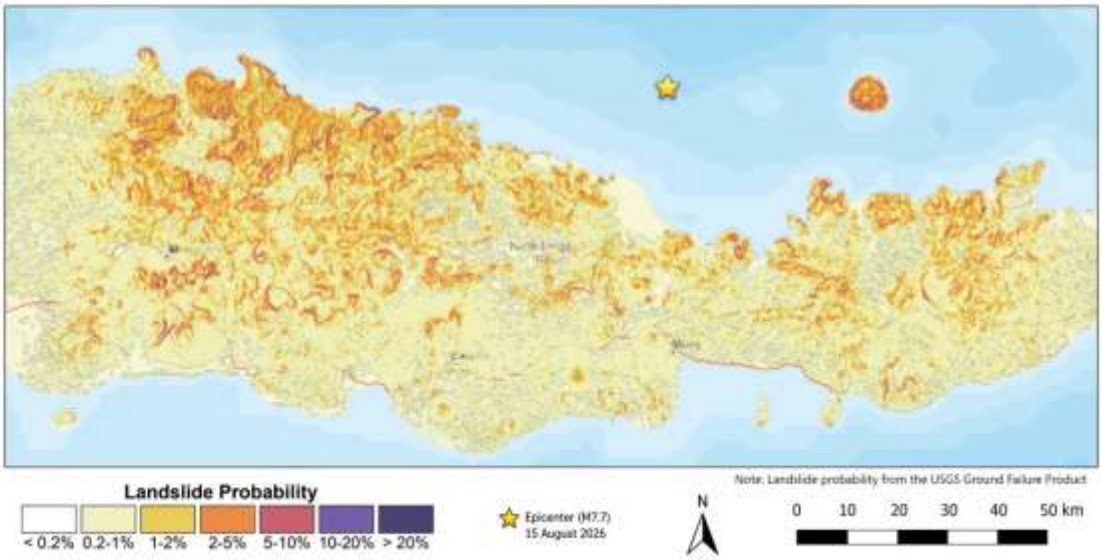

Figure 2. Earthquake-triggered landslide hazard following the 2026 Flores earthquake

The modeled distribution indicates that potential landslide exposure is not confined to locations immediately surrounding the earthquake epicenter. Instead, areas of elevated modeled probability extend across substantial portions of Flores, reflecting the combined influence of seismic shaking and pre-existing susceptibility conditions. This spatial pattern is particularly relevant to emergency response because transportation corridors and settlements may be affected by slope failures even when they are located at considerable distances from the epicenter.

The result also illustrates the value of considering ground failure separately from conventional earthquake-impact mapping. A settlement may experience limited structural damage while remaining connected to surrounding areas through roads crossing steep or potentially unstable terrain. In such circumstances, landslide screening can provide an additional basis for identifying transportation routes and communities that may require inspection, particularly where access is essential for humanitarian response.

The USGS landslide model should nevertheless be interpreted as a regional probabilistic screening product rather than a site-specific prediction. The higher-probability areas identify locations where the modeled combination of ground-motion and susceptibility conditions is more favorable for earthquake-triggered landsliding; they do not establish that a landslide has occurred at every location within those areas. Field verification is therefore required to determine the actual occurrence, magnitude, geometry, and consequences of individual slope failures.

For the Flores earthquake, this distinction is operationally important. The extensive distribution of modeled landslide hazard provides a means of narrowing an otherwise large field-assessment domain. Rather than treating every slope or road segment as an equivalent priority, response teams can use the spatial pattern as an initial screening layer and subsequently combine it with reports of blocked roads, affected settlements, terrain conditions, and other field information to determine where verification is most urgent.

4.3 Spatial Distribution of Liquefaction Hazard

The modeled liquefaction hazard presents a substantially different spatial pattern from the landslide hazard. Higher probabilities are more spatially localized and occur primarily in areas where the model identifies a combination of favorable ground-motion, near-surface material, hydrological, and geomorphological conditions. Compared with the broadly distributed landslide pattern across the mountainous interior of Flores, the liquefaction output is therefore more concentrated in selected low-lying and depositional environments.

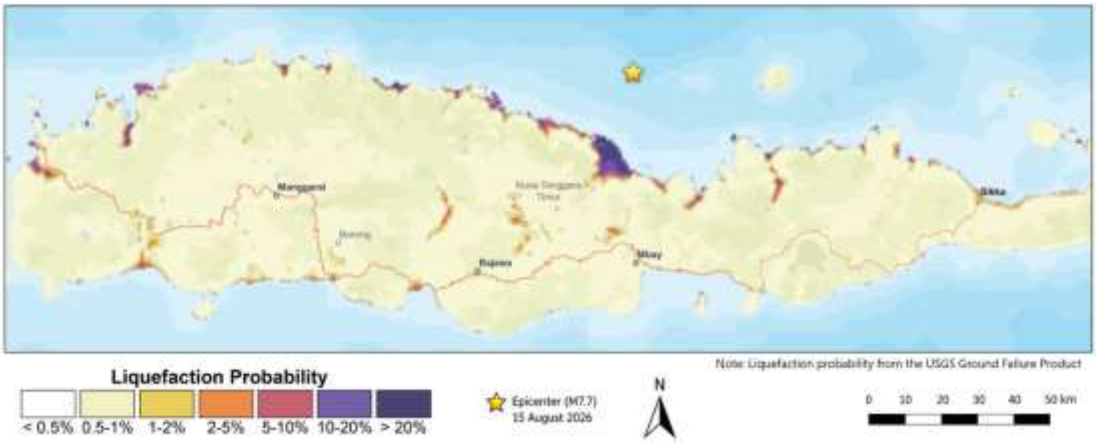

Figure 3. Liquefaction hazard following the 2026 Flores earthquake

The contrasting spatial distributions of the two outputs demonstrate why earthquake-triggered ground failure should not be treated as a single homogeneous hazard. Landslide susceptibility is strongly associated with slope and terrain conditions, whereas liquefaction requires a different combination of subsurface and hydrological characteristics. Consequently, an area with relatively limited modeled landslide probability may still warrant attention because of its modeled liquefaction potential.

The liquefaction map is particularly useful as an early screening tool because evidence of liquefaction may not be immediately apparent from conventional structural-damage assessments. Ground deformation, settlement, lateral spreading, sand boils, or other manifestations may occur without producing the same level of visible building damage expected from severe structural failure. Areas identified by the model can therefore provide useful targets for field teams to investigate ground conditions, particularly around settlements, roads, bridges, river corridors, and other infrastructure.

As with the landslide output, the modeled probabilities should not be interpreted as confirmation of liquefaction at individual locations. The USGS product provides a regional estimate of expected ground-failure areal coverage under the modeled conditions. Local geological materials, groundwater conditions, drainage, site history, and other factors may produce conditions that differ from those represented in the global model. Field observations are consequently essential for determining whether the modeled potential corresponds to actual ground deformation or other evidence of liquefaction.

The different spatial characteristics of Figures 2 and 3 also have practical implications for response prioritization. The landslide model identifies a comparatively extensive set of potentially affected slope areas, whereas the liquefaction model highlights more localized zones requiring attention. Using both outputs together can therefore support differentiated field strategies: slope-oriented reconnaissance for areas of elevated landslide probability and ground-condition investigation in selected areas of elevated liquefaction probability. This complementary use of the two products strengthens their value as an initial screening layer before site-specific geotechnical assessment.

4.4 Field Observations of Earthquake-Triggered Landslides

The regional landslide probability map provides a broad spatial indication of areas potentially affected by earthquake-triggered slope failure; however, interpretation of the modeled hazard benefits from comparison with observations made at ground level. During ongoing post-earthquake response activities, three locations with visible evidence of earthquake-triggered landsliding were documented and designated as LO-1, LO-2, and LO-3. The observations included disturbed and exposed slope surfaces, displaced soil and rock materials, and accumulated debris along affected slopes and road corridors. The geographic locations and corresponding field photographs are summarized in Table 1.

Table 1. Geographic coordinates and field observations of earthquake-triggered landslides

Observation	Latitude (°)	Longitude (°)	Field photograph
LO-1	-8.647588	120.334252	
LO-2	-8.477826	120.488334	
LO-3	-8.463675	120.489532	

The documented observations are concentrated within the broader area characterized by elevated modeled landslide probability in the USGS Ground Failure product. Their locations relative to the modeled probability distribution are shown in Figure 4. This spatial comparison provides a qualitative basis for examining whether areas highlighted by the near-real-time model correspond with locations where ground failure was subsequently observed in the field.

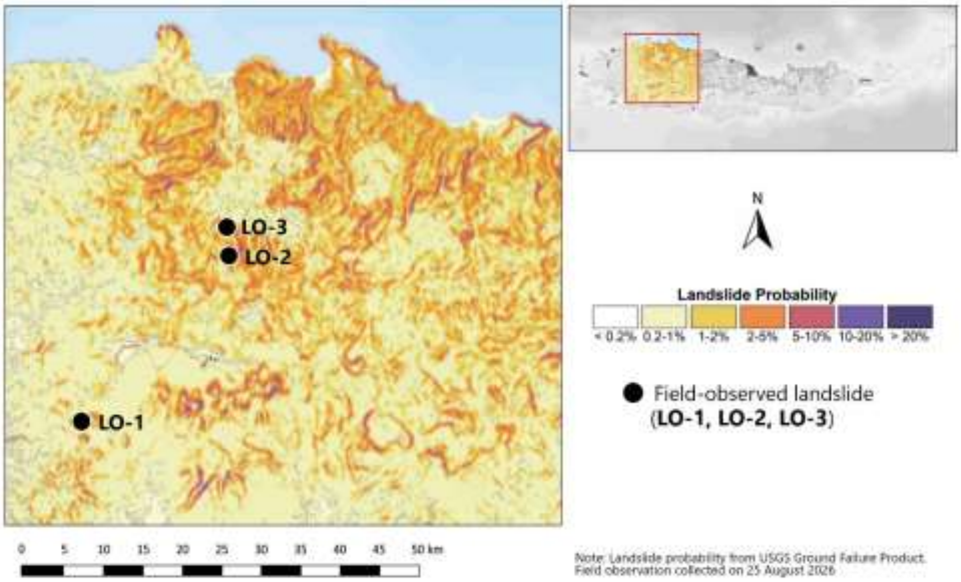

Figure 4. Field-observed earthquake-triggered landslides in the affected area

The spatial relationship between the field observations and the modeled probability surface is notable. The three observation points occur within a landscape where moderate to high landslide probabilities are spatially distributed, particularly across the mountainous and dissected terrain of the affected area. The field photographs further show physical evidence of slope disturbance, including fresh-looking exposed materials and displaced rock and soil along road-adjacent slopes. These observations are consistent with the type of earthquake-triggered slope instability represented by the USGS landslide model.

The comparison, however, should not be interpreted as a formal validation of the USGS probability model. The field observations were collected during ongoing response activities rather than through a dedicated systematic landslide inventory or geotechnical survey. Consequently, the reported coordinates represent the locations associated with the field observations and should not be interpreted as precisely surveyed landslide centroids, boundaries, or failure-source coordinates. Some positional uncertainty may also arise from the practical conditions under which field information was collected and transmitted during the response operation.

This limitation is particularly relevant when comparing point observations with a regional probabilistic product. A field-observed landslide represents a specific ground-failure occurrence, whereas the USGS product expresses modeled areal coverage of potential ground failure at the grid-cell scale. Therefore, the presence of a documented landslide within or near an elevated-probability area provides supporting spatial evidence, but does not establish a quantitative probability of occurrence at that particular point. Conversely, an observed landslide located outside a visually prominent high-probability zone would not necessarily demonstrate model failure, given the regional nature of the model, input-data limitations, and positional uncertainty associated with rapid field observations.

Within these limitations, the observations nevertheless demonstrate the practical value of combining probabilistic screening with field-based evidence. The USGS product was available during the early post-earthquake period, while field information developed progressively as response activities reached affected locations. The probabilistic map could therefore serve as an initial spatial reference for identifying terrain requiring attention, while field observations provide the local evidence necessary to determine whether further assessment is warranted.

The three observations also illustrate why ground-failure assessment should be considered complementary to conventional structural damage assessment. A slope may remain physically separate from a damaged building while still threatening roads, settlements, access routes, or other infrastructure located downslope or along transportation corridors. In this context, the significance of the modeled landslide probability is not limited to predicting where a landslide will occur; rather, its operational value lies in helping identify where ground conditions should receive additional attention during post-earthquake assessment.

Accordingly, the field observations support the use of the USGS Ground Failure product as a regional screening and prioritization layer, while emphasizing that field verification and, where warranted, site-specific geotechnical investigation remain necessary before decisions concerning permanent infrastructure safety, slope stabilization, reconstruction, or long-term risk reduction are made. The combination of modeled probability and preliminary field evidence thus provides a practical bridge between near-real-time regional hazard information and the progressively more detailed assessments required during disaster response and recovery.

4.5 Operational Integration of Ground-Failure Information

The preceding results demonstrate that near-real-time ground-failure information can provide an additional spatial perspective during the early post-earthquake response period. The USGS Ground Failure product does not replace field assessment; rather, its principal value lies in identifying areas where earthquake-triggered landslides or liquefaction may warrant increased attention. This function becomes particularly relevant when the affected region is geographically extensive and the availability of technical personnel for immediate field investigation is limited.

Based on the results of the Flores earthquake assessment, the practical application of ground-failure information can be organized into a sequential decision pathway: near-real-time ground-failure information → spatial prioritization → targeted field verification → settlement and infrastructure screening → site-specific geotechnical investigation where required → response and recovery decisions. This pathway distinguishes regional probabilistic screening from the progressively more detailed assessments required for operational and engineering decisions.

The first stage involves obtaining and interpreting the near-real-time USGS Ground Failure outputs for earthquake-triggered landslides and liquefaction. At this stage, the objective is not to determine whether a particular structure or location has failed, but to establish an initial regional picture of potential ground-failure exposure. The separate landslide and liquefaction products are particularly useful because the two mechanisms are controlled by different combinations of terrain, ground-motion, geological, hydrological, and geomorphological conditions.

The second stage is spatial prioritization. Areas exhibiting relatively higher modeled ground-failure probability can be considered candidate zones for further attention, particularly where they overlap with settlements, transportation corridors, critical infrastructure, or other elements relevant to emergency response. This approach can help transform a regional hazard surface into a practical screening layer for allocating limited field resources.

The third stage involves targeted field verification. The three landslide observations documented in this study illustrate the role of ground-level information in progressively refining the regional assessment. Field observations can determine whether visible slope disturbance, displaced materials, debris accumulation, or other evidence of ground failure is present. Importantly, field verification should be understood as a transition from model-based screening to local evidence rather than as a direct one-to-one validation of the probabilistic product.

Following field verification, settlement and infrastructure screening provides a further level of operational assessment. Where ground failure is observed or considered plausible, attention can be directed toward potentially exposed houses, roads, bridges, public facilities, utility corridors, and other infrastructure. The potential consequences for critical infrastructure further emphasize the need to consider ground-failure hazards alongside conventional structural assessment (Unal et al., 2024). The significance of a ground-failure hazard therefore depends not only on the modeled or observed ground condition itself, but also on the elements exposed to that condition and their functional importance to affected communities.

Where field observations indicate potentially significant instability, the next stage is site-specific geotechnical investigation. Such investigation may be required to characterize subsurface conditions, establish the extent and mechanism of failure, assess stability, and determine appropriate engineering or stabilization measures. The regional USGS product is not intended to provide this level of site-specific information and should therefore not be used as a substitute for engineering investigation where decisions concerning structural safety or reconstruction depend on detailed ground conditions.

The final stage concerns response and recovery decisions. Information generated through the preceding stages can support decisions concerning access, temporary exclusion or caution zones, infrastructure inspection, slope monitoring, stabilization, reconstruction priorities, and longer-term risk reduction. The principal contribution of the near-real-time ground-failure product is therefore not a standalone prediction of damage, but its ability to initiate a structured process through which regional hazard information can be progressively converted into locally relevant evidence and, ultimately, operational decisions.

4.6 Implications and Limitations

The findings indicate that ground-failure assessment can complement conventional post-earthquake damage assessment by addressing a component of earthquake impact that may remain poorly represented by early visual inspections of buildings and infrastructure. A structure may exhibit limited or no visible damage while the surrounding ground may still be affected by slope instability, liquefaction, settlement, or deformation. Incorporating ground-failure information therefore provides an additional dimension for understanding the conditions that may influence accessibility, infrastructure functionality, and the safety of subsequent response and recovery activities (Grimaz et al., 2022).

The Flores case also illustrates the importance of distinguishing between regional hazard screening and site-specific hazard determination. The USGS Ground Failure product provides a rapid and spatially extensive assessment based on globally applicable models and available environmental and ground-motion information. Its strength is consequently its speed and regional coverage rather than its ability to resolve local geological and geotechnical conditions. The modeled probabilities should therefore be interpreted as indicators of relative or areal ground-failure hazard and exposure, not as deterministic statements that failure will occur at a particular point.

The field observations presented in this study reinforce this distinction. Field-based investigations following major earthquakes have demonstrated that ground failure may occur in varied forms and spatial patterns, including landslides, liquefaction, and ground cracking, with consequences that may extend beyond the immediate failure area (Jibson et al., 2019). The three documented landslides in Flores therefore provide preliminary evidence that earthquake-triggered ground failure occurred within the affected region and provide useful spatial context for interpreting the modeled landslide probability. However, because these observations were collected during ongoing response activities rather than through a systematic landslide inventory, they cannot be considered a statistically representative dataset for model validation.

Another limitation concerns the temporal nature of near-real-time assessment. Ground-failure information available immediately after an earthquake represents an initial estimate based on information available at that time. Field conditions, rainfall, drainage, continuing slope deformation, secondary failures, and subsequent field discoveries may change the understanding of ground-failure extent as response activities progress. Consequently, the initial probabilistic product should be regarded as a starting point for assessment that can be progressively refined as local evidence becomes available.

These limitations do not eliminate the operational value of the approach. Rather, they define the appropriate role of probabilistic ground-failure information within disaster management. The results support its use as an early screening and prioritization layer, particularly during the period when comprehensive field information is incomplete. Its greatest value is achieved when it is integrated with field observations, exposure information, infrastructure screening, and subsequent site-specific investigation rather than interpreted in isolation.

For the 2026 Flores earthquake, the combination of regional probabilistic assessment and preliminary field observations demonstrates a practical pathway for moving from broad-scale hazard awareness toward progressively more targeted post-earthquake assessment. This approach can help ensure that ground conditions receive attention alongside visible structural damage and other conventional indicators of earthquake impact. In this sense, ground-failure information serves not as a replacement for field investigation, but as an early spatial intelligence layer that can help determine where investigation and response attention may be most needed.

CONCLUSION

The 15 August 2026 M7.7 Flores earthquake demonstrates that post-earthquake impact assessment should extend beyond immediately visible structural damage to include the condition and stability of the ground on which settlements and infrastructure depend. The USGS Ground Failure product provides a practical source of near-real-time information on earthquake-triggered landslide and liquefaction hazard, enabling regional screening while comprehensive field assessments are still developing.

The analysis shows that the modeled distributions of landslide and liquefaction hazard are spatially heterogeneous across Flores and reflect different physical controls associated with the two ground-failure mechanisms. Preliminary field observations of three earthquake-triggered landslides provide ground-based evidence of actual slope failure within the affected region and demonstrate the practical relevance of complementing regional probabilistic information with field observations. These observations are not considered a formal validation of the USGS models, but they illustrate how model-based screening and field-based evidence can be used together during an evolving disaster response.

This study proposes a sequential operational pathway in which near-real-time ground-failure information → spatial prioritization → targeted field verification → settlement and infrastructure screening → site-specific geotechnical investigation where required → response and recovery decisions. Within this framework, probabilistic ground-failure information is not treated as a substitute for field verification or site-specific geotechnical investigation. Its principal value lies in helping identify areas where technical attention and field resources may be prioritized during the critical period following an earthquake.

The Flores case therefore highlights the potential of integrating rapidly available geospatial hazard information into disaster-response practice in Indonesia. Incorporating ground-failure screening alongside conventional assessments of casualties, structural damage, accessibility, and humanitarian needs could reduce the risk of overlooking unstable ground conditions during repair, reconstruction, and recovery. Further field investigation and systematic inventories are required to refine the preliminary observations presented here and to evaluate the relationship between modeled ground-failure probabilities and observed failures at greater spatial detail.

Overall, the study demonstrates that rapid ground-failure assessment can serve as an important bridge between earthquake occurrence and detailed field-based investigation, supporting a more risk-informed approach to post-earthquake response and recovery.

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