RELIABLE SEISMIC HAZARD ASSESSMENT: NDSHA[1]

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> "You never change things by fighting
> the existing reality. To change something,
> build a new model that makes
> the existing model obsolete."
>
> \- Buckminster Fuller

ABSTRACT

A New Paradigm is now needed for Reliable Seismic Hazard Assessment (RSHA) – one that is intrinsically data-driven and formulated on scientific judgment, unlike current and unreliable risk-analysis models. Neo-Deterministic Seismic Hazard Assessment (NDSHA) integrates earthquake geology, earthquake science, and particularly earthquake physics to finally achieve this New Paradigm for RSHA. Although observations from many recent destructive earthquakes have all confirmed the validity of NDSHA's approach and application to earthquake hazard forecasting – nevertheless damaging earthquakes still cannot yet be predicted with a *precision* requirement consistent with issuing red alert and evacuation orders to protect civil populations. But now proper integration of both seismological and geodetic information together reliably contributes to a reduction of the geographic extent of alarms – and it therefore defines a New Paradigm for Time-Dependent Hazard Scenarios: Intermediate-Term and Narrow-Range Earthquake Prediction.

Keywords: NDSHA; RSHA; Earthquake prediction.

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[1] Invited keynote lecture

1. INTRODUCTION

Since our world-wide experiences (expressed in terms of *unacceptable* human losses) from now over more than half-a-century of equating earthquake risk-analysis models with earthquake hazard (or likelihood of an earthquake) have proven unreliable, a New Paradigm (one that is intrinsically data-driven and formulated on scientific judgment, unlike the current PSHA) is needed for Reliable Seismic Hazard Assessment RSHA.

Neo-Deterministic Seismic Hazard Assessment (NDSHA), fully described in Panza and Bela (2019) and references therein, integrates earthquake geology, earthquake science, and particularly earthquake physics to finally achieve this New Paradigm for RSHA.

Building upon both the familiarity and long experience of successful practice with DSHA and seismic zonation, NDSHA now convolves a comprehensive physical knowledge of: (i) the seismic source process; (ii) the propagation of earthquake waves through anelastic media; and then (iii) their combined interactions with site conditions – and thus effectively accounts for the *tensor* nature of earthquake ground motions. In such a way NDSHA computationally copes with the physical fact that so-called “site effects” are not intrinsically stable at any given site (Olsen 2000; Boore 2004; Molchan et al 2011; Panza and Bela 2019), but rather reflect a strong *signature* of earthquake-source properties.

By computationally using all available information about the spatial distribution of large Magnitude earthquake phenomena, including: (a) geological and geophysical data; and (b) Maximum Credible Earthquake (MCE) – M_{design} is effectively set equal to the maximum observed or formally estimated magnitude M_{max}, plus some multiple of its accepted global standard deviation σ_M (Rugarli *et al*., 2019). Since NDSHA does not rely on *scalar* empirical ground motion attenuation models GMPEs, as these are often both: (a) weakly constrained by available observations and (b) fundamentally unable to account for the tensor nature of earthquake ground motions (Olsen 2000; Molchan *et al* 2011; Panza and Bela 2019) – it provides both robust and safely conservative hazard estimates for engineering design and mitigation decision strategies. Importantly, these are accomplished without invoking the *chimeric* or illusory and physically-rootless Hazard Curve: annual frequency of earthquakes | earthquake return-period (see Figure 1) – generally depicted as either a “475 yr. earthquake” or the more rare “2475 yr. earthquake.”

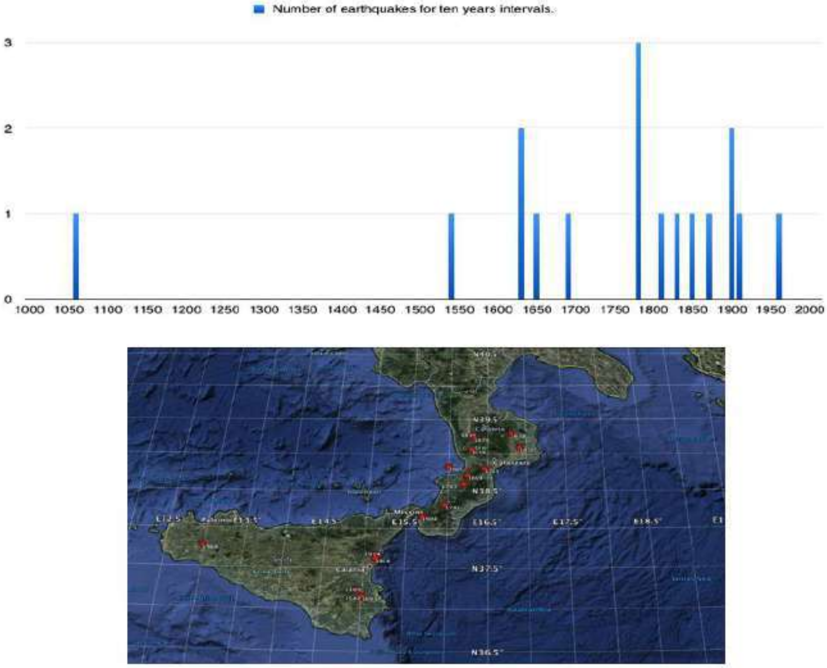

Fig. 1. Earthquakes with I$_{MCS}$ ≥ X (Mercalli, Cancani, Sieberg scale), since 1100, in Messina strait area s.l. (Italy): (a) to be conservative all intermediate Intensity values are rounded up to the nearest integer accordingly with Grünthal (1998); (b) the sometimes-clustered sporadic locations of epicentres, in *space-and-time*, threatens at its core the *chimeric* concept of "average return period" or "return time" – the promoted presumed *appropriate* cornerstone for *expressing* seismic risk in PSHA! What is the real *practical value* that an engineering seismic risk analysis should assign to the Messina strait area for the "average return period" or "return time?" – which here we can calculate at about "60 years" for historic events with I$_{MCS}$ ≥ X occurring in the last millennium? (courtesy of D. Bisignano).

Earthquake Hazard and Earthquake prediction

Although observations from many recent destructive earthquakes have all confirmed the validity of NDSHA's approach and application to earthquake hazard forecasting — nonetheless damaging earthquakes still unfortunately cannot yet be predicted with a *precision* requirement consistent with issuing red alert and evacuation orders to protect civil populations. However, intermediate-term (several months) and middle-range (few 100s km scale) *predictions* of main shocks above pre-assigned thresholds that are based on seismicity "alarms" generated by interpretative algorithms (Keilis-Borok and Soloviev 2003; Keilis-Borok 2018) – may be properly used for the implementation of low-key preventive safety actions for affected at-risk populations, as recommended by UNESCO in 1977 (Kantorovich and Keilis-

Borok 1977; Molchan 1997). Progressive reduction of prediction uncertainty in both *space-and-time* remains an ongoing and challenging task, and aforementioned CN, M8 and M8S algorithms have now been tested and evaluated for some decades for *intermediate-term* – *middle-range* – earthquake predictions (e.g. Peresan et al 2005).

Through a retrospective analysis of both the 2012 Emilia sequence and also the 2016-2017 Seismic Crisis in Central Italy (Panza *et al*., 2018, Crespi *et al*., 2019), space-time precursory features have been already highlighted within both GPS *ground velocities* and instrumentally monitored seismicity. Overall, it is demonstrated now that the proper integration of both seismological and geodetic information can achieve what here is called — *intermediate-term* (several months) – *narrow-range* (few 10s km scale) – earthquake prediction. Therefore, the extent of the alarmed areas, identified (as above) for the strong earthquakes by earthquake prediction algorithms based on seismicity patterns (e.g. Kossobokov and Shebalin 2003), can be significantly reduced from linear dimensions of a few hundred to now a few tens of kilometers, leading to an improved and more specific *implementation* of low-key preventive actions, like those recommended by UNESCO as early as in 1991 (Kantorivic and Keilis-Borok, 1991).

NDSHA in Albania

The NDSHA scenario studies so far performed for Albania are those by Muço *et al*., (2001; 2002) and Marku *et al*., (2014). In the area most severely affected by the M 6.4 earthquake of 26 November 2019, the NDSHA DGA (~ PGA) value at the bedrock is around 0.3g, which well *envelopes* the observed ground motions reported — https://earthquake.usgs.gov/earthquakes/eventpage/us70006d0m/shakemap/pga — with larger values being observed where strong "site effects" are to be expected; and a model (Stein and Sevilgen 2019) shows "amplification" factors of 4 - 5 greater than the shaking that was experienced at bedrock sites. Predicted PSHA values, however, do not exceed 0.18g! (Muço 2013). Marku et al (2021) concluded that, for the reliable assessment of seismic hazard, the most logical procedure to be followed from now on is the NDSHA methodology, which has provided, so far, data that certainly is closer to reality.

Last but not least, the tsunami hazard in the Adriatic Sea had been modeled by Paulatto et al (2007) following NDSHA approach; and their pioneering results were also later confirmed by Tiberti et al (2009). Notwithstanding that both the conservative NDSHA estimates, as well as the subsequent confirmation by Tiberti *et al*., (2009), *excluded* any significant tsunami generation hazard caused by the M 6.4 earthquake of 26 November 2019 – the Italian Istituto Nazionale di Geofisica e Vulcanologia (INGV)'s

Center for Tsunami issued (7 minutes after the quake) an alert to Civil Protection for tsunami hazard in Albania, Montenegro and Italy. That alert was appropriately rescinded the very following morning of November 27, based on records of tide gauge measurements. https://www.agi.it/estero/terremoto_albania-6620218/news/2019-11-26/.

2. CONCLUSION

Our world-wide experiences from now more than half-a-century of equating earthquake risk analysis models with earthquake hazard (or likelihood of having an earthquake) have proven unreliable; and they therefore have prompted the development of a New Paradigm (one that is intrinsically data-driven and formulated instead based on scientific judgment, unlike the current PSHA), in order to meet the need for Reliable Seismic Hazard Assessment (RSHA). NDSHA methodology now convolves a comprehensive physical knowledge of: (i) the seismic source process; (ii) the propagation of earthquake waves through anelastic media; and then (iii) their combined interactions with site conditions – and thus effectively accounts for the *tensor* nature of earthquake ground motions.

By computationally using all available information about the spatial distribution of large Magnitude earthquake phenomena, including: (a) geological and geophysical data; and (b) Maximum Credible Earthquake (MCE) – M_{design} is set equal to the maximum observed or formally estimated magnitude M_{max}, plus some multiple of its accepted global standard deviation $\sigma_M \approx 0.2\text{-}0.3$ (Båth 1973, p.111).

NDSHA, since it does not rely on GMPE inputs into so-called Hazard Models, as these inputs are often both: (a) weakly constrained by available observations and (b) fundamentally unable to account for the tensor nature of earthquake ground motions – alternatively provides both robust and safely conservative hazard estimates for engineering design and mitigation decision strategies.

Further examples illustrating the reliability of NDSHA, including detailed updates on NDSHA research and application methodologies in Africa, America, Asia and Europe, that hopefully will encourage responsible people and authorities to seriously employ these more reliable procedures for SHA evaluation, are presented in “Earthquakes and Sustainable Infrastructure: Neo-Deterministic (NDSHA) approach guarantees prevention rather than cure.” Edited by Panza G., Kossobokov V., Laor E. and De Vivo B. (2021, in press) for Elsevier.

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