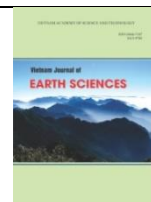




Vietnam Academy of Science and Technology

Vietnam Journal of Earth Sciences

<http://www.vjs.ac.vn/index.php/jse>



NDSHA - The New Paradigm for RSHA - An Updated Review¹

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Received 10 December 2020; Received in revised form 16 January 2021; Accepted 21 February 2021

ABSTRACT

A New Paradigm (data driven and not like the currently model driven) is needed for Reliable Seismic Hazard Assessment RSHA. Neo-Deterministic Seismic Hazard Assessment (NDSHA) integrates earthquake geology, earthquake science, and particularly earthquake physics to finally achieve a New (and needed) Paradigm for Reliable Seismic Hazard Assessment RSHA.

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 cannot yet be predicted with a *precision* requirement consistent with issuing a red alert and evacuation order to protect civil populations. However, intermediate-term (time scale) and middle-range (space scale) *predictions* of main shocks above a pre-assigned threshold may be properly used for the implementation of low-key preventive safety actions, as recommended by UNESCO in 1997. Furthermore, a proper integration of both seismological and geodetic information has been shown to also reliably contribute to a reduction of the geographic extent of alarms – and it therefore defines a New Paradigm for TimeDependent Hazard Scenarios: Intermediate-Term (time scale) and Narrow-Range (space scale) Earthquake Prediction.

Keywords: NDSHA; RSHA; Earthquake prediction; Time-dependent earthquake hazard; Site effects warnings; Macroseismic Intensity; PGA

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1. Introduction

Since our world-wide experiences (expressed in terms of *unacceptable human losses*) of now more than half-a-century of equating earthquake risk models with earthquake hazard (or likelihood of having an

earthquake) have proven *unreliable*, a New Paradigm is needed for Reliable Seismic Hazard Assessment RSHA. The Neo-Deterministic Seismic Hazard Assessment NDSHA method, proposed some twenty years ago, is shown to both reliably and realistically *simulate* the wide suite of earthquake ground motions that may impact civil populations, as well as their heritage buildings.

¹Invited paper

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Building upon the familiarity and long experience of successful practice with Deterministic Seismic Hazard Assessment, NDSHA now convolves a comprehensive physical knowledge of: (i) the seismic source process; (ii) the propagation of earthquake waves; and (iii) their combined interactions with site conditions - and thus effectively accounts for the *tensor* nature of earthquake ground motions.

Standard NDSHA, using geological and geophysical data, *computationally* estimates an envelope of scenario ground-shaking characteristics from both: (1) the largest historically observed earthquake within a region; and (2) also from the Maximum Credible Earthquake MCE. Because each scenario is always “a real earthquake”, it therefore does not require considerations of either probabilistic hazard model *temporal* representations of earthquake “likelihood”, or *scalar* empirical Ground Motion Prediction Equation attenuation models (GMPEs).

Hence NDSHA provides both robust and safely conservative hazard estimates for engineering design and mitigation decision strategies; but, importantly, without invoking the *chimeric* (illusory) and physically rootless Hazard Curve: "annual frequency of earthquakes"|"earthquake return period"- often depicted as a "475 yr. earthquake" or the more rare "2475 yr. earthquake". Observations from recent destructive earthquakes in Italy: (i) Mw 5.9 Emilia 2012; (ii) Central Italy - Mw 6.3 L'Aquila 2009; and 2016-2017 Seismic Crisis - Mw 6.1 Amatrice; Mw 5.9 Visso; Mw 6.5 Norcia; Mw 5.7 L'Aquila; (iii) Mw 7.8 Nepal 2015; and (iv) Mw 3.9 Ischia 2017 - have all *confirmed* the validity of NDSHA's approach and application: (1) NDSHA has been applied to schools
- <http://www.xeris.it/CaseStudies/index.html>

- and (2) to tangible cultural heritage - <http://www.veneto.beniculturali.it/prevenzion-e-sismica-area-veneta>.

Therefore, we not only recommend, but also very strongly encourage its widespread application in all earthquake-prone regions - to enhance both earthquake safety of civil populations to reduce human losses, and also to provide for *resilience* of community economies and infrastructure.

Rugarli et al., 2019b have pointed out that the consideration of a fixed increment of a given earthquake magnitude at a specific fault is very analogous to multiplying the mechanical moment at that fault by some *factor*, as is similarly done in structural engineering practice when determining the *applied loads* mandated by the most current structural engineering standards (e.g., Eurocodes). Then, in parallel with the currently accepted Eurocode 0 Paradigm (CEN EN-1990, 2002), these same authors introduced a *tunable safety factor* γ_{EM} - which quantitatively captures uncertainties in the seismic moments of assessed faults.

When a comparison was made between the hazard maps obtained with the scenario NDSHA technique (however using two different and completely independent approaches for the definition of the seismic sources considered for the computation of the synthetic seismograms) - for most of the territory considered: (i) the hazard map computed using *seismogenic nodes* (Gorshkov et al., 2003), together with the *tunable safety factor* γ_{EM} ; (ii) envelopes (or is comparable to) the alternate hazard map obtained using instead the 1000 + years-long earthquake catalogue record! Since the two hazard maps are developed from totally independent data sets, and further because the Italian earthquake catalogue is very long - these together supply both a *validation* of the

seismogenic nodes method of Gorshkov et al (2003), and also a refined quantitative estimate of the tunable safety factor $\gamma_{EM} \approx 2$.

Although deadly and damaging earthquakes cannot yet be predicted with a precision requirement consistent with issuing a *red alert* and evacuation order to protect civil populations; however, intermediate-term (i.e. several months' time scale) and middle-range (i.e. few hundred kilometers space scale) *predictions* of main shocks above a pre-assigned threshold - based on seismicity "alarms" generated by interpretive algorithms like CN and M8 (Keilis-Borok and Soloviev, 2003) - may be properly used for the implementation of low-key preventive safety actions, as recommended by UNESCO in 1997.

Furthermore, a proper integration of both seismological and geodetic information has now been shown to also reliably contribute to a *reduction* of the geographic extent of alarms. Indeed, recent experiments focused on the joint use of CN algorithm with GPS and GNSS data have led from formerly only intermediate-term and middle-range scale predictions to *now* intermediate-term and *narrow-range* scale (Panza et al., 2018; Crespi et al., 2019) - and it therefore defines a New Paradigm for Time-Dependent Hazard Scenarios: Intermediate-Term (time scale) and Narrow-Range (space scale) Earthquake Prediction!

A detailed description of the development and evolution of NDSHA methodologies during these last two decades has been previously published in Panza and Bela (2019) and *Supplementary material* therein. This paper now presents both a critical updating of that previous work, which *comprehensively* also includes as illustration - "A Bibliographic Journey to a New Paradigm" - [\(7\) \(PDF\) Supplementary material for "NDSHA: A new paradigm for reliable seismic hazard assessment"/Giuliano](#)

[Panza - Academia.edu](#) - as well as a focused orientation on how we can better *keep alert* for the "safety of human lives" - by also more selectively basing our efforts on reliable seismic hazard assessment methods, as are available in NDSHA. The inclusion of selected examples which illustrate the engineering applications of NDSHA to strategic buildings and cultural heritage, we hope underscores our commitment that "it is not acceptable (and indeed *unbearable*) that so many people continue to die from earthquakes!"

2. "Return period" or chimera?

Cuiusvis hominis est errare: nullius nisi insipientis, in errore perseverare

Cicerone: Filippiche, XII. 5

Quantitative estimates of "engineering seismic risk analysis", per Cornell 1968 and McGuire 1992; 1995; 2004 - are *by design* associated with Hazard Curves and their oft misunderstood implicit *concept* of an "average return period" or "return time". But, in light of the huge human losses that unfortunately have accompanied the application of the method, in now its own 50 yrs... the fundamental question needs to be asked again, revisited and re-examined: "Return Period" or Chimera?

These seismic risk models falsely *presume* that "once the fracture is created" - then the *seismic cycle* dutifully resets again from zero, per "the average activity rates assigned to them", until the next fracture occurs, and in roughly equal time intervals (Parkfield EQ Prediction 1985). The Cornell method, which was later known as the Cornell - McGuire PSHA (Wang 2012; McGuire 1976), was *originally* formulated "for the evaluation of the seismic risk at the *site* of an engineering project;" and formally required using the "more commonly assumed magnitude distribution and attenuation laws" -

Gutenberg-Richter Law and now present-day “next-generation” (but unfortunately now problematically *unstable*) GMPEs!

The above *postulated* earthquake behavior could perhaps be possible if the physical and chemical conditions around the fault did not *change!* However, both: (i) immediately after the fracture; and (ii) on longer time frames as imposed by the active tectonics - the fault *boundary conditions* can vary considerably. And indeed, some recent evidences of this *earthquake-induced* transformation of the crust have been described in illuminating detail by Jamtveit et al. (2018) and Zhang et al. (2019). Furthermore: (a) the theoretical model by Carlson (1991) gives rise to *slipping events* of all sizes - the *smaller* events being consistent with the Gutenberg-Richter statistical law, whereas the *characteristic* events (here meaning larger and near the maximum) have separate statistical distributions; (b) the theoretical study by Cattania 2019, in extending the modeling to a *continuum*, explores why small earthquake sources can produce *quasiperiodic* sequences of identical events; whereas earthquakes on large faults are intrinsically more variable, showing that simple, isolated faults do not *necessarily* produce regular and periodic earthquakes, especially when the faults are relatively large.

2.1. Tried but Not True...Return to Sender

Since nothing provided in the Cornell “return period” risk model has ever been both successfully tried and *experimentally* verified (e.g., Chen et al., 2020); we must therefore agree that this unsupported concept of aseismic design *belief* and *convenience* - per Cornell 1968, that: “Owing to the uncertainty in the number, sizes, and locations of future earthquakes it is appropriate that *engineers express seismic risk, as design winds or floods are, in terms of return periods* [cited references 1952-1967]” - is too simple and

simplistic to survive the limitations of its own probabilistic presumptive assumptions! Bummer!

Also, there is even further proof that a collective pause is now warranted in the appropriateness of this concept of “expressing seismic risk in terms of return periods” - given that flood risk is no longer expressed in terms of either the “100-year flood” or the “500-year flood” - rather now, for flood insurance purposes, flood risk is expressed as “a flood that has a 1% or a 5% chance of occurrence *in any one year*, based on stream-flow hydrograph records. (See USGS “The 100-Year Flood” -

https://www.usgs.gov/special-topic/water-science-school/science/100-year-flood?qt-science_center_objects=0#qt-science_center_objects - and also Wang and Ormsbee 2005).

Because *concepts* are fundamental building blocks of thoughts and *belief*, they can cognitively create their own *concept space* - meaning therefore that they can mean different things in the minds of different individuals (e.g., see Tall and Vinner 1981; FEMA P-749 2010; Geller et al., 2016). This has, unfortunately, become especially problematic when practitioners are *no longer* intimately involved in *all* of the qualifying aspects of the earthquake resistant design process; and, in particular, when they may also lack a correct and fundamental knowledge of both why and how that process came to be (see Preface in Junbo, 2017).

Finally, it should be emphasized that even though it failed to make clear distinctions between facts and seismic risk model presumptions and assumptions; importantly, the Cornell 1968 *probabilistic* (or quantitatively crafted) “return period” concept was originally intended to both enhance and also facilitate the *other* stated requirements for an engineering seismic risk analysis, namely that: (i) “the engineer must consider the performance of the [building, dam, highway

bridge or other infrastructural] system under *moderate as well as large motions*;" (ii) "the engineer should have available all pertinent data and professional judgement of those trained in seismology and geology"; and that most importantly (iii) *that information* should then be provided "in a form most suitable for making this decision *wisely*." Clearly the "return period" is not the "form most suitable for making this decision wisely" - which seems to us to have been Cornell's intended *conclusion* here, albeit one rather based on *circular reasoning* (a *logical fallacy* wherein the premise and the conclusion are one-and-the-same) . . . and not so much on the *science* behind "all the pertinent data and professional judgement of those trained in seismology and geology!"

With these original and qualifying *safeguards* now seemingly (and bewilderingly so) *expunged* from the fully complemented Cornell 1968 seismic risk analysis method, . . . we observe: (i) Return Period alone now tends to dominate the *design decision process*, which has always had at its root the belief that "the engineer professionally responsible for the aseismic design of a project must make a fundamental trade-off between costly higher resistances and higher risks of economic loss (Blume, 1965)"; (ii) Return Period is represented as capturing *public policy* requirements to then address "uncertainty in the number, sizes, and locations of future earthquakes"; and finally when (iii) Return Period is, as it now is, *scaled* to apply to the entire civil population (new buildings, existing buildings, cultural heritage buildings and infrastructure) - the true collective and geographically regional risks are neither effectively conveyed nor addressed so that (per Gilbert 1909... "safety shall be secured"!

That this is not, indeed, *a surprise* is because, as Ferraes (1967), Kanamori (1981), Cisternas et al. (2017) and Craig et al. (2016)

all have shown - the lithospheric thought concept that an "average return period" (supposedly realistic physically only over very long time-scales not yet observed) is *qualified* as an "appropriate expression of seismic risk" - unfortunately *disagrees* with too many of the available data!

2.2. Sometimes a Great Notion

Nevertheless, the notion of "average return period", convolved systematically *behind-the-curtain* with the mystique of "probability", is still today (more than a half-century later) the basis of most *probabilistic* methods (See Hays 1980; Geller et al., 2016; Stark and Freedman, 2001; 2016; and here particularly Stark, 2017). In the oft required Probabilistic Seismic Hazard Analysis/Assessment (PSHA) method, it is postulated that in a certain place, of unspecified size, the "annual probability" of experiencing an earthquake *ground motion* having an intensity greater than Y (in short, "a probability of exceedance") does *not* change from year-to-year. This stationary hypothesis has certainly never yet been verified; and given the driving mechanism of progressive accumulation of energy that characterizes earthquakes, such verification remains unlikely, as do many other things consistent with early simple models of *elastic rebound*. More details are given in section 8.

P : annual probability of *exceedance* (a dimensionless number between 0-1).

$P < 10\%$ or $P < 0.002105$ (required by Ordinance).

1- P : annual probability of *non-exceedance*

Let the "annual probability of exceedance" be indicated by the symbol P . Then, in order for $P < 10\%$ in 50 years (as required for example by Ordinance 3274/2003 - http://www.bosettiegatti.eu/info/circolari/statali/2003_ord3274_sismica.htm - the annual probability P must be less than 0.002105. Conversely: (a) the annual probability of non-exceedance is $(1-P)$; (b) the biennial 2 yr

probability of non-exceedance is $(1-P)^1 \times (1-P)^1$, the semicentennial or 50 yr. probability of non-exceedance is $(1-P)^{50}$. If such a *probability of non-exceedance* is, as above, set by law to be $(1 - 0.10) = 0.90$ - then we obtain $(1-P)^{50} = 0.9$ that gives back $P = 0.002105$.

Now, if the earthquake were more like a comet and could have an *annual* probability equal to 0.002105 per yr, this would then imply that it *returns* every $1/0.002105$ years = 475 years. This is how the earthquake "average return period" is defined.

2.3. *The fault lies not in our stars, but in ourselves*

The rules for making these calculations are *exactly the same* as those used to calculate the "probabilities" of *lottery numbers* or those associated with repeated throws of the dice! The next step of a PSHA (but which is totally wrong and without any scientific foundation), is that: *if* the indicated earthquake has an "annual probability of exceedance", which is by definition an *adimensional* or dimensionless quantity (between 0-1) equal to 0.002105, then its "average return period", which now surprisingly has dimension of *time*, must be $(1/0.002105)$ years, or about 475 years.

The *error* (one which anyone is liable to make) is similar to the one committed by those who, having established that the probability of *exit* or of an outcome of 3 with a *throw-of-a die* is $1/6$, wanted to conclude that the 3 returns "on average" every 6 throws! This is the known *fallacy of the player*, who persists in his error because he *attaches a memory* to the probability, where it does not and *cannot* have it!

From Earthquake Science, which at the time of Aristotle postulated but four theories on earthquakes -

http://www.geophysics.geol.uoa.gr/frame_en/histo/aristotle_en.html - we can only conclude

that, due to the *inadequate* amount of data available: (i) there is no scientific evidence to define which memory model to assign to earthquakes; and (b) PSHA is based simplistically (and with obvious internal contradiction) on the presumption that earthquakes occur *randomly* over time following a process without *memory* (e.g., Bilham, 2009). For more details see section 8.

Aristotle found the but three preceding theories of earthquakes that existed at his time to be *illogical, irrational, unfounded*, and replete with what we today would describe as *parascientific* reasoning underlying their hypotheses. We find today that the *concept space* surrounding the "average return period" underpinning of PSHA is likewise similarly fraught with both *parascientific* reasoning and *error* - such that, even in the last 50 yrs, PSHA hasn't even climaxed at a 10% chance of *exceeding* expectations. The conundrum is, however, because PSHA remains the *required* basis of the many seismic building regulations in force in various parts of the World, including Italy and the United States - safety is neither *secured*, nor assured!

The late Carl Sagan strongly believed in the power of *science*, here observing in a 1987 conference keynote address:

In science it often happens that scientists say, 'You know that's a really good argument; my position is mistaken,' and then they would actually change their minds and you never hear that old view from them again. They really do it. It doesn't happen as often as it should, because scientists are human and change is sometimes painful. But it happens every day. I cannot recall the last time something like that happened in politics or religion.

He would later add, noting both that "we live in a society absolutely dependent on science and technology" and "yet we have cleverly arranged things so that almost no one

understands science and technology. That's a clear prescription for disaster”.

Thoughtful discussions have, therefore, both *loosely pondered* and also really *in much detail* examined “how is it possible that such *parascientific* blunders may involve such vast multitudes of both *learned* (members of national academies, honored fellows of elite societies) and *professionally-trained* participants (nuclear plant siting consultants) without collectively *a screeching brake to a halt!* - or other lifesaving remedy: i.e. *Seismic Ghostbusters* eradicating psha's *paranormal* distributions? More simply put, per Ralph Waldo Emerson - if “men love to wonder, and that is the seed of science,” then why hasn't PSHA planted any seed since the time of Plato, when “science was nothing but perception”? It was found in both Rugarli (2014; 2016) and in Kossobokov (2017) that: (a) “there is nothing new under the sun, but there are lots of old things we still don't know”; (b) “there are some people who, if they don't already know, you can't tell 'em”; and (c) “it is difficult to get a man to understand something when his salary depends upon his not understanding it”!

“Even if you are a minority of one, the truth is still the truth”

- Mahatma Ghandi

There seems to us to be a real *conundrum* of confusion (our polite term for total *befuddlement*, lack of *ethical responsibility* and a distanced *disregard* for a secured public safety) in the engineering practices between *what is scientifically accepted* and what is accepted by the *majority* in power.²

²Engineering Societies: ASCE, EERI, LATBSDC; Seismological Societies: SSA, GEM, AGU, EGU; Building Code Organizations: NEHRP, BSSC, ICBO, EUROCODE; National, Federal and State Earth Science related formal Agencies and Institutions: INGV, USGS, USNRC, NSF, UCB, UCLA, UCSD, Stanford, PEER, NAS, NAE, CDMG - to name some of the more major *seismic roulette* players responsible.

This conundrum reflects two very distinct realities, wherein: (1) *science* is the inquiry into finding the best explanation for a physical event or phenomenon; while (2) *politics* is what people want! While it's certainly “better to be right than to be consistent,” part of the blame to go around for *inadequate* public response (e.g., Peterson, 1988) to earthquake hazards (and sadly the *huge human losses* that have resulted from them) seems to devolve from the fact that, even though we've long recognized that science cannot be *democratic* (or left to be determined by the *political* science will of the majority: See e.g., “Science Is Not A Democracy, And Can Never Be One: it isn't arguments or votes or opinion that herald the acceptance of a scientific explanation: it's the evidence.” by Ethan Siegel 2016) - communities-wide, we all have not been well-enough educated to intelligently select our leaders... and the *standards* they produce! (see also “The Role of the Standards in the Invention of the Truth” - Rugarli 2016).

Galileo Galilei, founder of the experimental method and one of the first members of the Italian *Accademia dei Lincei*, was a strong minority among his contemporaries in observing: “In questions of science, the authority of a thousand is not worth the humble reasoning of a single individual.”

In fact, there has always been clear evidence from the time it was *authoritatively* first proposed that PSHA is wrong (Panza and Bela, 2019), but particularly within this past decade - with our benefit finally (calendar-wise) now of true *2020* hindsight! (Wyss et al., 2012; Bela 2014; Panza et al., 2014; Mulargia et al., 2017; Stark and Freedman, 2016; Stark, 2017; Rugarli et al., 2019a) - we can say for certain that PSHA's “technological inexactitudes”, which unfortunately make up its *body of knowledge*, cannot ever reliably fulfill on either their presumptions or their promises! But, for a better future, this systemic problem remains:

when *parascience* has a legal chrisom covering it, *removing* it can be very difficult!

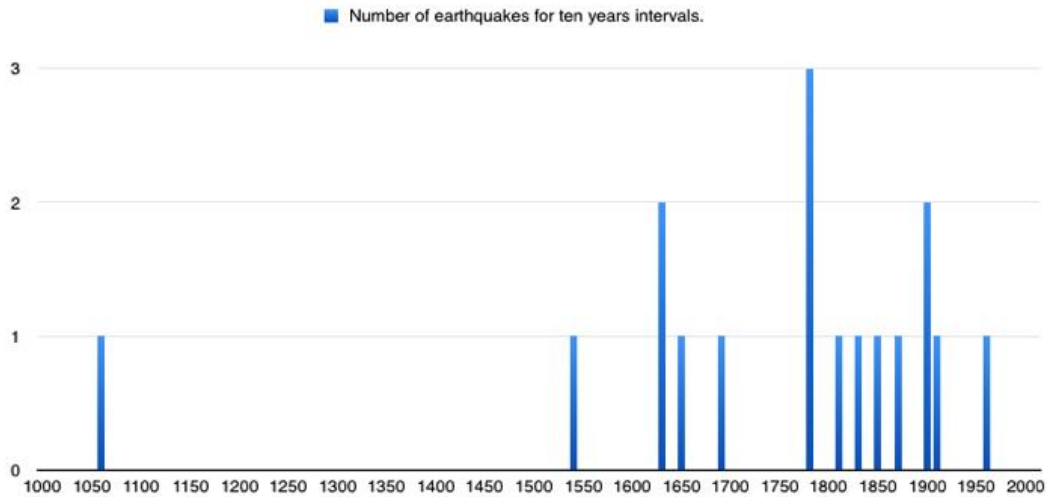
“Law was always made by the few and in general for the purpose of preserving the ‘existing order’, or for the reestablishment of the old order and the punishment of the offenders against it”

- Alfred Korzybski, *Manhood of Humanity*

The legal framework of law sometimes gives body and substance to the most absurd *chimeric* dreams (outcomes hoped for but *illusory* and impossible to achieve). The *probabilistic* method, which again is based on the false presumption that “owing to the uncertainty in the number, sizes, and locations of future earthquakes it is *appropriate* that

engineers express seismic risk, as design winds or floods are, in terms of return periods”... has been proven to be not only an *unreliable* analysis, but also a *fallacious* concept as well!

For example, how many times have we waited in the city for a public transport? - for an hour or more? - only then to see more than *one* of them arrive together? The same thing is true for *earthquakes*, as shown for example in Figs. 1 and 2, which sometimes occur in groups (or clusters) within a given seismically active area - as has been well documented by Rundle et al. (2000).



←Figure 1. Earthquakes with $I_{MCS} \geq X$, since 1100, in Messina strait area s.l. (Italy): (a) to be conservative all intermediate Intensity values (see section 4. Macroseismic Intensity, Magnitude and Peak Acceleration) are rounded up to the nearest integer; (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 *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 $I_{MCS} \geq X$ occurring in the last millennium? (courtesy of D. Bisignano)

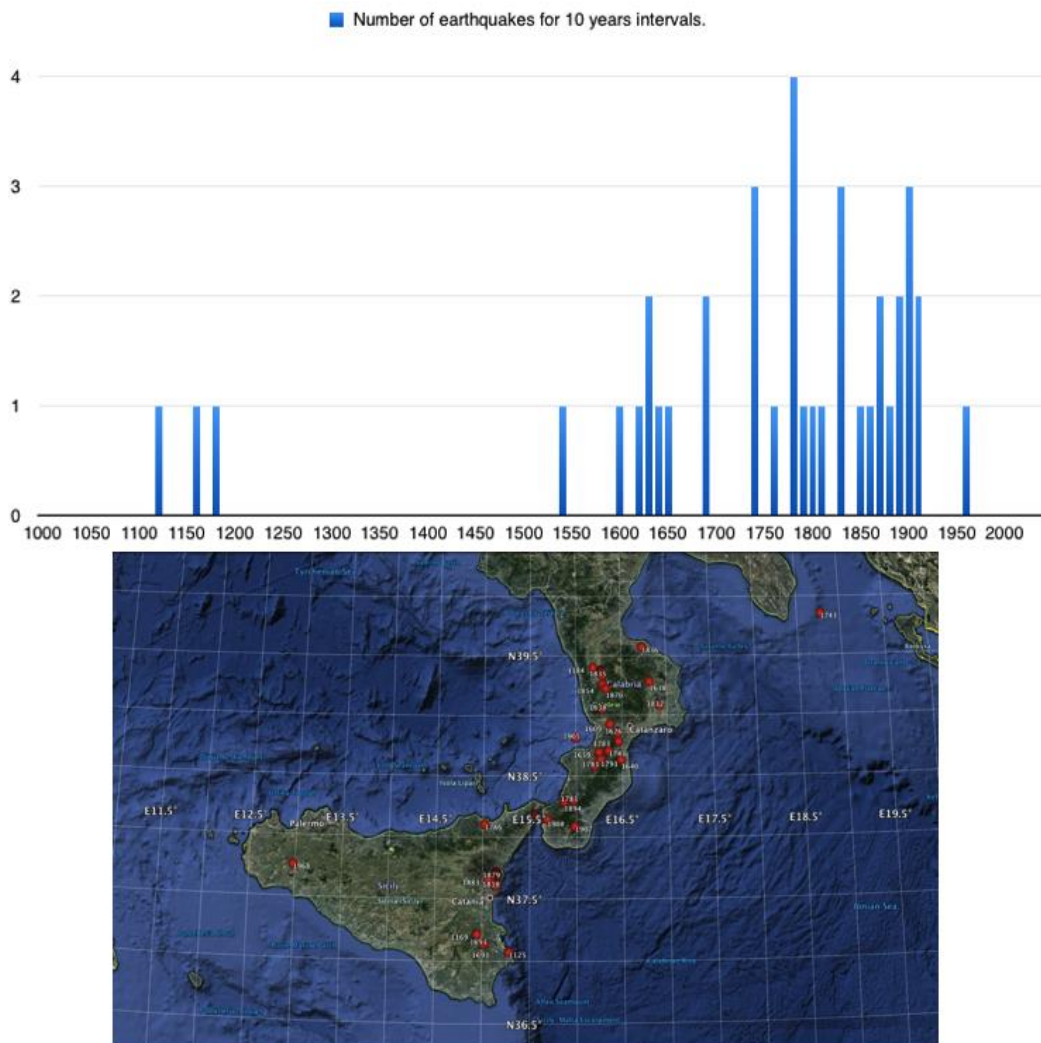


Figure 2. Earthquakes with $I_{MCS} \geq IX$, since 1100, in Messina strait area s.l. (Italy): (a) to be conservative all intermediate Intensity values (see section 4. Macroseismic Intensity, Magnitude and Peak Acceleration) are rounded up to the nearest integer; (b) the clustered sporadic locations of epicentres, in *space-and-time*, threatens at its core the *chimeric concept* of "average return period" or "return time" - the promoted *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 "25 years" for historic events with $I_{MCS} \geq IX$ occurring in the last millennium? (courtesy of D. Bisignano)

“The Map is not the Territory” *

- Alfred Korzybski

*An abstraction derived from something, or a reaction to it, is **not** the thing itself.

The PSHA methodology, like the Mythical Beast of Asia Minor in Greek Mythology - the **Chimera** - is made up of three main parts: (1) “return period”; (2) seismic risk model; and (3) illusory but imposed fault behavior - or what we *here* humorously (in the mythology and spirit of PSHA’s always self-congratulatory praise) might now refer to as “the *beast* available science”!

When we apply the formal “body of knowledge”, however, for Territories of *limited extension*, such as those currently considered in its applications (e.g., Seismogenic Zones ZS9 in Italy); it is not readily *falsifiable* (or proven easily by the evidence to be *false!*) - and primarily so because such *very long* time-intervals are required (Panza, Kossobokov et al., 2014). In general, if (in a certain area or territory) the method declares that in the next 50 years the “probability” of an earthquake with seismic shaking severity (danger) greater than Y is 10%, then the occurrence of a seismic event with *much greater shaking* than Y does not falsify the forecast! And in fact, there is disconcertingly *still* a “probability” of 10% that even the *strongest* possible earthquake occurs! If, on the other hand: (a) the event greater than Y does not occur; or even if (b) no event at all occurs then the method would still be right! In the Greek Mythology of the Chimera: you may encounter the mighty roar of the Lion, the intermediate bleating *baa* of the Goat, or the slithering slowness (or even hibernation) of the Serpent!

A quite common value for the “return period” at which PSHA computations are made is 475 years (for ground motions which have a 10% in 50 yr. chance of exceedance). But this is a *half-millennium* time interval far much longer than the length of our most *adequately complete* earthquake catalogues -

for a very unique exception to this limitation, see CPTI04 Parametric Catalogue of Italian Earthquakes (CPTI Working Group 2004), which spans a time interval of some 1000 years!

Thus, the answer to our opening question of whether “Return period” or Chimera? is obviously that: **“Return period” is a Chimera!** - i.e., its own mythical and illusory *body-of-knowledge* beast! We are reminded... as Albert Einstein very timely noted: “The distinction between the past, present and future is only a stubbornly persistent illusion.” And since “losing an illusion makes one wiser than finding a truth,” for Reliable Seismic Hazard Assessment RSHA, it is always best therefore, we believe, to “*never think of* [the earthquake as off in] *the future* - it comes soon enough”!

“When going to a new territory it is best to take a good map, and then to compare that map with the actual territory” (Alfred Korzybski, 1931) “A map,” Korzybski says, “is not the territory it represents, but, if correct, it has a similar structure to the territory, which accounts for its usefulness.” see also - <https://fs.blog/2015/11/map-and-territory/> - Since, therefore, “a prudent question is one-half of wisdom”, the naturally wise and consequential question to ask now is: Is any scientifically sounding quantitative seismic risk model based on the “return times” or the “average return period” useful?

Although the concept of “return period” is the basis underlying familiar *earthquake hazard maps* in Building Codes world-wide, and also upon which most public policy laws and legislation are based; it is unfortunately *not* adequate for the effective protection of civil populations from the earthquake (Panza et al., 2014).

Moreover, both from an anthropocentric and also an effective public policy perspective, it is *essential* that at least the strategic and public structures (buildings, facilities, bridges) are designed to withstand

future strong earthquakes. When an earthquake occurs with a given magnitude M , it generates a seismic ground motion acting on whatever favorable or unfavorable site conditions exist - and that certainly does not depend on how *sporadic* or *infrequent* an event of this magnitude is within the area of study. Therefore, the anti-seismic or earthquake-resistant design parameters must not be scaled according to the *greater* or *lesser* earthquake likelihood, given the actual sporadic recurrence of earthquakes - but must *instead* take into account the values of M_{EQ} consisting of: (i) the historic seismic and paleoseismic history; and (ii) the seismotectonic terrane (including *seismogenic nodes* identified by morphostructural analysis, as described in section 5. Methodology - as both are requisitely considered and evaluated by NDSHA, which then uses data-driven realistic and computationally generated *scenario earthquakes*.

Consequently, to move from our present earthquake paradigm focused on *emergency management*... to a new one based on *prevention* and *resilience*, it is necessary to substantially re-evaluate the scope of not only the applicability, but indeed also of the promised “appropriateness” of the probabilistic approach PSHA (Keilis-Borok, 2018), limiting its use we advise only to the *cautionary* classification of the “territory” on the basis of the probability that, within a certain relatively large area, an earthquake with a given magnitude M_{EQ} may occur within a certain interval of time (e.g., disastrous earthquake - perhaps about 500 years?; large and strong earthquakes - perhaps about 140 years?; and frequent earthquake - perhaps about 70 years?)

If we then therefore consider two possible sites that have earthquake hazards of the same magnitude (for example $M = 7$), or are prone to the same ground motion effects due to their site conditions; then, *all other conditions being equal*, the site where the sporadic

recurrence of earthquakes is greater becomes naturally preferable for new settlements (and vice versa for any required preventive retrofitting actions). However, the *reference* parameters of an appropriate earthquake-resistant design (Design Ground Acceleration - DGA, Peak Ground Acceleration - PGA, Peak Ground Velocity - PGV, Peak Ground Displacement - PGD, SA - Spectral Acceleration, etc.) must be the *same* at both sites, since the magnitude M_{EQ} from which we must defend ourselves, $M = 7$ (or the seismic ground motion of the soil and site conditions), is the same!

Any risk assessment is necessarily different when we consider a purely *actuarial* perspective for losses. This may be satisfactory for the insurance/reinsurance market system. However, lacking an adequate statistical characterization (generally not possible due to the scarcity of available observations), the usual practice is then to rely on *probabilistic* risk models - wherein it is recognized that the probabilities in these “black boxes” are *subjective* (and not real), because there is no truly reliable and indisputable data; and *necessary safeguards* must therefore be taken to compensate for *unacceptable* losses - should the model (“the man behind the curtain” - e.g. Stark, 2017) turn out to be wrong! *Bummer!*

2.4. “The Great and Powerful Odds”

The concept of “return period” is related to the idea that a single fault behaves like a spring (elastic rebound theory of Reid 1911; USGS PSHA - UCERF 3, 2015a,b), which can therefore be *deterministically* fully understood or assimilated to an oscillating system with a single degree-of-freedom (simple pendulum). However, in nature faults are not single, individual and isolated objects, but form more-or-less numerous (collective) systems of faults. So, we are then really dealing with sets of coupled pendulums, whose global behavior is no longer simply

periodic (closed loop), but which can be well-used to describe *deterministic chaos*, an apparent oxymoron because it connects two familiar ideas that are generally regarded as incompatible!

Mathematical models of the *deterministic* type are generally associated with the notions of regular and predictable phenomena (e.g., the oft presumed “earthquake cycle”), which repeat over time; whereas the *chaotic* term oppositely refers to situations characterized by both an absence of rules and therefore an unpredictability.

The discovery of “deterministic chaos” breaks this dichotomy by showing how *deterministic* mathematical models (i.e., models lacking any random element in their defining equations) are able to nonetheless generate *chaos*! That is, they are able to generate extremely complex trends, in many respects *unpredictable*; so as to be almost indistinguishable from stochastic sequences of events generated through random process - more details e.g., at - <http://pespmc1.vub.ac.be/CHAOS.html>.

Seismic processes are essentially the end result of the Earth’s lithospheric dynamics, wherein: (i) the lithosphere is viewed as a self-organized hierarchy of different-sized blocks; (ii) the relative displacements (fault motions) show up as seismic activity at their boundaries; and (iii) interactions can be complex among these many but self-similar systems of faults.

“Prediction is very difficult, especially if it’s about the future”

- Nils Bohr

Since the behavior of such a dynamic system is, in general, controlled by *nonlinear* laws and is therefore *chaotic* to a great extent - in principle, it is not possible to predict the behavior of such a system in detail. However, the *prediction* of extreme events resulting from the dynamics of such a system is *possible*, at least for the relatively near future;

and also, after a heavy effort or round of *averaging* the complex set of observable variables (Keilis-Borok and Soloviev, 2003).

Although accuracy of any prediction can be improved hierarchically by adding into analysis new observable variables from lower levels of averaging, under a refined resolution of the system; it is still rather evident that an efficient prediction in such a complex system can hardly be based on a single phenomenon. Therefore, suppose (i.e., assume), based *solely* on the seismic history, that a “return period” of 1000 years is estimated for a certain area where there are some faults (a system of faults). However, because we certainly cannot know *when* the millennium began for each fault - then we can, we advise, legitimately conclude that any quantitative seismic risk analysis that is based singly on the “return times” or “average return period” of earthquakes is neither scientifically valid nor practically useful! The map does not have “a similar structure to the territory”, and therefore “safety is not secured”!

An application of “intermediate-term middle-range” earthquake prediction is at the base of the *time-dependent* hazard briefly described in section 8. Time-dependent earthquake hazard. In the same section the new paradigm **intermediate-term narrow-range** earthquake prediction is briefly discussed.

3. Change of Paradigm: From PSHA to NDSHA

“All generalizations are false, including this one”

- Mark Twain

PSHA relies upon statistics. As the late physicist Richard Feynman (not only Nobel Laureate but also creative genius and even *jokester*) still reminds us: “Sometimes we make *guesses* because we wish with our limited knowledge, to say as much as we can about some situation.”

Really, any *generalization* is in the nature of a guess. Any physical theory is a kind of guesswork. There are good guesses and there are bad guesses. The theory of probability is a system for making better guesses. The language of probability allows us to speak quantitatively about some situation which may be highly variable, but which does have some consistent average behavior.

PSHA relies heavily upon both the language and the prestige of *statistics*, asserting that (since it self-defines its very own “Hazard Model” inputs as “the best available science”) its outputs with regard to the *earthquake* situation are also science! - despite the troubling paradox that the earthquake situation does not even casually “have some consistent average behavior.” (See e.g., “What is the Chance of an Earthquake?” - Stark and Freedman, 2016).

As a rule, however, the data considered in a PSHA do not satisfy *basic* requirements for reliable statistical data processing - that branch of mathematics dealing with the collection, analysis, interpretation, presentation, and organization of data (Båth, 1973). Therefore, then with the subsequent application of that data into *probabilistic models* that measure the *likelihood* that an event will occur (i.e. that a certain level of ground shaking will be exceeded within a specified period of time), it is unfortunately found both: (a) that the models are *not* really science; and (b) that therefore the resulting risk analysis is also *unreliable*, because (per Castaños and Lomnitz, 2002) “its data are *inadequate* and its logic is *defective*.”

The general shape of a (pseudo) spectral response acceleration (elastic response spectrum) is popularly applied in seismic codes, where the prescribed design acceleration response spectrum, expressed as a function of natural period, provides “a general procedure to estimate the expected dynamic load on a structure.” Thus, knowing

the period response of a structure, design load can be calculated and energy dissipation requirements also considered.

Shapes of standard code spectra, when in specific cases they are obtained by a heavy statistical processing of *actual* earthquake records [which we note here is in sharp contrast to design response spectra developed from the PSHA framework - which are constructed by their own *sets-of-rules* argued over by committees] are, so far, the only reliable way to describe earthquake ground motion at low periods ($T < 1s$) that may be of interest for seismic engineering or engineering seismology. However, the response spectrum method is by its nature not *precise*, because (although derivative shapes of standard code spectra are obtained through a demanding statistical processing of signals) these strong motion records are obtained under quite different background conditions and azimuthal directions; and they therefore cannot always be considered the best tools to assess a specific and individual structural behavior - indeed the scatter can be quite large!

“One finds limits by pushing them”

- Herbert Simon

Importantly, and as a rule, the NDSHA computations of time-history accelerograms containing accelerations at *short periods* ($T < 1s$) require a level of knowledge of earthquake *source processes* and wave medium *pathway* that so far is unattainable. However, accelerogram computations that are reliable at *longer periods* may always be extended to $T < 1s$ by using standard *elastic* acceleration response spectra. And therefore, in absence of *normalized* spectra derived from specific regionally recorded signals, in NDSHA the recommended procedure then (when within this high frequency range) is to use “Code spectral shapes”, e.g. Eurocode 8 (EC8 1993, 2008) - which defines the *normalized* elastic acceleration response

spectrum of the ground motion for 5% critical damping.

However sometimes, where available knowledge may allow us to account for *source* and *pathway* details that are required for short periods (less than the standard $T = 1s$ cutoff), then NDSHA is also able to computationally consider these high frequency characteristics (See e.g., NDSHA-MCSI, Rugarli et al., 2019a and references therein).

PSHA would not have been plausible or “able to be believed” without the availability and required critical input of earthquake *ground motion attenuation relations* in formulating a “probabilistic seismic hazard curve,” depicting annual frequencies of exceedance - that hazard curve systematically constructed from a presumed *composite* context of “earthquake magnitudes, locations, and ground motions.” (See e.g., Probabilistic seismic hazard analysis: Early history - McGuire 2007, 2008) These presumed *ground shaking* characteristics versus *distance* still remain the key data ingredient (later remodeled, reinvented and modernized to be called Ground Motion Prediction Equations GMPEs (Douglas, 2020) - and even these subsequently reimagined, with episodic Next Generation GMPE model iterations following) – despite the fact that they cannot shake their *scalar* and linear property underpinnings, which unfortunately do not and cannot account for the *tensor* nature of real earthquake ground motions!

Furthermore, because GMPEs are themselves similarly the result of *statistical cosmetics*, they cannot only sometimes be highly misleading, but they can also have a major *destabilizing* effect on what seismic design parameters are then codified and implemented in engineering practice. This means that, when those seismic code parameters are derived from PSHA hazard assessments that have been computed using

these *new*, or *next generation*, or even *after next* ground motion models - then their resulting imposed uncertainty in the design practice... from *decreases*, then *increases*; or *increases*, then *decreases*; becomes not only unsettling, but also potentially catastrophic for *good* engineering judgement, which requires a career of stable practice knowing not only: (a) *what* you are doing; but also (b) *why* you are doing it! (See e.g. Hamburger, 2016). For this reason alone, both authors wisely believe that GMPEs cannot be successfully relied upon in any earthquake hazard assessments, since the goals of which must always be the *reliable* and stable protection of civil populations!

In again asking, therefore: “What is the meaning of using the estimates from GMPEs (a scalar) to assess a *probability* to the earthquake ground motion, which in reality, is actually a *tensorial* quantity”? - we note that, for real earthquakes, GMPEs are known to be too linear to be of even any practical use in real-time Shake Map applications, wherein *interpolations* between strong motion data points, complemented by considerations of both Vs30 and topography, must be relied upon!

NDSHA uses computational (synthetic) accelerograms generated simulating source mechanism and wave propagation pathway through anelastic media: (i) exploiting all available knowledge; (ii) in agreement with basic physical principles of continuum mechanics; and therefore (iii) is totally independent of GMPEs!

PSHA, in order to incorporate the concept of an “average return period,” must presume plausible that the Gutenberg-Richter (GR) law is valid at *any* scale - including e.g. even sometimes at one single fault! The Gutenberg-Richter (GR) law, which “states that earthquake magnitudes are distributed exponentially as $\text{Log}_{10} N(m) = a - bm$, where $N(m)$ is the number of earthquakes with magnitude larger or equal to m , b is a scaling

parameter and a is a constant... is assumed to be the expression of earthquake self-similarity” (Godano et al., 2014). In our view, many of the difficulties complicating the application of the Gutenberg-Richter (GR) law (and the many derivative attempts to deduce local and regional earthquake scaling laws, in particular b -values or the proportion of small earthquakes) in seismic hazard assessments can be explained by the fact that its authors (Gutenberg and Richter, 1944; 1949; Panza and Romanelli, 2001) formulated their relation as a law valid only at *global* scale!

The misapplication of GR relation as a “law” to relatively *small areas* with detailed fault paleoseismologic studies led the PSHA community to accept the introduction of the Characteristic Earthquake CE model (Schwartz and Coppersmith 1984; Wesnousky 1994), which postulated that “individual faults and fault segments tend to generate essentially same size or *characteristic* earthquakes having a relatively narrow range of magnitudes near the maximum,” because: (i) an alteration was required in order to explain the recurrence intervals and large magnitudes of earthquakes interpreted from paleoseismology; and because (ii) the *frequency of occurrence* of these large or characteristic earthquakes had been “grossly underestimated” from simple and linear extrapolation of the GR cumulative recurrence curve from *smaller* earthquake magnitudes.

However, while the Characteristic Earthquake model concept was later solidly proven to be wrong (Molchan et al., 1997; Kossobokov and Mazhkenov, 1994; Bak et al., 2002; Nekrasova and Kosobokov, 2006; Kagan et al., 2012) - since the end result of a PSHA is not design guidance for any specific magnitude of earthquake threat, as was formerly the case when seismic code requirements were based on seismic zones, it

is not always possible to intuit the characteristic earthquake model’s impact on the final result in any derivative PSHA generated seismic hazard curve (i.e., whether hazard actually increases or decreases)!

NDSHA does not consider GR frequency-magnitude relation as a *law*, but rather simply as *knowledge*; or a tool to grossly assess the level of completeness in earthquake catalogues, which historically have always been used to assess hazard.

The CE model and concept, which complicates PSHA’s other competing concept of an “average return period” based on the GR law, is immaterial for NDSHA, which simply requires some completeness in earthquake catalogues for earthquakes with $M \geq 5.0$, i.e., a little below the $M \geq 5.5$ threshold widely associated with *observable damage* near the epicenter.

PSHA is founded on the chimeric concept of an “average return period”. (see section 2. “Return period” or chimera?) But this is only numerically (not physically) linked to the slope of the Gutenberg-Richter (GR) law. In order to satisfy the *presumed* objective that engineers should express seismic risk in terms of “return periods” per Cornell 1968, it became necessary to also presume that earthquake recurrence could be treated as a *Poissonian* process, which characterizes random (but stationary) processes in terms of frequency, time and probability of exceedance. However, since there is neither “annual frequency” of floods, earthquakes nor of public safety (Wang and Ormsbee, 2005; Wang and Rogers, 2014; Wang, 2015), the endgame result of all this presumptive and really *haphazard* mathematical chess playing has been, after first constructing a hazard model, then to unfortunately compute “something” with neither physical nor statistical meaning!

3.1. Confusing and Inappropriate

It must be underlined here that: (i) the use of a set of *misleading* terms, like "probability", "return period", "exceedance", "collapse prevention", "performance-based", "best science", as well as the systematic use of complex math *symbolically* to more authoritatively hide simple baseless rules, has also (using *Parascience*) *pseudo-scientifically* deceived the population; and (ii) this population was not told the real truth, that: (a) new buildings were designed for potentially unsafe earthquake damage; (b) existing buildings that should be strengthened may not be, because earthquakes are *believed* unlikely; and that (c) *rather crude* reasoning was applied to their lives (McGuire 2004). Furthermore, to our knowledge there are no observational or theoretical bases for either the guesses, statistical presumptions, or illogical assumptions underlying the PSHA method: namely that the return periods of MCEs along fault segments can be estimated by *extrapolation* from the seismicity rate and distribution!

Using standard scientific logic, we know that any hypothesis that fails all available tests and is not based on a theory, as is the case for the basic PSHA hypothesis, is considered to be rejected (Wyss 2015).

From the now more than 50 yrs. of PSHA results (a variant of "Extreme Value Statistics" per Gumbel 1958) that presume a *composite* context for "earthquake magnitudes, locations, and ground motions," we know that not only engineers but also most people have often been confused regarding the differences between an earthquake and ground motion. Ground motion, to clarify, is *ground shaking* that is a consequence from having an earthquake. In other words, if No earthquake occurs, NO ground motion will be felt and no damage observed!

However, in PSHA hazard models, ground motion occurrence in time could be *different*

from that of a damaging earthquake. How can the composite ground motion that is depicted on the map occur in time intervals from every 500 yrs to only some several years, if the presumed damaging earthquake occurs every 500 years? For example, PGA hazard curves for San Francisco, CA indicate only a 1/250 or 0.004 chance or probability of annually exceeding a certain level of ground motion (as depicted on the curve), which, when translated to engineers or to an unassuming public, becomes reinterpreted as an earthquake with a 250 yrs "return period" or most popularly (but false)... a "250 yr earthquake"! Although PSHA hazard models can derive annual exceedance probabilities as low as 0.0000001 per yr., with a corresponding 10,000,000 years "return period" for ground motions - in nature, both *time* and ground motion *occurrence* must be consistently coincident with earthquake occurrence and energy release... "period"! (Romanelli et al., 2013).

A more viable alternative that is capable of minimizing the drawbacks of standard PSHA is represented by the use of scenario earthquakes, as is provided by NDSHA. In the original formulations by Panza et al., 2001, 2012 - NDSHA is solving, in a first approximation, fundamental physics-based problems posed by an adequate description of the physical process of earthquake occurrence. Therefore, NDSHA considers the largest event physically possible, usually termed Maximum Credible Earthquake MCE (from earliest regulatory language: FEMA 65, 2005; USBR 2019), whose magnitude M_{design} at a given site is then set equal to the maximum observed or estimated magnitude M_{max} plus some multiple γ_{EM} of its accepted global standard deviation (σ_{M}). In areas lacking information on faults, or with very sparse data, both historical and morphostructural analysis methods are used to estimate the MCE (Rugarli et al., 2019a).

The factor γ_{EM} can be considered a “tunable safety factor” to Earthquake Magnitude to be applied systematically with the other safety factors that are used in structural engineering. So $M_{design} = M_{max} + \gamma_{EM} \sigma_M$, where it is currently assumed $\sigma_M \approx 0.2 - 0.3$ (Båth 1973, p. 111) and it is proposed to then use $\gamma_{EM} \approx 2.0$ per Rugarli et al 2019b. Since the design value M_{design} is determined by adding this further tunable increment to the maximum estimated value M_{max} , it must be considered approximately a one-half Magnitude step to realistically *envelope* uncertainty, evaluated at the very best of our present-day knowledge and geologic judgement.

3.2. PSHA and NDSHA: The Similarities are Different!

(I) PSHA seeks a biased advantage toward lowering first costs of construction (McGuire, 1992; 2004; Hanks, 1997; Somerville, 2000), and it both easily and familiarly fits within the standard business model, whereby: (a) the focus is on production of products and services by fast, efficient and repeatable protocols; (b) the details, science, validity and truth underlying these methods, as well as any accountability for using them, are not as important, if even considered at all; and (c) the decisions made are, therefore, not always either error-free, consistent with past practices, or actually the best decisions! (Egan 1989; Kahneman 2011). It is, therefore, not surprising to us that the code writers maintaining the now institutionalized regional and global dominance of PSHA are, indeed, the very same individuals from business that are (at the same time) also using these methods in their daily practices! What is surprising... is that Universities have now joined-in with business in these efforts?

(II) NDSHA seeks RSHA... as is best described by the historically eminent USGS Geologist “Rock Star” G.K. Gilbert, who

offered these observations now more than a century ago (or the equivalent of two 50 yr. lifetimes... in PSHA’s alternate universe):

It is the duty of investigators seismologists, geologists, and scientific engineers - to develop the theory of local danger spots, to discover the foci of recurrent shocks, to develop the theory of earthquake-proof construction. It is the duty of engineers and architects so to adjust construction to the character of the ground that safety shall be secured. It should be the policy of communities in the earthquake district to recognize the danger and make provisions against it.

- Gilbert 1909

RSHA also incorporates this lesson from the twentieth century poet T.S. Eliot:

“Where is the wisdom we have lost in knowledge? Where is the knowledge we have lost in information?” And now... Where is the information we have lost in PSHA?

What, we wondered, makes the similarities between PSHA and NDSHA so different? while still at the same time so many of its practitioners continue to claim that “there is nothing better”? And we found in Celeste Adams’ thoroughly enjoyable reflections on “The Vision of Buckminster Fuller” some both amusing and also very realistic answers! Buckminster Fuller (1895-1983) “was one of the world’s first futurists and global thinkers,” and “he set forth ideas that would overthrow all the old paradigms” (Adams 2002):

(a) Buckminster Fuller, like NDSHA, focused on large scale patterns, rather than details, like PSHA.

(b) PSHA is “educated to death,” such that it is “only able to communicate *that* in which it is educated,” but

(c) Fuller’s most applicable insight came from what he described as the “scandal of pi.” That is, he said:

Generations of ‘circle-squarers’ attested to the persistent intuition that it [π] ought to have a rational value, but nobody ever found one!

Eventually it was proven that none was findable. The decimal sequence for pi is 3.14592653589793 . . . and will go on forever I reached the decision right at that moment that nature didn't use pi . . . and I decided then, in 1917, that what I'd like to do was find *nature's geometry*.

NDSHA, we believe, is more soundly rooted in nature's geometry . . . and therefore, as widely proven... provides Reliable Seismic Hazard Assessment RSHA!

PSHA has been going on forever (pi sha, if you will), adding integer - after other integer - after other integer, but still without any "rational value"... or any end in sight that one can see, even if now with super-computing! And what cosmetic statistical gamesmanship (Kossobokov, 2017) may seem logical for "one single engineering site" - gambling with nature to achieve (as the numbers seem to promise) a "maximum utility"... then completely falls apart when required to be *scaled-up* to include every single building - with all of its supporting infrastructure, heritage buildings and community resilience also at stake! In that circumstance (e.g., "The Seismic Future of Cities"- Bilham 2009)... "taking a chance on a guess"... well, it just doesn't seem rational anymore!

A further implicit and important confirmation (through granting of legal authorization as a seismic building code procedure) of the validity of adopting NDSHA as the most realistic and effective available preventive tool is given in Norme Tecniche per le Costruzioni 2018 (NTC 2018), which deepens and expands the concept contained in chapter 3.2.3.6 of NTC 2008 as follows:

L'uso di storie temporali del moto del terreno generate mediante simulazione del meccanismo di sorgente e di propagazione è ammesso a condizione che siano adeguatamente giustificate le ipotesi relative alle caratteristiche sismo genetiche della

sorgente e del mezzo di propagazione e che, negli intervalli di periodo sopraindicati, l'ordinata spettrale media non presenti uno scarto in difetto superiore al 20% rispetto alla corrispondente componente dello spettro elastico.

The use of accelerograms generated simulating source mechanism and wave propagation is allowed, provided the hypotheses about the seismogenic characteristics of the source and the properties along the pathway are duly justified and that, in the considered period intervals, the average spectral ordinate is not less than 20% of the corresponding component of the elastic spectrum.

Further details can be seen in Rugarli et al., 2019a.

PSHA, because it has too often delivered not only erroneous but also too deadly results (Wyss et al., 2012; Panza et al., 2014; and Bela, 2014), has remained a "conundrum," despite it having been extensively debated and also challenged over these last three decades. A comprehensive sample of contributions is contained in the PAGEOPH Topical Volume 168 (2011) and references therein. In the evidence against PSHA: too many damaging and deadly earthquakes (like the 1988 M 6.8 Spitak, Armenia earthquake; the 2011 M 9 Tohoku, Japan Megathrust and Tsunami; and the 2012 M 6 Emilia, Italy events) have all occurred in regions rated to be "low-risk" by PSHA Seismic Hazard Maps (e.g., Peresan and Panza, 2012; Danciu and Giardini, 2015).

In concluding this chapter, let us briefly consider how strong earthquakes (M 6.0 - 6.9) that have been induced or "triggered" by oil production have impacted our approaches to seismic hazard assessment. Hough and Page (2016) found that during the 1900-1935 oil boom in the Los Angeles Basin, four out of the five major earthquakes in the region may have been caused by oil and gas production - including the M 6.4 1933 Long Beach

earthquake (the largest), which killed 120 people, caused \$50 million damage, and was the impetus for California instituting public policies to address earthquake hazards.

However, as California already is an active tectonic region that is prone to $M \geq 6$ earthquakes regardless of any additional triggering, these sorts of induced earthquakes would not change the NDSHA estimates of hazard. That is because there is nothing to say that the oil production is not simply bringing forward in time the energy release from earthquakes that would have happened eventually anyway.

Summarizing, if the area of interest is, as in California: (i) active tectonically; (ii) known already to be seismically active; and has (iii) reliable catalogues - then there is no problem with NDSHA in reliably assessing its seismic hazard!

Finally, human induced earthquakes (Foulger et al., 2018) would, however, introduce an additional problem to the application of the PSHA method anywhere globally, as they would perturb the recurrence time interval of earthquakes (i.e., if the numbers of smaller M earthquakes increase, the hazard model presumes likewise an *increase* in the numbers of larger M events, which presumably shortens the “return period”). And therefore, the answer to this further induced earthquake question is the same: the “return period” remains a Chimera!

4. Macroseismic intensity, magnitude and peak ground acceleration

A shaking of 30% g (0.3 g) is about the level of shaking that would make it difficult for you to walk down the airplane aisle without holding onto a seat during turbulence, because 30% of your mass is pushing you sideways. In the M 7.8 Nepal earthquake in 2015, the shaking intensity (Peak Ground Acceleration: $PGA < 0.2g$) in Kathmandu was only moderate, but the strong motion

recordings of $\sim 0.5g$ spectral acceleration at $\sim 5s$ period (e.g. Pokharel and Goldsworthy 2015) seem to indicate that practically any modern high-rise building (say > 40 stories) would have been vulnerable to collapse in these long period motions.

Familiar scales of moderate to strong earthquake shaking *intensity* (e.g. European Macroseismic Intensity Scale EMS-98) that can be both perceptibly felt by humans and also cause from *slight* to *completely devastating* damage to buildings are, however, often not very informative for the earthquake response of long-period structures - such as taller buildings and long span bridges, particularly during large magnitude earthquakes.

Although a single parameter is insufficient to completely describe an event, the first number any structural engineer should want to know is Peak Ground Velocity - PGV (for at recorded levels > 50 cm/s, there is typically damage). The second number is Peak Ground Displacement PGD; for when greater than 1 m, then tall buildings are also likely to be in trouble.

A detailed historical review of earliest seismological attempts to quantify sizes of earthquake sources through a measure of their energy radiated into seismic waves, which occurred also in connection with the parallel development of the concept of earthquake magnitude, is supplied by Gutenberg and Richter (1949); Panza and Romanelli (2001) and Okal (2019).

Large earthquakes are produced by large slips on large faults, and they therefore differ from small earthquakes in that they produce large velocities and large displacements at large distances from the earthquake source - which can result in significant to sometimes catastrophic effects and damages. Obviously then, it necessarily falls to macroseismic intensity data (perceptible earthquake shaking that can be felt without the use of instruments) to supply the longest time period record of

damaging earthquake effects, since the first earthquake magnitude scale from *instrumentally* recorded ground displacements was not developed until 1935 by Charles F. Richter - in close cooperation with Beno Gutenberg (Richter 1935). This means that for some seismic regions like *Italy* fortunately there is a 1000 + years' long and exceptionally reliable earthquake catalogue available, while in most other parts of the globe (where the data is mostly reflecting magnitudes estimated from seismograms), the catalogue record is only close to ~ 100 years.

Macroseismic intensity is considered a "classification of the severity of ground shaking on the basis of its observed effects" (EMS-98, Grünthal 1998, Grünthal and Musson 2020). EMS-98 (European Macroseismic Scale) (gfz-potsdam.de).

From this definition of the Intensity Scale, it is evident that, for a given earthquake magnitude M , the intensity I can be different in different places.

4.1. General Considerations

The most important general consideration in applying such a scale is that it brings together both: (a) long-period; and (b) short-period effects. The latter are in the majority and may be roughly correlated with acceleration, or PGA - whereas the long-period effects represent large displacements, which often occur accompanied by comparatively only moderate levels of ground shaking acceleration. (see e.g. Gupta 1980) Importantly, with increasing magnitude M , the proportions of long-period to short-period phenomena tend to increase at all distances from the epicenter; and since the macroseismic scale historically has in general placed the long-period effects where they appear most frequently during earthquakes of moderate magnitude, serious confusion has sometimes arisen when dealing with the greater territorial ranges observed with large

shocks. (See "The long and the short of it" below).

In the now more than one century since the first macroseismic intensity scale was put forward by Mercalli in 1902 (at first with ten grades of intensity, later with twelve following a suggestion by Cancani 1904, who attempted to express these grades in terms of acceleration), many different scales have come into widespread existence. The sheer existence of *many* different scales is a demonstration of the *complexity* of the problem in describing earthquake effects. This resulting multiplicity of scales generates some problems in practical applications, which therefore must rely upon very conservative assumptions.

Any macroseismic intensity scale (e.g., Mercalli, Cancani, Sieberg - I_{MCS} ; Modified Mercalli - I_{MM} ; Medvedev, Sponheuer, Karnik - I_{MSK} ; European - I_{EMS}) is individually distinct and discrete, having *unit* incremental steps. This means accordingly: (a) intermediate values, even though arbitrarily often used, are not defined; and (b) the long-period and short-period effects are comingled, as previously discussed.

4.2. Defining patternicity

Analyzing two independent data sets of Maximum Macroseismic Intensity values for Italy, namely (1) Mappa della Massima Intensità Macrosismica Risentita in Italia (Scalera et al., 1995) and (2) Massime intensità macrosismiche osservate nei comuni italiani (Molin et al., 1996) - Panza et al., 1997 proposed correlations between macroseismic Intensity patterns (I) and seismic Ground Motion Parameters (GMPs) that differ by one degree I_{MCS} . Based on these past efforts and analyses (which required not only a *holistic* approach, but also judgment based on comprehensive and detailed knowledge of earthquake phenomena and their effects) we feel that a further comment on the use of *intermediate* values ("half-

degrees” per Kárník and Algermissen, 1978 or “Intensity factors” per Klügel, 2015) in any macroseismic intensity scale is important and warranted, because these intermediate values have caused several drawbacks when subsequently used to obtain: (a) quantified estimates of hazard; and then (b) derived seismic design parameters (GMPs) which can be characterized as follows:

“The problem is not precise language. The problem is clear language”

- Richard Feynman

(i) *Ambiguity* - we wonder whether the derivative intensity *estimation* realistically actually captures, reflects and *envelopes* the MCE, which is a requirement for a Reliable Seismic Hazard Assessment RSHA, in order to protect civil populations and their cultural heritage buildings. The ambiguity here is coming because the “half degree” or “Intensity factor” is simply not telling the *whole truth* since “the magnitude assigned is characteristic of the shock as a whole, and it thus differs from the intensity, which varies from point-to-point of the affected area (Richter 1935)”. See also Hays (1980), Somerville (2000) and Gomez-Capera et al. (2020).

(ii) PGA - Intensity Relations and Ground Motion Intensity Conversion Equations GMICEs (used to compute instrumental intensities on ShakeMaps) are used in many applications to translate pre-instrumental earthquake observations (macroseismic intensities) to instrumental recordings of earthquake ground motions, primarily PGA and PG... and vice-versa;

(iii) Magnitude and Intensity - (Io at the epicenter, I_{max}, and I) can be expressed as an equation transfer function from empirical observations. In some engineering-practice applications, the *correlation* between Intensity factors (expressed decimally as .1 - .2 - .3, etc.) and PGA - as an anchor starting point in setting Earthquake Resistant Design EQ-RD Criteria, and one log-linear relation for

converting Intensity (here EMS-98) to PGA (in gals) is via the equation $\text{Log}_{10}(\text{PGA}) \approx 1.6682 \times I + 1.2821$. Here, of course: (a) the intensity grades must be treated as *true* numerical quantities, which they are not! And (b) peak values of both ground motion parameters GMPs and intensity I are often poorly correlated in the correlation hypothesis $\text{Log}(y) \approx b_0 + b_1 I$ - and their scatter is considerable! (e.g., Ambraseys, 1974 and Decanini et al., 1995).

(iv) Intensity Factor Wild Card - an “intermediate values” intensity card can easily be played (without challenge) in the deck-shuffling that is currently practiced with the touted money-saving applications available in Performance-Based Earthquake Engineering PBEE, which (also not telling the whole truth) ignores at its convenience the fact that *earthquake phenomena* (not numbers of earthquakes) are a “power law” Pareto distribution, or a distribution with “fat tails” i.e. outside the normal bell-shaped or Gaussian distribution for PGV and PGD. Earthquakes are the *Wild Card*, and they should be dealt with! See e.g. “Will Performance-based Earthquake Engineering Break the Power Law?” (Heaton, 2007);

(iv) Confirmation Bias - persuading us to believe our *guess* with perhaps a great deal more conviction than it rightly deserves, simply because we are biased by our presumed *precision* of having employed “half degree” or “Intensity factors” at decadal incremental scale; without now an equally close-enough attention paid to the more fundamental and important aspects of selecting earthquake-resistant design criteria (Miranda and Bertero, 1994, Miranda, 1997; Bertero, 1996), whose primary functions are, as Bertero (1996) emphasizes: “to restate a complex problem that has unknowns and uncertainties in an unambiguous, simplified form having no ambiguities.” (Housner and Jennings, 1977; 1982).

4.3. Magnitude Power Broadcast

Richter compared Magnitude “to the power output in kilowatts of a radio broadcasting station” and likened the Intensity at a site location then “to the signal strength noted on a receiver at a given locality. Intensity, like signal strength, will generally fall off with distance from the source; it will also depend on local conditions at the point of observation, and to some extent on the conditions along the path from source to that point.”

Magnitude M and Macroseismic Intensity I_0 at the epicenter can be accurately equated mathematically: $I_0(m) = 1.5 (M-1)$ and inversely $M = 2/3 I_0 + 1$. And there are also empirical relations for linking I_0 and PGA, e.g., $I_0 = 2.97 \text{ Log}_{10}(\text{PGA}) + 6.71$. So, when one performs the math in these conversions (or consults early comparative MMI - to - PGA tables as in Hays, 1980), one in fact does get an Intensity Value (integer) followed then by a decimal. When still *further* one does a literature search through time, one also finds: (a) a wide range of scales and indices describing natural hazards and their impacts (Blong 2003); (b) studies on “PGA-intensity relations with applications to damage estimation” (McCann et al., 1980; Li et al., 2020); and (c) an “instrumental intensity scale” format that is now reported on near-real time ShakeMaps (Wald et al., 1999a, b; Wald et al., 2019); and even now Ground Motion to Intensity Conversion Equations GMICEs. (Caprio et al., 2015, Cilia and Baker, 2015, 2018; Cilia et al., 2017).

In then summing up, we want to begin by first returning to the definition of any intensity scale: “A sequence of Natural Ordinal Numbers, i.e., a scale in which each number tells the position of something in a discrete scale of integers, such as I, II, III, IV, V, etc.” And within our combined experience, we cannot locate any problem for which “the artefact of introducing half-values of intensity” is both a *solution* and a *benefit*!

Simply put this illusion of precision does little to improve accuracy in the final product resulting from using this pre-instrumental system for recording the sizes of damaging earthquakes as witnessed by their effects!

Accuracy, we believe, has more to do with both a knowledge-based consideration and also a comprehensive integration of all the other judgements that have to be made, because “science is a way of *thinking* much more than it is a body of knowledge.” (Carl Sagan). For RSHA, “we aim above the mark to hit the mark.” (Emerson).

The critical issue then, for earth science and natural hazards awareness and planning, is more elegantly revealed in this well explained observation from Richard Feynman:

The real problem in speech is not precise language. The problem is clear language. The desire is to have the idea clearly communicated to the other person. It is only necessary to be precise when there is some doubt as to the meaning of a phrase, and then the precision should be put in the place where the doubt exists. It is really quite impossible to say anything with absolute precision, unless that thing is so abstracted from the real world as to not represent any real thing.

One of the co-authors, James Bela, explored the ranges of greatest applicability for some of the familiarly available empirical conversion equations relating Magnitude M , Intensities I , I_0 , I_{max} and PGA - specifically by examining four damaging earthquakes between M 5.6 - M 7 (and within earthquake magnitude step intervals at $1/4 M$ between M 5.6 - M 9.5). Conversely, and corollary to Richard Feynman’s comment above, it was found that “the doubt is put where the precision exists”!

“As far as the laws of mathematics refer to reality, they are not certain; and as far as they are certain, they do not refer to reality”

- Albert Einstein, “Geometry and Experience”
January 27, 1921

The “Table for Thought” that tabulated these results revealed that: (a) the range of greatest applicability for these empirically generated numbers is M 5.5 - M 7.0, noting in particular that above M 8 they are not reliable; (b) PGA is probably useful (perhaps even robust) up to M 7, but only to one decimal point; (c) ASCE 7-10 computed results for “expected maximum intensities” (PGA_M) were problematic and unreliable as a basis of determining reliable EQ-RD criteria (Housner and Jennings, 1977, Bertero, 1996); and (d) “If you do not expect the unexpected, you will not find it, for it can’t be found by [very precise calculations of what you expect!]”.

So, again we can say with additional confidence that we feel that the undissected and unperturbed Macroseismic Intensity Scale has been *really* useful... and a *step* in the right direction... for now 1000 + years!

As noted previously above, with increasing magnitude M, the proportion of long-period to short-period energy tends to increase at all distances from the epicenter (a point for small slips) or fault rupture (for large slips). However, since the Macroseismic Intensity Scale in general places these long-period effects where they geographically appear during earthquakes of moderate magnitude, serious confusion has sometimes arisen when dealing with large magnitude and distant shocks. For example, large landslides (particularly those of the earth-slump type) are one typically long-period phenomenon that is triggered more readily by large displacement and slow velocity motion than by rapid high frequency shaking closer to the source. This long-period triggering phenomenon then favors assigning larger slides to Macroseismic Intensity X in I_{MM} , while smaller slides (many of them of the earth-avalanche type) are more commonly, as indicated, assigned at Macroseismic Intensity VII. However, great earthquakes ($M \geq 8$) sometimes precipitate large slumps in distant regions where the felt intensities may otherwise only be indicated

perhaps as low as VI (I_{MM}). The formation (triggering) of cracks and fissures, especially those due to *earth lurches*, behaves similarly; and therefore, the Macroseismic Intensity level based on such evidence has to be seismologically reviewed and then carefully assigned with some reference and consideration given to both magnitude and distance.

This same judgement applies to site effects on works of construction where a long-period coupling or resonance with seismic waves occurs - as in the swaying and distortion of tall buildings or towers, and also in the overturning of elevated tanks.

A special grouping of long-period effects is presented under Intensity Level I (I_{MM}): (i) dizziness or nausea; (ii) birds or animals uneasy or disturbed; (iii) swaying of trees, structures, liquids, bodies of water; and (iv) doors swing slowly - the swinging of chandeliers may also be added. This sensory confusion comes about from the fact that all of these phenomena may be observed even when no actual felt shaking is perceptible: (i) many are pendulum effects - chandeliers and large branches of trees acting as long-period seismoscopes; (ii) oscillations of bodies of water are termed seiches; and (iii) the increased number of such observations with higher magnitude earthquakes is reflecting the greater proportion of *long-period* motion as magnitude increases.

Reliable information about long period ground motion is automatically recognized as particularly relevant for the correct planning of seismic isolation systems (e.g., Martelli et al., 2014), but it is also an equally important (but often overlooked) consideration for tall buildings located at some far distance from large magnitude earthquake sources, as we illustrate in the two following examples.

As shown in Fig. 3 from Bertero et al. (2018), tall buildings in Buenos Aires (1280 km away from the epicenter), although a great distance away from the 2015 Mw 8.3

Illapel, Chile earthquake, experienced horizontal acceleration time-series of motion that were significantly higher than the “motion perception threshold” limit for wind-induced vibrations as specified in ISO 10137 (2007) for human comfort, productivity and well-being - because motions at frequencies less than 1 Hz can provoke fear, discomfort and symptoms of motion sickness in buildings occupants.

“International Standard 10137 specifies peak acceleration magnitudes over the frequency range (0.06 Hz - 0.5 Hz) expected to be satisfactory for people living and working in tall buildings during wind storms with a ‘return period’ of one year.” Additionally, the recorded motions also indicated that some level of nonstructural damage (such as light cracking) was also a possibility.

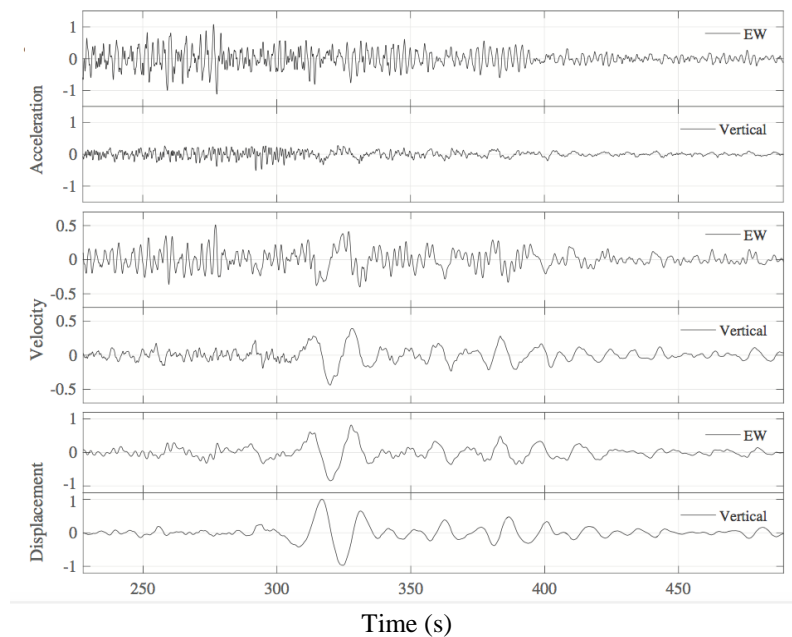


Figure 3. Vertical and East-West (EW) Motions (North-South component is not available) in Buenos Aires (1280 km away from the epicenter) of acceleration (cm/s^2), velocity (cm/s), and displacement (cm) time series for the strong shaking portion of the $M_w = 8.3$ 2015 Illapel, Chile earthquake: Sept 16, 2.015, at 22:54:32 UTC, originating 48 km offshore from Illapel, Chile (modified from Bertero et al., 2018)

Although these *low frequency* motions induced by high winds will generally meet building strength and safety requirements, concerns have always been that they may nevertheless cause a wide range of adverse effects on building occupants, including: alarm or fear, discomfort, difficulty concentrating and symptoms of motion sickness (See e.g., “Human Exposure to Wind-Induced Motion in Tall Buildings: An Assessment of Guidance in ISO 68987 and ISO 10137”, Howarth, 2015).

Per these “motion perception threshold” limits for buildings, which are based on *activities* of occupants and *frequencies* of events, we amusingly find some irony in the fact that, since PSHA is founded on the *presumption* that earthquakes (“like wind”) should be designed based on “return period,” nevertheless engineering wind design is *all-over-the-wind-map* regarding concerns reflected in (we guess) obligatory wind “return periods”: (i) peak acceleration magnitude limits over a low frequency range expected to be satisfactory for people living

and working in tall buildings during wind storms with a “return period” of only one year; (ii) worst 10 min of infrequent events having a “return period” of at least 5 years; as well as (iii) zone maps for “high wind regions” and “hurricane prone regions” as well. Similar to the earthquake problem, Nature may not always offer up “Gaussian” wind distributions nor acceleration “crest factors” as assumed. In short, “return period” is likewise a Chimera in the wind universe . . . to which PSHA astrologers first looked (Cornell 1968) to foretell (they say) the most universally *appropriate* way to handle “the uncertainty in the number, sizes, and locations of future earthquakes”!

Finally, it is important to point out that both wind-resistant and seismic-resistant design considerations (although fundamentally different) identically share the same vulnerability to *fatigue strength* degradation of welded joints in steel frame buildings: due to low cycle fatigue phenomena (Kim and Hwang, 2019) The caveat: the tall building performance in the extreme wind event, or alternatively in the MCE earthquake (Parvez et al., 2011)... may not be per the design intent - but rather actual performance will reflect the integrated sum of all (both wind and seismic) low cycle events affecting degradation of the fatigue strength of welded joints - meaning that the building is now more realistically “what it *is* cracked-up-to-be”!

Bertero’s results show that design practices for *tall buildings* that are located at far distances from high-seismicity areas with large faults need to be revised - in order to consider both *comfort* criteria and *nonstructural* damage control - because of the energy input from an extraordinarily large number of cycles of vibration at very low frequencies (over the frequency range 0.06 Hz - 0.5 Hz) and occurring over an exposure duration of well more than 5 minutes!

Just such kind of a warning is confirmed by Rong-Gong Lin II’s August 15, 2019 report in Los Angeles Times: “Earthquake shook L.A. skyscrapers so hard some got vertigo.”

<https://www.latimes.com/california/story/2019-08-14/ridgecrest-earthquake-produced-minutes-of-shaking-new-story>.

In the newspaper report: *acceleration time series* recordings (supplied by Monica Kholer, Caltech) were published for both the 2nd floor (~ 0.02g) and the 50th floor (~ 0.04g) of a high-rise building in Los Angeles that felt the Mw 7.1 Ridgecrest earthquake of July 5, 2019 (Celebi et al., 2020). In this record the long period (low frequency) energy dominates the waveform on the 50th floor, leading to long-duration displacements persisting for 2-3 minutes following the earthquake (M. Kholer, personal communication).

Therefore, it is abundantly clear that both *site-specific* design spectra and also *scenario* earthquakes are required for purposes of addressing both occupant comfort and damage control from large magnitude and distant earthquake sources, whose long period energy may couple with and excite tall buildings, causing them to sway for many minutes:

On the 48th floor of another building in downtown Los Angeles, Beth M. Foley said she felt vertigo, and her husband motion sickness, after what seemed like minutes of swaying. Eventually, the building creaked and came to a stop. The couple said they plan to pack anti-nausea medications in their earthquake kit. ‘These things swayed like loblolly pines in a storm,’ Foley said.

Furthermore, this tall building *energy coupling* to long period seismic waveforms from distant earthquake sources can neither be accounted for nor addressed using familiar *site effects* parameters such as Vs30 (Peng et al., 2020).

As further noted in Bertero et al. (2018), regarding these distantly generated long period effects in Buenos Aires - where firm

soil is found in the upper layers: site “amplification” resulting from *polarization* of seismic wave motion in the horizontal plane is produced because of the large depth of soil deposits.

These local observations of site amplification in Buenos Aires, which highlight the *inadequacy* of relying solely upon V_s30 for defining response spectra for large magnitude and long-distance earthquakes, can be extended more generally to all earthquake phenomena. And in all such cases our recent experiences are showing that: (a) the *tensor* and nonlinear nature of earthquake ground motion is much more frequent than commonly believed; and (b) therefore it cannot be neglected!

For familiar cases: where both site amplification and basin response effects are persistent (e.g., Molchan et al., 2011; Panza et al., 2014; The SCEC Phase III Report, 2000. <http://sceinfo.usc.edu/phase3/>) often the best preferred parameter to define the design spectra can be the soil site period. However, as a rule, comprehensive and detailed performance evaluation must make use of the actual (and non-modified) recorded ground motions from far-distant earthquakes; and/or realistic synthetic scenario simulations, as is naturally done by NDSHA.

5. Methodology

The procedure for the Neo-Deterministic Seismic Hazard Assessment NDSHA (Panza et al., 1996; 2001; 2012; Panza, 2017; Panza and Bela, 2019) is based on the computation of realistic and physics-based synthetic seismograms (earthquake scenarios) - and the end products of NDSHA are therefore synthetic ground motion accelerograms, velocity-grams and displacement-grams. In NDSHA, seismic hazard is defined as “the envelope of the values of earthquake ground motion parameters”: (a) considering a wide set of scenario events (including Maximum Credible Earthquakes MCE); and

(b) calculated by means of physically-rooted models formulated using the available physics-based knowledge on earthquake source and wave propagation processes. NDSHA therefore does not rely on empirical attenuation models (GMPEs), as these are: (i) often weakly constrained by the available pertinent observations and (ii) unable to account for the tensor nature of earthquake ground motions, which are formally described as the “tensor product” of the earthquake source tensor with the Green’s functions of the transmitting medium (Aki and Richards, 2002).

NDSHA (Fig. 4) employs numerical modeling codes that are based upon: (1) the physical description of the earthquake rupture process; and then upon (2) the seismic wave propagation pathways to then reliably predict resulting ground motion parameters resulting from the many considered potential seismic sources. (See e.g., Panza et al., 2001; 2012; Magrin et al., 2016; Panza et al., 2013 and the references therein).

Regional geologic and seismic wave velocity structural models of the lithosphere-asthenosphere system (thickness, S- and P-wave velocities of the crust and uppermost mantle layers) can be defined in several ways, starting from available information in the literature. Particularly suitable are: the cellular models introduced by Panza and Pontevivo (2004), Pontevivo and Panza (2006), and as later optimized by Boyadzhiev et al., 2008. These models are already used in many NDSHA applications worldwide: Bangladesh; China; Cuba; Egypt; India; Indonesia; Italy; Iran; Macedonia; Vietnam. (Al-Hussaini et al., 2017; Zhang et al., 2012; 2013a; 2013b; 2014a; 2014b; Gonzales et al., 2007; 2012a; 2012b; 2018; El-Sayed et al., 2001; Hassan et al., 2017; Irwandi 2017; 2020; Parvez et al., 2003; 2017; Motaghi et al., 2015; Rastgoo et al., 2018; Brandmayr et al., 2010; Milkova et al., 2018; Cao et al., 2008b; Bisignano et al., 2011).

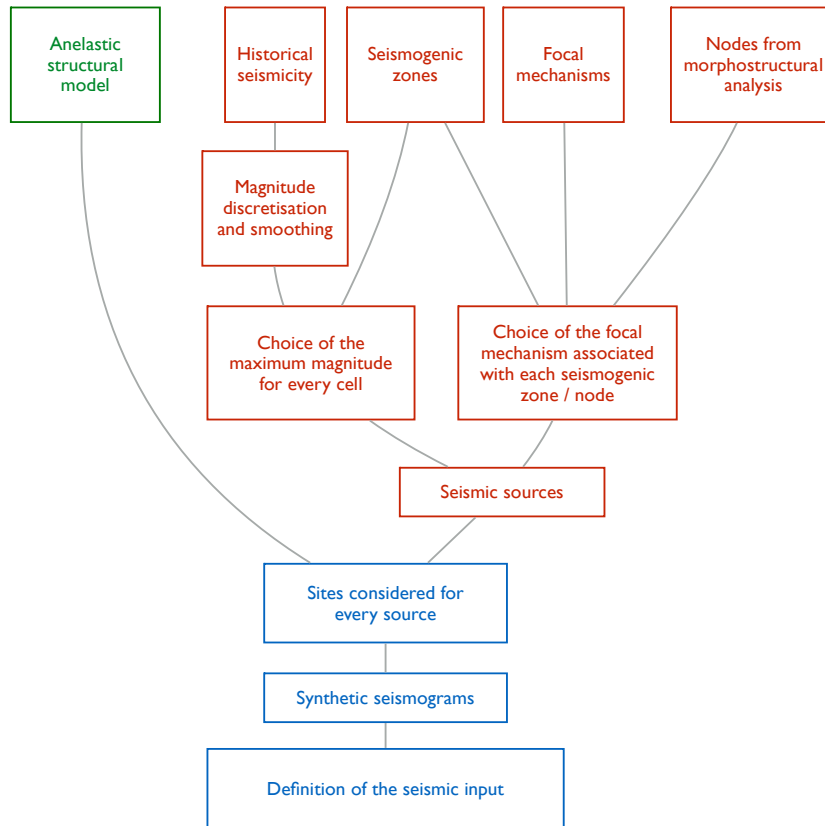


Figure 4. Flow Chart of NDSHA at Regional Scale: details for computations at local scale of the Maximum Credible Seismic Input - NDSHA-MCSI - are given in Rugarli et al. (2019a) and references therein

The definition of seismic sources is based not only on available reliable parametric earthquake catalogues, including source focal mechanisms, but also, and equally important, on: (a) the identification of *seismogenic zones* per Meletti et al. (2000); and (b) the identification of *seismogenic nodes*. Since by definition seismogenic nodes, which can be identified by pattern recognition via morphostructural zonation (MZ), per Gorshkov et al. (2003) - accommodate earthquakes with a magnitude above a fixed threshold M (Gorshkov et al., 2002; 2004; Peresan et al., 2015; Gvishiani et al., 2020) - therefore their use is recommended in the NDSHA procedure whenever either historical parametric catalogues are unavailable or, although available, they cannot be considered

sufficiently complete. A comprehensive *validation* of seismogenic nodes as a viable alternative to both seismogenic zones and observed seismicity, for the definition of seismic hazard at regional scale, is given by Rugarli et al. (2019b).

Since 1972 the methodology of the *pattern recognition* of Earthquake-Prone Areas (EPA) has been systematically applied (for different values of M) in many seismic regions throughout the world: the Tien Shan and Pamir (Gelfand et al., 1972); Balkans, Asia Minor, Transcaucasia (Gelfand et al., 1974a,b); California and Nevada (Gelfand et al., 1976); Italy (Caputo et al., 1980; Gorshkov et al., 2002); Andean South America (Gvishiani and Soloviev, 1984); Kamchatka (Gvishiani et al., 1984); Western

Alps (Cisternas et al., 1985); Pyrenees (Gvishiani et al., 1987); Greater Caucasus (Gvishiani et al., 1988); Lesser Caucasus (Gorshkov et al., 1991); Himalaya (Bhatia et al., 1992); Carpathians (Gorshkov et al., 2000); Alps and Dinarides (Gorshkov et al., 2004); Alborz (Gorshkov et al., 2010); Ecuador (Chunga et al., 2010); Iberian Plate (Gorshkov et al., 2010); North Vietnam (Tuyen et al., 2012); Kopet Dagh (Novikova and Gorshkov, 2013); Caucasus Region (Soloviev et al., 2013); and Northeast Egypt (Gorshkov et al., 2018). Various validations of seismogenic nodes as identified by pattern recognition in morphostructural zonation (MZ) are given by: Gorshkov et al. (2005); Gorshkov and Novikova (2018); and Gvishiani et al. (2020); and other applications of pattern recognition techniques, intended for use in seismic hazard analysis, were similarly evaluated and reviewed by Mridula et al. (2013).

5.1. Scenario Earthquakes

NDSHA generated earthquake scenarios are determined consistent with: (i) the available knowledge about the earth's structure (through which seismic waves propagate); (ii) the earthquake sources, and (iii) all previously known seismicity within the study area. Therefore, it is then possible to compute realistic synthetic seismograms that are suitable for engineering applications.

It is thus possible to quantify peak values of Acceleration (PGA), Velocity (PGV) and Displacement (PGD) or any other ground motion parameter relevant to seismic engineering. The Design Ground Acceleration (DGA) can be computed consistently with the shape of any preferred Design Spectrum (Panza et al., 1996), as shown in Fig. 5. DGA is the "Spectral Acceleration" SA(g) anchoring the Elastic Acceleration Response Spectrum (RS) at a period of $T = 0s$. This quantity is comparable to PGA, since an

infinitely rigid structure (i.e., a structure having a natural period of $0s$) moves exactly like the ground: the Maximum Acceleration of the Structure (MSA) is the same as that of the ground, which is the PGA. Moreover, DGA is practically equivalent to Effective Peak Acceleration (EPA), which is defined as the "average of the maximum ordinates of elastic acceleration response spectra within the period range from 0.1s to 0.5s, divided by a standard factor of 2.5, for 5% damping (Panza et al., 2004)".

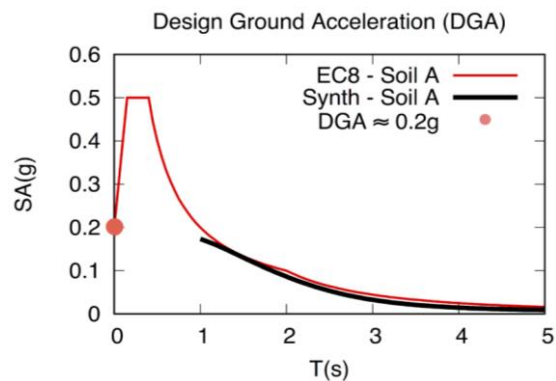


Figure 5. Elastic Acceleration Response Spectrum. To obtain an estimate of $PGA \approx DGA \approx EPA$ (Panza et al., 2004), overcoming the $T = 1s$ or $1Hz$ cutoff (consistent with the available detail in the input data used for the modeling at national scale) the "shape" of any code design spectrum can be used. The thin (red) line represents the shape of the chosen Standard Seismic Code Normalized RS (EC8 - Soil A), scaled here with the long period ($T > 1s$) RS, thick (black) line: determined with NDSHA computed time histories (Synth) at the site of interest (Panza et al., 1996). These approximations $PGA \approx DGA \approx EPA$ hold as follows: (a) $DGA = PGA$ for elastic Design Spectra; (b) $DGA \approx EPA$ at bedrock - although, importantly, it is also controlled by the earthquake source time-history; EPA (although it is correlated with the real Peak Value) is then, as a rule, actually not "equal to," nor even "proportional to" it. (Panza et al., 2003)

Importantly, and as a rule, the computations of time history accelerograms containing accelerations at short periods ($T < 1s$) require a level of knowledge of earthquake source processes and wave medium pathway that so far is unattainable; but accelerogram computations that are reliable at long periods may be extended to $T < 1s$ by using elastic acceleration response spectra (Fig. 5). In absence of normalized spectra derived from specific regional recorded signals, the recommended procedure is to use “Code Spectral Shapes”, e.g., Eurocode 8 (EC8 1993, 2008), which defines the normalized elastic acceleration response spectrum of the ground motion for 5% critical damping. Thus, it is possible now to obtain DGA by: (i) computing the RS for each synthetic accelerogram computed for periods of 1s and longer; and (ii) by then extending this spectrum to shorter periods using any normalized elastic acceleration RS of the ground motion (e.g. corresponding to soil A, as in Fig. 5). DGA estimation has been validated in many instances: both regionally and at regional and local scale (See Fasan et al., 2016; Panza, 2017; Parvez et al., 2017; De Natale et al., 2019; Panza, 2020).

The normalized code elastic RS method, although physically rooted in *structural dynamics*, is by nature of its origin from many different earthquakes and the required smoothing of data, not precise. The smoothed shapes of standard Code Elastic RS (which prescribe strength base shear requirements for new structures) are obtained, as a rule, through a demanding statistical processing of signals - obtained however under quite different earthquake conditions, and they cannot therefore always be considered the “best tool” to assess structural behavior.

These limitations result from, among other things: (a) our inability to duly consider both

the wavelength phases; and also (b) the durations of the recorded earthquake signals. However, it is still today the most frequently used method for application in seismic design codes, because of its relative ease in estimating the peak or maximum elastic response of a building, which forms the basis for calculating the “forces” that a structure must be designed to resist. For engineering purposes, the seismic hazard is still today defined by a code prescribed normalized elastic design response spectrum, which perhaps takes indirectly into account the variability of the possible signals. These response spectra, however, in most of the cases, do not have true direct links to the site under examination, but rather refer to average national shapes. Malhotra (2015) found that the latest empirical ground motion prediction equations (GMPEs) do not always preserve the shape of the normalized RS and he recommends: (i) that ground motion prediction models should only be developed for PGA, PGV and PGD; and (ii) that the response spectra for various damping ratios should be generated from PGA, PGV and PGD by using the normalized RS.

5.2. NDSHA Grid Cells: A Honeycomb of Seismic Sources / Computed Seismograms

In NDSHA, as a general rule: (a) a regular grid ($0.2^\circ \times 0.2^\circ$) is placed over the study region; (b) the earthquake sources are centered in the grid cells that fall within the adopted seismogenic zones; (c) the receiver or computation sites (points where the seismograms are computed) are centers of a companion grid that is offset from the source grid by 0.1×0.1 degrees - the maximum distance receiver site from a double-couple point source centered in the grid is “usually 150 km” or about 7 grid square distances

away; while the computation sites are placed at the nodes of a grid that is staggered by 0.1° with respect to the sources' regular grid; (d) a smoothing procedure for the definition of earthquake location and magnitude M is then applied to partly account for spatial uncertainty, catalogue incompleteness and for earthquake source extension; (e) after smoothing, only the cells (earthquake sources) located within the seismogenic zones and/or within each seismogenic node, as identified by pattern recognition techniques, are retained; (f) a double-couple point source is placed at the center of each cell, with a representative focal mechanism, which is consistent with the known present-day dominant tectonic regime of the corresponding seismogenic zone (cellular source) - (i) to define the magnitude of each source (cellular magnitude), the NDSHA procedure makes use of information about the space distribution of large-magnitude earthquakes ($M > 5$), which can be defined from historical, instrumental and geological observations; and (ii) the source depth is taken into consideration as a function of magnitude, in agreement with literature. (e.g., Caputo et al., 1973; Molchan et al., 1997; Doglioni et al., 2015).

In addition, NDSHA permits (if really necessary, as claimed by PSHA addicted practitioners fearful of "overdesign" because a damaging earthquake is unlikely) an *accounting* for earthquake occurrence rate (Peresan et al., 2013; Nekrasova et al., 2013; Magrin et al., 2017; and references therein): first, the characterization of the Frequency-Magnitude (FM) relation for earthquake activity in Italy is performed, according to the "multi-scale seismicity model" (Molchan et

al., 1997), such that a robust estimated occurrence (not recurrence) rate is associated to each of the NDSHA modeled sources; and second, the occurrence rate assigned to the source is thus associated to its pertinent synthetic seismogram, coherently with the physical nature of the problem. Accordingly, then, two separate maps are obtained: (1) one for the "ground shaking" and (2) another for the corresponding perceived "average occurrence rate", as shown in Fig. 6. From the Figure it is evident that even the availability of the CPTI04 parametric earthquake catalogue (CPTI04 Working Group 2004), reliable for events with $M \geq 5.0$ since year 1000, does not allow the computation (over the entire territory of Italy) of reliable "average occurrence rates" - "open circles" in (B); and there are many "?" symbols appearing for DGA in (C): i.e., sites where the occurrence estimate of maximum ground motion is unreliable due to the lack of sufficient data in Fig. 6.

Since, in policy decisions to protect civil populations, the authors believe that the engineering use of these "average occurrence rates" (per Cornell 1968) is not only questionable... but also both unsafe and unsound; they can neither recommend nor even suggest their use! Therefore, "in policy decisions to protect civil populations" - (a) when considering two sites prone to earthquakes with the same Earthquake Hazard M , given that all the remaining conditions are the same; (b) the parameters for seismic design must be equal at the two sites - since the magnitude we have to defend against is the same M , independently from the sporadic nature (i.e., perceived likelihood) of the earthquake's occurrence (not recurrence).

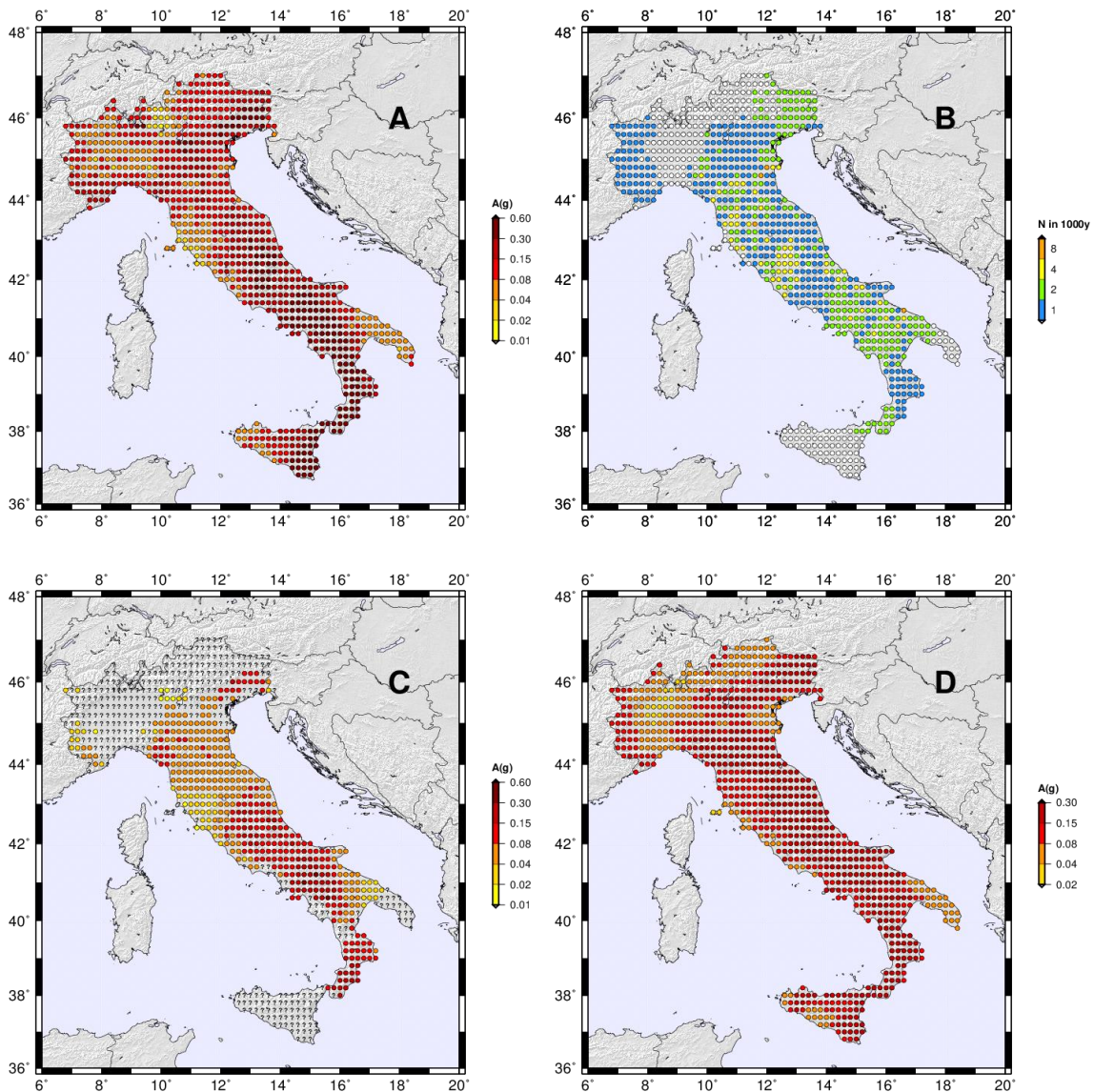


Figure 6. Maximum DGA (A) computed considering both seismogenic zones and seismogenic nodes; and, also, its Occurrence (B) expressed, to be conservative, as the upper bound of the "integer" number of times the ground motion is likely to be observed in 1000 years; Neo-Deterministic DGA (C); and Probabilistic PGA (D) for a time interval $T = 475$ yr. Question Marks "?" represent sites where occurrence estimate of maximum ground motion is unreliable, due to the lack of sufficient data. (modified after Magrin et al., 2017)

5.3. "Information is not knowledge"

- Albert Einstein

When available knowledge may sometimes permit reliable accelerogram computations comprising frequencies > 1 Hz (higher

frequencies at periods less than the standard $T = 1$ s cutoff in Fig. 5), such accelerograms can be considered. Remembering: (a) $T = 1/f$; and that (b) building period can be approximated at 0.1s per story - the physics-

based ground motion modeling is however, as a rule, limited within the frequency range from 1 to 10 Hz, because any estimates of ground motions at higher frequencies (shorter periods) would require a comprehensive knowledge of: (i) source heterogeneity, (ii) physical properties of the rock/soil, and (iii) ground motion attenuation parameters - all with a resolution realistically not attainable (Rugarli et al., 2019a and references therein).

This is well in agreement with Aki's (2003) conclusion: results about (i) the source-controlled f_{\max} ; (ii) non-linear soil response; and (iii) the studies of seismic attenuation from borehole data - all indicate that there is no need to consider frequencies higher than about 10 Hz in strong motion seismology.

In fact, the quality of the results obtained by physics-based ground motion modeling depends on the quality of the input data. The NDSHA procedures allow for sensitivity analyses to evaluate evidence and also to address the uncertainties using different input data and varying levels of knowledge about seismic sources and attenuation velocity structural models. Proper presentation and evaluation of uncertainties, associated with the ground motion computation, will help the potential users determine how much confidence to place on the NDSHA computed seismic hazard map.

Further insight into the hierarchical interrelationships of NDSHA procedures considers the following: (a) the strength of the source is determined as the maximum between a lower bound and the magnitude defined by the smoothing procedure. The lower bound for magnitude inside the seismogenic zones is $M = 5$, that also is conventionally (D'Amico et al., 1999) taken as the lower bound magnitude of damaging earthquakes; (b) the lower bound of earthquake magnitude within the seismogenic nodes is the magnitude threshold identified for that node by the morphostructural analysis (Gelfand et al., 1972); (c) the orientation of the double-couple

point source is the one representative of the parent seismogenic zone or seismogenic node; (d) hypocentral depth, in fairly good agreement with existing literature, is taken as a discrete function of magnitude $f(M) = (10 \text{ km for } M < 7) (15 \text{ km for } 7 \leq M < 8) \text{ and } (25 \text{ km for } M \geq 8)$. A quite complete description of the NDSHA methodology, including the joint use of earthquake sources within seismogenic zones and seismogenic nodes, can be found in Panza et al. (2001), and its updates and validations in Panza et al. (2012), Fasan et al. (2016), Magrin et al. (2016), Parvez et al. (2017) and Hassan et al. (2017). Specific 3D NDSHA applications can be found in La Mura et al. (2011) and Panza et al. (2013).

5.4. Validations by the facts

NDSHA, unlike PSHA, is "falsifiable", and therefore it can be tested! Since PSHA is false, it is not falsifiable and it cannot be tested! A detailed review of the traditional PSHA method (see *Supplementary material* in Panza and Bela, 2019) revealed that the method itself is inadequate to describe the physical process of earthquake occurrence, because of its built-in and required assumption of a "memoryless" stochastic process, or Poisson process. (e.g., Ferraes, 1967, Panza et al., 2014).

It is obvious that strain and stress renewal needs time, and therefore the process of rebuilding the conditions for the next earthquake is "time-dependent". Furthermore, the locations of earthquakes (even at and along the same faults) are changing with time, as well as are fault strength mechanical properties, in particular after each event. Each magnitude range of earthquakes, as defined by USGS - (Moderate: $M 5 - M 5.9$); (Strong: $M 6 - M 6.9$); (Major: $M 7 - M 7.9$); and (Great: $M \geq 8$) - is modifying the boundary conditions for the next earthquake. <http://www.geo.mtu.edu/UPSeis/magnitude.html>.

Recent evidences of an earthquake-induced transformation of the crust are described in some detail by Jamtveit et al. (2018) and Zhang et al. (2019). This means that a mathematical *probabilistic* model has to be at least bivariate, and probably also bimodal. This is outside of the scope of our human knowledge due to: (a) lack of data; and (b) also the shortness of human observation time in comparison with geological time scales. Furthermore, the theoretical *discrete* model by Carlson (1991) shows that the smaller events are consistent with the Gutenberg-Richter statistical law, whereas the larger and same-size characteristic events have a separate statistical distribution. Carlson's 1991 model has been extended to a *continuum* by Cattania (2019), who explored: (a) why small earthquake sources can produce quasiperiodic sequences of identical events; whereas (b) earthquakes on large faults are intrinsically more variable - and showed that simple, isolated faults do not necessarily produce regular and periodic earthquakes, especially when the faults are relatively large. Both models illustrate the absolute fallacy of the "return period" concept! (see also section 2. "Return period" or chimera?).

As does any physical earthquake model, NDSHA must deal with *uncertainties* intrinsic in the basic model input data, here chiefly coming from: (a) earthquake catalogues; and (b) lack of satisfactory theories about earthquake source (slip distribution at initiation of rupture, and slip distributions in cascading multi-fault ruptures). For this reason, the hazard values at both national and regional scale supplied by NDSHA are given as ranges over geographic areas - whose values are consistent with the information content of the basic data. (See section Macroseismic Intensity, Magnitude and Peak Acceleration).

Typical values are displayed on a geographic grid mesh of about 25-50 km

spacing (e.g. see Fig. 6), and hazard values are color-coded in discrete ranges of geometrical progression close to 2X (Fig. 7). More specific hazard estimates can be obtained at local scale by means of ad hoc studies, e.g. Rugarli et al., 2019a.

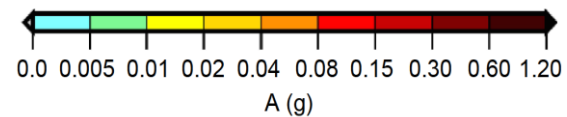


Figure 7. Typical Discrete Ranges of Hazard Values (units of g): shown in geometrical progression (close to 2X), consistent with the real resolving power of the worldwide available data (e.g., Cancani 1904 and Lliboutry 2000)

In the original formulation of NDSHA (Panza et al., 2001; 2012), physics-based computer computation was: (i) combined with a comprehensive geologic and geophysical overview of the regional tectonic setting and earthquake history to; (ii) solve, in a first approximation, the fundamental problems posed by an adequate description of the physical process of earthquake occurrence (which in the real earth is a tensor phenomenon). It examined the "largest" potential seismic event - termed Maximum Credible Earthquake (MCE) - whose cellular magnitude M_{design} at a given site can be tentatively, until proven otherwise, set equal to the Maximum observed or estimated earthquake magnitude M_{max} , plus some multiple of its accepted global standard deviation σ_M . In areas where information on faults and other input data are sparse, the historical data and morphostructural analysis are relied upon to estimate this Maximum Magnitude M_{max} .

For estimating M_{design} specifically, we presume statistically that no more than $1/k^2$ of a distribution's values can be more than k standard deviations away from the mean (or equivalently, at least $1-1/k^2$ of the distribution's values are within k standard deviations of the mean). If $k = 2$, then at least 75% of the values fall within $2\sigma_M$; and if

$k = 3$, then at least 89% of the values fall within an interval of $3\sigma_M$ centered on the mean. This factor k can therefore be considered a "tunable safety factor", e.g. γ_{EM} (EM = Earthquake Magnitude), which may be applied systematically jointly with the other *safety factors* that are used in structural engineering. So $M_{design} = M_{max} + \gamma_{EM}\sigma_M$ - where it is currently presumed $\sigma_M \approx 0.2 - 0.3$ (Richter 1935; Gutenberg and Richter 1956; Båth 1973, p. 111; 1979, 1981), and it is proposed to use $\gamma_{EM} = 1.5 - 2.5$ (Rugarli et al., 2019a).

Since the design value M_{design} is determined by adding this further tunable increment to the maximum estimated value M_{max} , it must be considered an envelope - evaluated at the best of our present-day knowledge. This choice is consistent with Chebyshev's theorem: "for a very wide class of probability distributions, no more than a certain fraction of values can be more than a certain distance away from the mean" (but here a Maximum estimated M value, M_{max} , is used by analogy).

As an instructive example illustrating NDSHA's global applications: (i) when considering the upper limit of $\gamma_{EM}\sigma_M$; and then (ii) applying this "tunable safety factor" to the Maximum observed M ($M_{max} = 7.5$) in southern California within the time interval from 1932-2011 (Chiou and Miao, 2013); we can then determine here that $M_{design} = M_{max} + \gamma_{EM}\sigma_M = 7.5 + 0.7 = 8.2$; this result is well in agreement with Kijko (2004), where $M_{max} \approx 8.3$; and with Field et al. (1999), wherein $M_{max} \approx 8.0$.

It is, however, also important to first: (1) remember that the purpose of estimation is to first and foremost inform judgement; and then secondly; (2) to therefore realize that good engineering and seismological judgement is required whenever M_{design} should exceed magnitude levels that can range from perhaps "too high" to even "physically unrealistic", as is discussed below.

For example, when examining M_{design} computed values for the following countries, the results are high: Chile (10.2); Alaska (9.9); Sumatra (9.8 - 10.0); Japan (9.8); Cuba (8.3) and Iran (8.0). While the results for both Cuba and Iran are compatibly close to M_{max} events already experienced in those countries; the very high values for the major subduction zones in Chile, Alaska and Sumatra, while perhaps possible, are all greater than the largest Megathrust event ever so-far recorded (Mw 9.5 - Chile 1960)!

Therefore, the selection and application of the M_{design} definition to site-specific locations and ultimate selection of design values within each country then requires *targeted* ad hoc studies, keeping in mind that, for example: (a) the fault length for earthquakes with $M \sim 9$ is of the order of 1000 km or more (Wells and Coppersmith, 1994); and (b) ground motion amplitudes saturate at $M \sim 8$ - and do not necessarily increase linearly with Moment Magnitude M_w (which for these very large faults is more physically reflecting the amount of energy the rocks can store before they break, than it is what the *individual* record of any strong motion recording station might be).

"One must never say anything too specific about earthquakes"

- Perry Byerly

As long as these caveats are fully understood and then sufficiently factored into our judgments, nevertheless a physically sound way to estimate and assess the magnitude of the largest event physically possible, usually termed Maximum Credible Earthquake MCE, is to set its magnitude equal to M_{design} , i.e., the *maximum* observed or estimated magnitude M_{max} , plus some multiple of its accepted global standard deviation σ_M , as given in parentheses ($\sigma_M \approx 0.2 - 0.3$):

$$MCE = M_{design} = M_{max} + \gamma_{EM}\sigma_M \approx M_{max} + 0.5$$

Since NDSHA's computations then supply a bounding or *envelope* value (in other words,

a value that should not be geologically or seismologically exceeded in nature) - this value is immediately falsifiable: (1) if an earthquake occurs with a magnitude M_{eq} larger than that indicated by NDSHA's M_{design} ($M_{eq} > M_{design}$), then $\Delta M = M_{eq} - M_{max} > \gamma_{EM}\sigma_M$, and γ_{EM} should then be increased. Given the way M_{design} is defined, however, this is expected to be a rare circumstance!

The tunable increment to M_{max} , γ_{EM} , could similarly be increased, should recorded peak ground motion values (e.g., PGA, PGV, or PGD) on the bedrock (at the occurrence of an earthquake M_{eq} after the compilation of NDSHA maps) exceed, within error limits, those values given in these same maps. By way of improving usefulness and applicability of future strong ground motion recordings, this would suggest targeting installation of additional strong motion network stations over stiff soils, so as to avoid the local amplifications due to site effects - since the majority of the strong ground motion stations of the Italian strong motion network are sited upon soft soils.

While the selection of the multiplier γ_{EM} to be applied to σ_M cannot be derived by equations (indeed, it would be misleading to try), today it is partly heuristic, or a "rule-of-thumb" practical method of approximation learned from experience. See also Tversky and Kahneman (1974). Nonetheless, should this heuristic be falsified by natural experiments, this multiplier can be gradually reset to the new minimum safe value. This is what has already been done with all the already *safety factors* used in engineering: (i) the 1.5 safety factor for material limit stresses was used well before the availability of reliable statistical measures; and (ii) the semi-probabilistic methods used in structural engineering are de facto tuned to confirm these already validated-by-experience values (Rugarli et al., 2019a).

In an important recent finding, Rugarli et al. (2019b) have shown, using the unique

1000 + years' catalogue available for Italy, that *seismogenic nodes* may represent a viable alternative to *seismogenic zones* and *observed seismicity* for the reliable definition of seismic hazard at regional scale. Their paper provides both a *validation* of the seismogenic nodes method, and it also further supplies a tentative *tuning* of the safety factor γ_{EM} at about ≈ 2 . Therefore, they recommend to start both the seismic hazard assessment and also the derivative earthquake resistant design planning process with the generalized use of:

$$M_{design} = M_{max} + \gamma_{EM}\sigma_M = M_{max} + 2.0 \sigma_M$$

6. A warning about site effects

The experimental approach to the estimation of the site response ("large modifications of seismic waves produced by variations of material properties in superficial geological layers near the Earth's surface") is based on the instrumental measures of the amplitudes and frequencies of ground motions at different sites (Boore, 2004a; Panzera et al., 2017). This necessarily implies the recording, with a network of strong motion instruments, of multiple seismic sources - all impacting the site from various azimuthal directions, as well as under seismological influences of pathway (including buried and surface topography) and seismic wave velocity of the transmitting geologic medium.

If a network of N sites has recorded J events, the amplitude spectrum, O , of the j -th event recorded at the n -th site is usually represented as (e.g. Field and Jacob, 1995) as $O_{nj}(\omega) = E_j(\omega) \cdot P_{nj}(\omega) \cdot S_n(\omega)$, where E is the source term, P is the path term, and S is the site-effect term. In the time domain: $O_{nj}(t) = E_j(t) \cdot P_{nj}(t) \cdot S_n(t)$, where \cdot indicates the convolution operator, a mathematical way of blending two signals to form a third signal.

The most traditional techniques for site effect estimation of the S_n term, known as *convolutive* methods, are based upon computation of the ratio between: (a) the spectrum of the signal (or a portion of it) at

the (sedimentary) site of interest; and (b) the spectrum of a reference signal, preferably recorded at a nearby (bedrock) site. Similarly, Nakamura (1989; 2008) and Nakamura and Gurler (2001) analyzed site effects by a method based on the computation of the *spectral ratio* between horizontal (usually the square root of the product between the spectra of the NS and EW components is used) and vertical components (H/V) obtained from seismic noise (microtremors).

Theoretical investigations (e.g., Lachet and Bard, 1994; Dravinski et al., 1996) as well as experimental studies (e.g., Field and Jacob, 1995; Field 1996) have further shown that, while Nakamura's method can reveal the fundamental resonant frequency of a site, it is usually not able to give the correct amplification level. Furthermore, Nakamura's 1989 original assumptions now seem *questionable*, since several later studies (e.g., Lachet and Bard, 1994; Konno and Ohmachi, 1998) have demonstrated that the horizontal-to-vertical spectral ratio HVSR is more strictly correlated with the *polarization* of Rayleigh waves - these tending to be more concentrated in the horizontal plane whenever there is an increasing thickness of sediments with poor mechanical properties (Panza et al., 1972; Rugarli et al., 2019a). Of course, poor mechanical properties may be responsible for an increase of wave train duration, always within the principle of energy conservation. Recent studies have shown that the difference between the HVSR and the actual amplification during an earthquake can be extremely large (Perron et al., 2018).

A comprehensive comparison of: (i) the various empirical techniques for describing and characterizing site effects, found in Bard (1997); (ii) "Advances in seismic site response: Usual practices and innovative methods," in Panzera et al. (2017); and (iii) "Emergence of seismic metamaterials: Current state and future perspectives," in Brulé et al. (2020) - all testify to their

importance. Additionally, the paper by Dal Moro et al. (2019) is of particular interest to us, since it critically illustrates a series of "technical aspects" regarding the holistic acquisition and analysis of Rayleigh waves acquired by a single 3-component geophone.

6.1. Can site response be predicted?

Boore (2004b), in posing this question, points out that "because the soil amplifications can be as large as a factor of ten, they are important in engineering applications that require the *quantitative* specifications of ground motions... What is often missing in these studies, however," as he points out, "are discussions of the uncertainty of the predicted response." Observational studies of site response (site effects) have demonstrated that ground motions have both: (a) "large site-to-site variability for a single earthquake"; and (b) "large earthquake-location-dependent variability for a single site." - and that therefore (c) "this variability makes *site-specific*, earthquake-specific predictions of site response quite uncertain, even if detailed geotechnical and geological information is available near the site". Alternatively, however, "predictions of site response for *average* classes of sites exposed to the motions from many earthquakes can be made with much greater certainty if sufficient empirical observations are available." (e.g., Clemente-Chavez, 2014 and Poggi et al., 2017).

6.1.1 Warning I: Calculated ambiguities are not so easily understood

Although the most frequently used techniques for the *empirical* estimation of site effects, based on $O_{ij}(\omega) = E_j(\omega) \cdot P_{ij}(\omega) \cdot S_n(\omega)$, supply reliable information about the site response to *non-interfering* seismic phases or to *single* modes of vibration; they are not adequate in most real cases when the seismic sequel of seismic phases or modes is formed

by either: (a) several *interfering* waves; or (b) equivalently by several *modes* - generated, e.g. by a rupture on a finite dimension fault buried within a deep sedimentary basin.

Also, in a mathematically very simple situation, i.e., in the far field region (where one can consider a “point source” approximation for the initiation of seismic wave energy) - the l -th component of *seismic ground displacement* is given by $u_l(t) = \sum_{ij} M_{ij}(t) * G_{li,j}(t)$, where: (i) G is the Green's function that represents the transmitting medium (pathway) response; and (ii) M_{ij} are moment tensor functions representing the source properties (e.g. Šílený and Panza, 1991; Šílený et al., 1992).

If G and M_{ij} are considered to be independent in their descriptions of the source, the above equation is *linear* and represents a mechanism generally varying with time. However, if we constrain their independence and ask for a constant mechanism (even one that is unconstrained, i.e. the full moment tensor); i.e. if we impose the constraint $M_{ij}(t) = M_{ij} \cdot m(t)$, then the problem becomes non-linear because of the product $M_{ij} \cdot m(t)$, where both M_{ij} and $m(t)$ are the model parameters controlling source properties.

Thus, the inverse problem (i.e., the separation of source and medium terms), is therefore *non-linear* in the time domain; even without the double-couple constraint usually assumed for seismic sources. An additional non-linearity derives, in fact, from the double-couple constraint, which imposes a non-linear combination of the components of the moment tensor - namely a zero value of its determinant.

6.1.2. Warning II: Site Effects are dependent upon source properties

Alternatively, within the frequency domain - where $M_{ij}(\omega) = M_{ij} \cdot m(\omega)$ - the inverse problem may seem simpler, because: (i) the convolution is converted to pure

multiplication; and (ii) the equation is solved for each frequency separately. Since within linearity we can determine $M_{ij}(\omega)$, we can further see from $O_{nj}(\omega) = E_j(\omega) \cdot P_{nj}(\omega) \cdot S_n(\omega)$ - that site effects are dependent upon *source properties!* To separate the source time function transform $m(\omega)$ and the space tensor M_{ij} , again a *non-linear* constraint is needed - so therefore the advantage of the frequency domain is fictitious.

6.1.3. Site Effect Ground Motions computed from Scenario Earthquakes

A complementary alternative to the questionable empirical approach to site response estimation, evidenced for example by De Ferrari et al. (2010) and Molchan et al. (2011), is based on computer codes, developed from the detailed knowledge of the seismic source process and the propagation of seismic waves. (e.g., Romanelli and Vaccari, 1999; Field 2000; Olsen 2000; Panza et al., 2001; Rugarli et al., 2019a; Panza and Bela, 2019). This approach can simulate the ground motion associated with a given earthquake scenario, as done by NDSHA. Thereby using available geological and geotechnical information, a low-cost parametric analysis of site responses can be performed - without using the empirical | convolutive methods that are based on $O_{nj}(\omega) = E_j(\omega) \cdot P_{nj}(\omega) \cdot S_n(\omega)$.

Summarizing - the Warnings for the empirical | convolutive models are: (a) *uncertainty*, which remains unknown for any site-specific application (as previously discussed); and most importantly (b) *validity* is also proven not general - since site effects are, as a rule, dependent upon *source properties* that are a direct consequence of the telluric and tensor nature of the motion equation: $u_l(t) = \sum_{ij} M_{ij}(t) \cdot G_{li,j}(t)$, where: (i) G is the Green's function, that represents the transmitting medium (pathway) response and (ii) M_{ij} are moment tensor functions representing the source properties.

7. Case studies

A very natural question to ask, as a consequence of what has already been proven in earlier sections Change of paradigm and Methodology, is: “What is the appropriate way to estimate seismic hazard for our historical buildings and monuments”? - since we must now be considering time intervals of hundreds of years (or perhaps even more, since, even if naturally perishable, we want to keep *cultural heritage* as long as possible).

It is our best judgment that probabilistic methods of seismic hazard assessment, i.e., PSHA, must be rejected when considering cultural heritage, because of their severe shortcomings deriving from: (i) erroneous mathematical presumptions; (ii) defective logic; (iii) incorrect and unverifiable earthquake science assumptions; and (iv) too simplistic physical considerations of earthquake occurrence. Summarizing: PSHA turns out by far to be *failingly* inapplicable for cultural heritage and monuments!

Since PSHA quantitatively displays results in terms of peak ground acceleration PGA and spectral response acceleration SA, both design professionals and the public inhabitants of buildings have often been rather confused between: (a) what an “earthquake” actually is? - and (b) what exactly the PSHA modeled “ground motion” derivations represent?

Ground motion is *ground shaking* that is simply a physical consequence from having an earthquake! In other words: NO earthquake occurs! - NO ground motion will be observed! However, in the PSHA earthquake hazard model, “ground motion” occurrence in *time* is a “concept” that is tied to *regulatory* earthquake-resistant design requirements - and therefore the PSHA hazard model “ground motion” could be (and too often is) *different* from that felt in experiencing an actual earthquake (Klügel et al., 2006).

“Whenever you think that you are facing a contradiction, check your premises. You will find that one of them is wrong”

- Ayn Ran

A viable alternative capable of minimizing the drawbacks of ground motion and other systemic confusions of standard SHA is given by the use of *scenario earthquakes*, which can be characterized in terms of: (i) magnitude - including MCE; (ii) distance; (iii) faulting style; and (iv) by the treatment of complex source processes (Klügel et al., 2006; Rugarli et al., 2019a, b; Panza and Bela, 2019).

Scenario-based seismic hazard maps: (a) are purely based on geophysical and seismotectonic features of a region; and (b) take into account the occurrence of earthquakes only for their classifications into descriptive hazard categories: exceptional (catastrophic); rare (disastrous); sporadic (very strong); occasional (strong); and frequent - therefore they may provide an *upper bound* for the ground motion levels that can potentially be expected for most regions of the world. Knowledge of an upper bound is first and foremost more appropriate than probabilities of exceedance, in view of the longer time scales required for the protection of historical buildings. Secondly, and as was pointed out in section 6. A warning about site effects, a calculated ambiguity (which in PSHA sometimes can also be counter-intuitive) is often difficult to communicate - so as to be understood!

Since the NDSHA approach naturally supplies realistic time-series of ground motion, it can also provide reliable estimates of ground displacement that are readily applicable to seismic isolation techniques (e.g., Martelli et al., 2014 and references therein) - techniques that are very useful in preserving historical monuments and other culturally important man-made structures. The relevance of the realistic modeling provided by NDSHA, which permits the generalization

of empirical observations by means of physically sound theoretical considerations, cannot be overstated - as it allows for the optimization of the structural design with respect to the site of interest, especially in Italy.

Presently, the new and comprehensive book **“Earthquakes and Sustainable Infrastructure: neodeterministic (NDSHA) approach guarantees prevention rather than cure”**, now (in early 2021) in advanced stage of preparation (edited for Elsevier by Panza G, Kossobokov V, Laor E and De Vivo B) aims to communicate in one very complete volume our “state-of-the-art” scientific knowledge on earthquakes and related seismic risks.

7.1. 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 - <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).

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 had also been 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 following morning of November 27, based on records of tide gauge measurements.

https://www.agi.it/estero/terremoto_albania-6620218/news/2019-11-26/

7.2. Bangladesh

Bangladesh lies within a historical earthquake-prone region, with evidence pointing to past major earthquakes within or close to the country. There is now general consensus among national and international experts about the possibility of a large magnitude earthquake occurring in Bangladesh (and the surrounding region) at any time. Historical records of “major” earthquakes in and around Bangladesh, including: 1930 M 7.1 Dhubri Earthquake; 1918 M 7.6 Srimangal Earthquake; 1897 M 8.3 Great Indian Earthquake; 1885 M 7.0 Bengal Earthquake; 1762 M 7.5+ Chittagong-Arakan Earthquake - all bear testimony to the threat of major and even M 8+ great earthquakes for Bangladesh (Al-Hussaini et al., 2017). However, an absence of strong earthquakes affecting Bangladesh for quite a long period has left the current generation complacent about the possibility of a strong earthquake (M 6 - 6.9). Therefore, for example, in Dhaka, during the September 23-24, 2017 International Conference on Disaster Risk Mitigation: the first results of a focused NDSHA application to get reliable hazard assessment values for Bangladesh were illustrated and discussed (Panza, 2017; Al-Hussaini et al., 2017).

In response to the then recent publication by Steckler et al. (2016), about an anticipated “mega-earthquake” risk in Bangladesh, on an active, shallowly dipping and locked

megathrust fault (Magnitude ranging from M 8.2 - M 9.0) - NDSHA computations were performed (Chakraborty 2017) for some hypothetical scenario mega earthquakes (M 8.5 and M 8.0), with their epicenters 40 km east of Dhaka. For M 8.5 earthquake scenario, DGA in Dhaka can be 0.3 g - 0.6 g; while it can be ~1.0g near the earthquake epicenter in Comilla. These values, not surprisingly, far exceed the code specified values of 0.2g for Dhaka and Comilla. Obviously, for the lesser M 8.0 scenario earthquake, acceleration in Dhaka is lower, reaching only 0.15 g - 0.3 g - while within the more limited epicentral region it can still reach 1.0g.

7.3. China

China's pioneering application of NDSHA dates back to 1998 (Sun et al., 1998), and Sun's work has been followed now by two decades of international publications: Panza et al., (2002); Ding et al., (2004a, b); Wang et al., (2010); Wang and Shi (2010); Zhang et al. (2018) - all dealing with NDSHA's application to both seismology and structural engineering. At present a major *international* endeavor is developing: "China Seismic Experimental Site - Natural laboratory of earthquake science for seismic disaster resilience." - <http://www.cses.ac.cn/en/> - And one of this endeavor's projects is focusing on "Application research of the neo-deterministic seismic risk assessment (NDSHA) method in China Seismic Experimental Site."

<http://www.ief.ac.cn/home/index.html> -

<http://www.ief.ac.cn/ylaw/info/2020/22510.html> -

<http://www.ief.ac.cn/ylaw/info/2020/22512.html> -

<http://www.ief.ac.cn/eic/info/2020/22511.html>

7.4. Cuba

Pioneering work has been done focused on Santiago de Cuba city, the capital of southeastern Cuba's Santiago de Cuba Province, with special attention examining

earthquake source influence on "site effects". (see section 6. A warning about site effects). Analysis of the influence of both *depth* and *distance* of the source on the "site effects" shows that standard traditional methods (based on deconvolution analysis of nearby rock outcrop motions) can lead to erroneous results (Alvarez et al., 2001) - consistent with the fact that the deconvolution analysis is unable to specifically account for the *tensor* nature of realistic earthquake ground motions.

In other words, as a natural consequence of the tensor nature of earthquake ground motion, "site effects" are *not* persistent, when changing the relative positions of site-to-source - as has been confirmed both by modelling (e.g. Olsen 2000 for the Los Angeles basin) and also by formalized empirical observations in Molchan et al. (2011).

In Santiago de Cuba city, there are three different main zones identified, in addition to a small sector characterized by major resonance effects (due to the particular structural conditions). Each zone is characterized in terms of its expected ground motion parameters for both M 7 and M = $M_{design} = 8.0$. (Alvarez et al., 2004). In their later paper Alvarez et al. (2005) supply microzoning for Santiago de Cuba - where 11 zones are delimited, combining: (a) geological information; and (b) results of the classification based on formal analyses of the modeling of earthquake ground motion. Since the strongest earlier historical event in the region (06 Nov. 1766) reached M 7.6, the use of $M_{design} = M_{max} + \gamma_{EM}\sigma_M = 8.3$ is recommended (see also section 5. Methodology) - not so different, within experimental errors, from the value of $M_{design} = 8.0$ that was considered by Alvarez et al. (2004).

7.5. Venezuela

Three synthetically generated scenario earthquakes were chosen (located within the Guarenas - Guatire sedimentary basin) along

San Sebastian, Pichao (system La Victoria) and Tacagua Faults: with Mw 7, Mw 6 and Mw 5 respectively (Morfe et al., 2015). The following ground motion parameters were obtained: 2D/1D spectral ratio of the horizontal and vertical components H/V, and 2D/1D acceleration response spectrum ratio for the transverse, radial and vertical components. Response spectra of horizontal acceleration for the ground surface were developed from average relations of response spectra (considered as transfer functions) and response spectrum at bedrock obtained from a regional seismic hazard study.

In a similar study evaluating how the destructive effects of earthquakes may increase within sedimentary basins (not only due to the presence of sediments, but also because of basin geometry), Alvarado et al (2020) analyzed the results of 2D numerical simulations of seismic wave propagation from Mw 6.0 and Mw 7.0 scenarios: to estimate the soil response in the cities of Barquisimeto and Cabudare, located in the vicinity of Boconó fault, western Venezuela. The results obtained showed that the presence of sedimentary basins affect the amplitude, time duration and frequency content of the seismic source signal.

7.6. Egypt

In the last century, Egypt has experienced earthquakes with magnitudes ranging from m_b 5.8 up to Mw 7.3. The original pioneering work in the general framework and perspective of NDSHA in Egypt dates back to the work by El-Sayed et al. (2001). The computations of peak Displacement (DMAX), peak Velocity (VMAX) and Design Ground Acceleration (DGA) are chosen and then plotted to construct the Egyptian seismic hazard maps. These results have been validated against the few strong motion recordings available. Significantly, the areas

of high seismic hazard are also of great socio-economic importance.

While results obtained from the deterministic and probabilistic approaches are often comparable, the considerable differences observed in some areas may be related to the following factors that are peculiar to probabilistic methods. These methods: (a) are very sensitive to the completeness of the catalogue; and (b) use simple attenuation relations that oversimplify the wave propagation environment, which intrinsically is a tensor phenomenon. The most current reliable update on the seismic hazard maps available for Egypt incorporated the results of many recent studies, including: (i) revised historical earthquake catalogues; (ii) Morphostructural Zonation (MSZ) data; (iii) revised focal mechanism solutions; and (iv) revised mechanical models of the lithospheric structure - and was all completed within the framework of the Neo-Deterministic Seismic Hazard Assessment (NDSHA) procedure (Hassan et al., 2017).

In a recent hazard assessment that is based upon scenario earthquakes, Mostafa et al. (2019) use a "ground motion prediction equation" selected from already developed attenuation relationships, since there is no scaling attenuation relationship adopted in Egypt, due to the scarcity of strong ground motion observations - with obvious severe limitations on the reliability of results!

The set of relevant scenario earthquakes considered by Hassan et al. (2017) provides a large dataset of synthetic seismograms, particularly important for the areas like Egypt that suffer from an endemic lack of useful strong motion time-histories. This data set then comprises the basis for completing, in the future, more detailed and comprehensive seismic microzonation studies, like the one now in progress in the framework of the Suez Canal Economic Zone (SCZone). Availability of a wide spectrum of hazard maps is an

important prerequisite to making available the valuable information necessary for the significant improvements to current practices in seismic engineering codes.

The SCZone is a mega-project launched to both increase the role of the Suez Canal region in the international trading arena, and to also develop the urbanization of that region. Reliable Seismic Hazard Assessment, therefore, is crucial input information for the designers and planners of all facilities within this area. Accordingly, an updated seismic hazard map for the Suez Canal region has been compiled within the framework of the NDSHA procedure. To consistently both assess the uncertainty of the understanding of the seismic hazard, and also that uncertainty's effect on critical structures, a *sensitivity* analysis is performed varying, for example: (i) source focal mechanism; (ii) directivity; (iii) rupture process; and (iv) seismotectonic model. With a suite of ground shaking scenarios computed at the selected profile crossing the Suez Canal, variations of the ground shaking scenarios are then carefully evaluated by considering: (a) the amplitudes measured on the waveforms and the response spectra; (b) the changes in the shaking duration; and (c) the modifications in the amplification patterns.

Two recent papers by Hassan et al. (2020) and El Gabry et al. (2020) provide a specific focus on the NDSHA procedure, as applied to: (a) the seismic hazard assessment for the historical city of Cairo, which contains a large number of cultural heritage buildings; and (b) the seismic input definition (e.g., response spectra, time-histories) at a site of the tunnel that undergoes the Suez Canal to connect Sinai Peninsula with the western side of the country. Last but not least, ElGabry and Hassan (2020) have produced NDSHA estimates of design ground motion parameters - in the form of accessible online digital maps or databases (e.g., DGA, PGV, PGD, RS and time-histories) to be used as input for the next generation of the Egyptian Building code.

7.7. India

Parvez et al. (2003) published the first ever neo-deterministic seismic hazard map of India. Then, in 2017, by taking advantage of several enhancements to the original formulation of NDSHA, Parvez et al. (2017) supplied a revised NDSHA map for India. With respect to the original work by Parvez et al. (2003): (i) the velocity structural model for the entire Indian subcontinent was now redefined at a higher resolution of $1^\circ \times 1^\circ$ - amounting now to 387 cellular structures; (ii) the earthquake catalogue and the seismogenic zones were updated; and (iii) a more realistic source model, the Size and Time-Scaled Point Source (STSPS) described by Parvez et al. (2011), was adopted in the computations.

The highest seismic hazard, expressed in terms of DGA, lies in the range of 0.6 g - 1.2 g, and is mainly distributed: (i) in Western Himalayas and Central Himalayas - along the epicentral zone of the 25 April 2015 Mw 7.8 Nepal earthquake; (ii) in part of NE India; and (iii) in the Gujarat (Kachchh region). In these same areas, a similar pattern has been found for PGV and PGD values.

A comparison of NDSHA estimates with the maximum observed intensities I_{MAX} reported in EMS scale by Martin and Szeliga (2010) indicates that the modeled intensities are rarely exceeded by maximum observed intensities. That is, the *underestimation* of I_{MAX} is greater than one degree of intensity only: (a) in 2% of the NDSHA cells for I_{MAX} between VI (I_{EMS}) and VIII (I_{EMS}); and (b) in 7% of the cells for $I_{MAX} = IX$ (I_{EMS}); while (c) there is no underestimation for $I_{MAX} = X$ (I_{EMS}).

These gratifying and naturally supplied robust results (well consistent with the information content of the available data - Panza et al. (2013), and as also illustrated by Parvez et al. (2017), represent not only a major contribution to the reliable assessment

of the seismic hazard in India and neighboring areas, but they should also be used to update the building code IS 1893 of the Bureau of Indian Standards.

7.8. Indonesia

From a detailed *comparative analysis* considering the reliability of seismic hazard assessments given by PSHA and NDSHA, Irwandi (2017) stressed the need for a systematic application of NDSHA methodology to Indonesia, with particular attention paid to critical infrastructure at risk from seismic hazard. The Indonesian government has consistently provided updates of seismic hazard maps of PGA - releasing a series of official PSHA maps in 1978, 2002, 2010 and 2017. Most recently, Irwandi et al. (2020) compared the official PSHA 2010 and 2017 map values with those obtained by means of NDSHA.

The spatial resolution of the PSHA maps ($0.01^\circ \times 0.01^\circ$), i.e., a ten-times finer resolution than the more realistic NDSHA maps ($0.1^\circ \times 0.1^\circ$), is, we believe, an evident *numerical* artifact - totally inconsistent and at odds with the real resolving power of available data! The NDSHA comparison is naturally made by *smoothing* the PSHA values, thereby adjusting them to the same resolution ($0.1^\circ \times 0.1^\circ$) as the NDSHA data points.

In general, the resulting PGA value of the newer PSHA 2017 map is significantly greater than the previous PGA value of the preceding PSHA 2010 effort - except along the Sumatran fault in Central and South Sumatra. But in contrast, the PGA values estimated by using standard NDSHA (with 10 Hz cut-off frequency) are *higher* than those of the PSHA computed PGA - at a PE (Probability of Exceedance) of 2% in 50 years for both of the official PSHA maps released in 2010 and 2017.

Since NDSHA's ground motion values for Sumatra are based on the realistic physical

simulation of seismic wave generation and propagation, they provide reasonable, realistic and conservative envelopes of the complete suite of potential earthquake ground motions - therefore they should be seriously considered in those areas of Indonesia where critical infrastructure is at substantial risk from seismic hazards.

7.9. Iran

Seismic hazard maps for the Alborz region in northern Iran and adjacent areas have been compiled accordingly with NDSHA procedures by Rastgoo et al. (2018). The input data set consists of: (i) attenuation-velocity structural models (representing bedrock conditions); (ii) seismogenic zones; (iii) focal mechanisms; and (iv) the catalogue of past seismicity. The seismic hazard is mapped on a regular grid of $0.2^\circ \times 0.2^\circ$ over the entire region.

The results of this first order NDSHA mapping computation indicate a high seismic hazard in the Alborz region, and this may represent an important fundamental knowledge basis - essential for future and more detailed and comprehensive seismic microzonation studies.

A major *validation* of NDSHA results has been made against the records of the 20 June 1990 Mw 7.4 Manjil-Rudbar earthquake, which occurred in the Alborz region - and was both an *unexpected* left-lateral strike-slip motion on a previously unknown fault, and also the most destructive documented earthquake in Iran in the last century (Fig. 8). On account of the fact that earlier strongest events in the region had reached M 7.3, the use of $M_{\text{design}} = M_{\text{max}} + \gamma_{\text{EM}}\sigma_M = 8.0$ is to be recommended (see section 5. Methodology) - also exploiting, among other modeling techniques, the experience acquired with 3D NDSHA computations made so far (Gholami et al., 2012; 2014).

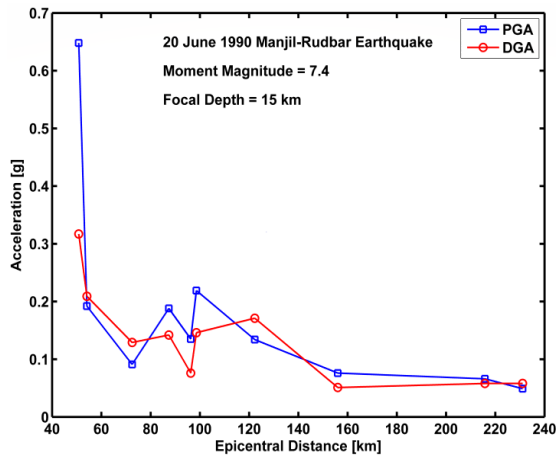


Figure 8. Alborz region, Iran: 20 June 1990 Mw 7.4 Manjil-Rudbar Earthquake. Plot of recorded PGA and estimated DGA versus epicentral distance. Apart from the closest station (which is at

near-source condition), the DGA and PGA values are well aligned (modified from Rastgoo et al., 2018)

7.10. Italy

The first NDSHA maps for Italy were published by Panza, Romanelli, and Vaccari in 2000. Subsequently, there were many earthquake “surprises” in Italy (as listed in Table 1), that not only *contradicted* but also *invalidated* the regulatory PSHA maps that were published in 2004 - and on which the current seismic code is based (e.g. Rugarli 2014).

Table 1 provides a detailed list of four significant earthquake-chapter “surprises” that *contradicted* the 2004 PSHA Map of Italy - after the 2000 NDSHA Map was published:

Table 1. List of Earthquake "Surprises" for the 2004 PSHA Map of Italy - After 2000 NDSHA Map

L'Aquila 2009 (6 April M 6.3; 309 victims) Occurred in a defined area with high seismic hazard, but the acceleration values observed exceed those foreseen by the anti-seismic code	Expected PGA (475 years) 0.250 - 0.275 g (map MPS04)	PGA observed: > 0.35 g
Emilia 2012 (20 May M 5.9; 29 May M 5.8; 17 victims) Occurred in a defined area with low seismic hazard, but the acceleration values observed exceed those foreseen by the anti-seismic code	Expected PGA (475 years) < 0.175 g (map MPS04)	PGA observed: > 0.25 g
Central Italy Earthquake Crisis 2016 (24 August M 6.0; 30 October M 6.5; 299 victims) Sequence occurred in a defined area with high seismic hazard, but the acceleration values observed exceed those foreseen by the anti-seismic code	Expected PGA (475 years) 0.250 - 0.275 g (map MPS04)	PGA observed: > 0.4 g value > 0.35 g in L'Aquila 2009
Ischia 2017 (21 August M 4.0 - 4.2; 2 victims)	Expected PGA (475 years) Bedrock D: 0.14-0.15 g (H), 0.0951 g (V) Soil B: 1.20D = 0.17- 0.18 g 1.0 D _v = 0.0951 g (Z) Soil C: 1.50D = 0.21- 0.23 g 1.0 D _v = 0.0951 g (Z) IOCA Station 40.7458 N; Long. 13.9008 E Sited on Soil B	IOCA Station PGA (observed) 0.280 g (E-W), 0.272 g (N-S), 0.192 g (Z) are > PSHA Map: Surprises for PSHA Map: Obs. (H) > 60% (Soil B) Obs. (H) > 30% (Soil C) Obs. (V) > 101% (Z)

NDSHA Map 2000 (for all events) computes values that include the observed ones. In example of the Ischia 2017 quake: [NDSHA] estimates values in the range [0.15-0.30g]; then when including the local site effects Soil B at Latitude 40.7458 and Longitude 13.9008, as determined by NTC08 (Norme tecniche - PSHA), NDSHA estimates [0.18-0.36g] - within which the observed value of 0.280g falls! If Soil C is assumed, the NDSHA range is then [0.23 - 0.45g]. More details in De Natale et al. (2019)
Surprise and Contradiction to the 2004 Map did befall! PSHA missed them all!

7.10.1. Emilia 2012

20 May 2012 - M 5.9; 29 May 2012 - M 5.8; PSHA PGA (475 years) < 0.175g.

In studying these two rapidly repeating sequential M 5.9 and 5.8 Emilia events, Tramelli et al. (2014) noted that: (a) quite similarly the "seismicity recorded in Italy in the last decades occurred frequently in sequences"; and (b) "on the other hand, the current practice of probabilistic seismic hazard analysis based on the Cornell approach assumes statistically independent seismic events"; and further cautioned that (c) "the occurrence of a consecutive seismic sequence may result in an enhanced PSA and Sd with respect to the values obtained for any single earthquake that composes the sequence," where PSA and Sd are response spectral values for acceleration and displacement.

Therefore, these same authors have strongly encouraged the earthquake engineering design community to more comprehensively consider design spectra which also take into account the occurrence of a *consecutive* sequence of earthquakes, at least for designing strategic structures, claiming that "a broader and modern approach (in line with the present knowledge of active faults locations, mechanisms, and interaction) would be more advantageous for seismic risk mitigation" - and they further implicitly encourage the more widespread use of NDSHA's methodology, since that is physically and systematically capable of addressing the endemic fundamental problems infecting PSHA, that they correctly have mentioned.

7.10.2. Central Italy

Norcia had been retrofitted after the Umbria-Marche Earthquake Crisis (a long sequence of moderate to strong earthquakes that began September 26, 1997.

<http://www.geo.mtu.edu/UPSeis/magnitude.html>
All earthquake damage reconstruction work used as a benchmark the PSHA map ("return

period" 475 yr.), on which the Italian building code seismic requirements were based.

Those maps, however, proved totally misrepresentative and erroneous upon the occurrence of the 30 October 2016 Mw 6.5 earthquake, where in Norcia the earthquake ground motion was much larger than what had been predicted previously by PSHA! The resulting damage was very large, corresponding to $I_{MCS} = IX$. Istituto Nazionale di Geofisica e Vulcanologia reports $I_{MCS} \approx VIII - IX$.

http://www.afs.enea.it/poggif/amatrice/docs/QUEST_rapporto_15nov.pdf. But it should be kept in mind that any Intensity Scale is defined by discrete integer values, thereby having unit-incremental-steps; and therefore, *intermediate* values are not defined (Grünthal 1998). On the NDSHA map, the hazard value indicated is slightly above the experienced ground motion generated by the 30 October 2016 earthquake. In all likelihood, if the reconstruction and retrofitting that followed the 1997 Umbria-Marche earthquake crisis would have been undertaken in due account of the NDSHA demand estimates, then the damage would have been much less (if not negligible), when compared with that actually observed after the 30 October 2016 M 6.5 event.

7.10.3. Italian Seismic Codes

To have simply and blindly followed PSHA designated design strength and detailing requirements for new buildings, while at the same time neglecting the fact that the Italian antiseismic code further provides:

L'uso di accelerogrammi generati mediante simulazione del meccanismo di sorgente e della propagazione è ammesso a condizione che siano adeguatamente giustificate le ipotesi relative alle caratteristiche sismogenetiche della sorgente e del mezzo di propagazione (NTC 2008 chapter 3.2.3.6).

The use of accelerograms generated simulating source mechanism and wave propagation is allowed provided the hypotheses about the seismogenic characteristics of the source and the properties along the pathway are duly justified.

Certainly allowed some (marginal) cost saving during the reconstruction and retrofitting following the 1997 events, when compared to the higher earthquake-resistant requirements indicated under NDSHA. Nonetheless, any apparent "savings" has been unrealized and ultimately seismologically frustrated by the 30 October 2016 Mw 6.5 earthquake - and now it is necessary to consider in the reconstruction and retrofitting the NDSHA values, which were so unwisely ignored after the 1997 earthquakes.

In the planning work performed by Cimellaro et al in both 2011 and 2015, a departure from the standard building code hazard assessment approach was found to be more advantageous. In the town of Calascibetta (Sicily), for example, the NDSHA scenario proposed by Panza et al. (2012) gives the value of the peak ground velocity in the range $PGV \approx 15 - 30$ cm/s. Following the alternative use of computed synthetic ground motions authorized under use of chapter 3.2.3.6 of NTC 2008 and NTC 2018 - the neo-deterministic approach has been preferred over the familiar and codified probabilistic seismic hazard analysis (per Cimellaro et al., 2015), because the latter provides non-conservative results (Panza, Kossobokov et al., 2014), when systematically applied to Urban Water Distribution Networks. Cimellaro et al. (2015) performed a comprehensive study about a new "Resilience Index" for urban water distribution networks, using therein the average NDSHA value of $PGV = 22.5$ cm/s and this value can be assumed *constant* over the entire water

distribution network, because of the network's limited extent.

7.10.4. Historic Napoli

Very recently Nunziata and Costanzo (2020), using local scale NDSHA procedures Rugarli et al. (2019a) modeled the ground motion at the historical center of Napoli for the 5 December 1456 and 5 June 1688 earthquakes - responsible for a maximum felt intensity VIII (MCS). The NDSHA propagation model is *validated* through the comparison of its computational synthetic signals with strong motion records obtained from within the historical center of Napoli, of a moderate earthquake on 29 December 2013 Mw 5.2, whose epicenter is close to the seismogenic fault responsible for the 1688 earthquake. Remarkable agreement exists between computed PGA and reported epicentral intensity values if the 1688 earthquake is modeled with: (i) magnitude $M_w = 7$, as reported in CPTI15 (2015) catalogue; (ii) normal fault sources striking 296° and 311° (i.e., either Calore river or Tammaro basin faults); and (iii) epicentral distance and focal depth varying in the range 45-62 km and 8-15 km, respectively. However, if the 5 December 1456 earthquake is modeled with the strike-slip fault source proposed by Fracassi and Valensise (2007), then the magnitude reported in CPTI15 2015 must be increased to at least M 7.3 - still, however, well within measurements error.

Keeping in mind the uncertainties of both the macroseismic intensities and the estimated magnitudes of these *historical* earthquakes, as well as the degraded conditions of the masonry heritage, the earthquake responsible for the highest ground motion parameters can necessarily be chosen for both the proper restoration and also future protection of the historical heritage of Napoli, whose historical center is also a UNESCO World Heritage site.

These NDSHA computational simulations, therefore, represent basic input data to be further considered in assessing the seismic response of these heritage buildings and to also further provide useful guidelines to improve building seismic resistance. Moreover, because it is not the "last" earthquake that should concern us, but rather the earthquake that comes after the next one - many now believe that it is both well validated and also scientifically justified to claim that NDSHA is not only a more reliable but also a ready alternative to the presently widespread use of PSHA.

7.10.5. *Reliable Seismic Hazard Assessment*

This is because NDSHA provides not only practical but also more realistic and Reliable Seismic Hazard Assessment (RSHA), particularly since PSHA's continued use has been so widely proven in the professional journals and publications to be a totally unjustified and unreliable procedure, i.e., a fabrication dependent upon magical realisms. (e.g. Saxe 1873; Krinitzky 1993a, b, c, 1995; 2003; Klügel 2008; PAGEOPH Topical Volume 168, 2011; Mualchin 2011; Wang and Cobb 2013; Klügel 2015; Mulargia et al., 2017; Stark, 2017).

A further implicit and important confirmation of the validity of considering NDSHA as a robust and effective *preventive* tool is given in the decadal updated Norme Tecniche per le Costruzioni 2018 (NTC 2018) that deepens and expands the concept contained in chapter 3.2.3.6 of (NTC 2008) as follows:

L'uso di storie temporali del moto del terreno generate mediante simulazione del meccanismo di sorgente e di propagazione è ammesso a condizione che siano adeguatamente giustificate le ipotesi relative alle caratteristiche sismo genetiche della

sorgente e del mezzo di propagazione e che, negli intervalli di periodo sopraindicati, l'ordinata spettrale media non presenti uno scarto in difetto superiore al 20% rispetto alla corrispondente componente dello spettro elastico.

The use of accelerograms generated simulating source mechanism and wave propagation is allowed provided the hypotheses about the seismogenic characteristics of the source and the properties along the pathway are duly justified and that, in the considered period justified and that, in the considered period intervals, the average spectral ordinate is not less than 20% of the corresponding component of the elastic spectrum.

(For more details see Rugarli 2018).

7.10.6. *Regione Emilia Romagna, Bologna*

The NDSHA computational synthetic ground motion procedure has been applied to many manufactured-goods situations as well as works of construction - both public and private, e.g. <http://www.studioaltin.com/work/> - and selected examples of engineering applications of NDSHA to strategic buildings and cultural heritage are shown in the following Figures 9-13. (see also VADEMECUM SVEB, 2015 - for the seismic verification of existing buildings).

The engineer Gian Carlo Giuliani, President of Redesco (Research-Design-Consulting) Progetti - <http://www.redesco.it/> - an internationally recognized consulting firm in Structural Engineering, in his message dated 26 October 2016, following publication of "Difendersi dal terremoto si può - L'approccio neo-deterministico" (Panza and Peresan, 2016), wrote about torre Regione Emilia Romagna in Bologna, shown in Fig. 9:



Figure 9. Bologna: torre Regione Emilia-Romagna

Caro Giuliano [Panza], ho preso nota di quanto tu e la dott. Peresan avete riportato nel vostro libro che corrisponde ai miei pensieri. Ho ordinato il volume perché è di sicuro interesse. Ti ricordo che, per il nostro

progetto della torre della Regione Emilia Romagna a Bologna, abbiamo utilizzato le tue previsioni sui possibili eventi sismici condensate in 6 accelerogrammi, derivanti da altrettante sorgenti sismogenetiche e quindi questa applicazione del NDSHA (anno 2001) dovrebbe essere aggiunta a quelle citate nel libro 'Difendersi dal terremoti si può - L'approccio neo-deterministico.'

Ad Majora! Gian Carlo

Dear Giuliano [Panza], I have taken note of how much what you and Dr. Peresan have reported upon in your book corresponds very much to my own thoughts. I ordered the volume because it is surely of interest. I remind you that, for our project of the tower of the Emilia Romagna Region Headquarters in Bologna, we used your predictions on possible seismic events, condensed in 6 accelerograms, and deriving from as many seismogenic sources; and therefore, this application of the NDSHA (year 2001) should be added to those already mentioned in the book 'Difendersi dal terremoti si può - L'approccio neo-deterministico.'

Ad Majora! Gian Carlo



Figure 10. University College Luciano Fonda - Trieste. Seismic verification made before the inauguration of the student college can be summarized as follows: NDSHA (0.16g) compatible with standard (475 yr) PSHA (0.12g) at bedrock



Figure 11. City Hall - Trieste. Built in an eclectic style between 1873 and 1875 on a project by the Trieste architect Giuseppe Bruni. The NDSHA study, supported by the municipality, has been performed in agreement with NTC 2008 and NTC 2018 chapter 3.2.3.6. <http://www.studioaltin.com/service/>



Figure 12. Marciana Library - Venice. The NDSHA study, performed in agreement with NTC 2008 and NTC 2018 chapter 3.2.3., has been supported by Segretariato Regionale of MIBACT. <https://www.veneto.beniculturali.it/prevenzione-sismica-area-veneta>



Figure 13. Prigioni by Michelangelo Buonarroti (Accademia Gallery, Florence); Prigione barbuto (bearded) on the left, Prigione Atlante (/Atlas) on the right. The stability test values, performed by non-linear kinematic analysis accordingly with the NDSHA approach, are satisfied for all the four statues in Accademia Gallery, while the stability tests carried out according to the standard PSHA approach values are not satisfied for the statues of the prigione barbuto and the prigione Atlante shown here. Therefore, in the Florence area, the use of PSHA hazard values leads to an overestimation of real hazard. (Negro et al., 2013)

7.11. Pakistan

The seismic hazard in both Pakistan and the adjoining regions has been assessed by Sarwar et al. (2018) using the Neo-Deterministic Seismic Hazard Assessment (NDSHA) approach. The peak Displacement D_{MAX} , peak Velocity V_{MAX} and Design Ground Acceleration (DGA) are extracted from synthetic signals generated from simulations of both source mechanism and wave propagation - thus duly justifying the seismogenic characteristics of the source and the physical properties interacting along the pathway.

The peak computational values have been plotted on a $0.2^\circ \times 0.2^\circ$ grid to construct the seismic hazard map of the study areas. The most severe hazard zone occurs within the epicentral area of the Mw 7.6 Muzaffarabad

earthquakes of 2005 in Kashmir, which regionally affected Pakistan, India and Afghanistan - where the DGA estimate falls within the range of 0.6 g - 1.2 g. The peak velocity and displacement within the same grid region are estimated as $V_{MAX} = 60-120$ cm/s and $D_{MAX} = 30-60$ cm. In the other regions of high seismicity, such as Islamabad, capital of Pakistan, and in Quetta (site of the deadly Mw 7.7 1935 earthquake), estimates of DGA values are as high as $DGA \approx 0.3$ g - 0.6 g. Similarly, the peak Velocity V_{MAX} and Displacement D_{MAX} are also high in these same earthquake-prone regions.

Since these estimated ground shaking values are definitely high for the existing infrastructure, they could result in great damage and huge socio-economic losses for the region, due to the high economic importance of these areas. This research and

the data it has produced have substantially enhanced our understanding of the seismic hazard from these repeating large major earthquakes in Pakistan and the adjoining regions, e.g., the M 7.6 Muzaffarabad and M 7.8 Awaran earthquakes of 2005 and 2013; and we believe it will be of great help to civil and earthquake engineers, whom (because of the region's very high seismic risk) we hope will be eager to launch future thorough and detailed studies of regional earthquake hazard.

7.12. Vietnam

In Vietnam's capital city of Hanoi, results of NDSHA synthetic seismograms generated from scenario-based seismic hazard analysis (Nguyen et al., 2000) show that the largest potential MM macroseismic intensity (I_{MM}) varies in a range between VI (I_{MM}) - IX (I_{MM}): (a) acceleration spectral ratios reach largest values in the frequency range from 1.0 - 3.0 Hz; and (b) the largest site amplification effects are observed in loose soils and for thick sediment areas.

The generation of synthetic seismograms from scenario-based seismic hazard analysis is particularly important in those earthquake areas that may be lacking a catalogue record of both strong and major earthquake events, and it further provides realistic magnitude-specific earthquake *input data* that is required for the prediction of nonlinear dynamic response of structures under the potential suite of future earthquakes (Romanelli et al., 2013).

Therefore, the timely development of a set of synthetic seismograms, both in the NDSHA and NDSHA-MCSI approximations, for the prediction of seismic response of structures in Vietnam (beginning with the more strategic ones), can be a productive future research effort, both reliably and effectively oriented towards *prevention*. In achieving this important goal, the pioneering work by: Cao et al. (2008b); Nguyen et al. (2008); Tuyen et al. (2012; 2018); Bisignano

et al. (2011); Romanelli et al. (2012) - all represents not only a major contribution, but also a *feasibility study* for future international cooperation!

8. Time-dependent earthquake hazard

Although damaging earthquakes cannot yet be predicted with ultimate precision and accuracy, *intermediate-term* (several months) and *middle-range* (few 100s km scale) predictions of main shocks above a pre-assigned threshold - based on seismicity "alarms" generated by interpretive 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.

Progressive reduction of the prediction uncertainty in both space-and-time is an ongoing and challenging task. Towards this aim, algorithms (like CN, M8 and M8S) based on objective recognition of seismicity patterns have been tested (already now for some decades) for: - *intermediate-term* - *middle-range* - prediction of strong earthquakes above a pre-assigned magnitude threshold (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-narrow-range* - earthquake prediction. The extent of the alarmed areas, identified 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.

Therefore, then, a new paradigm is defined for *time-dependent* hazard scenarios, based on the results of - intermediate-term - narrow-range - earthquake prediction (Panza, 2019). In this precautionary framework, GPS data are systematically used to reconstruct the station velocities and strain patterns along *pre-selected* transects, which are properly oriented according to information about the known tectonic setting. The goal then (and plan now presently in progress), is: (a) to generalize and apply the “seismo-geodetic” analysis to the Italian territory and, consistently with the availability of reliable data; (b) to supply the identification of relatively narrow areas where we would expect the occurrence of a strong earthquake within a specified time-interval, as indicated by Algorithms CN, M8 and M8S.

Some work has already been done so far in Vietnam regarding time-dependent hazard scenarios, as summarized in the paper by Cao et al. (2008a) that is echoing earlier works by Kossobokov in (2003) and (2004). Cao’s work, along with this and the results mentioned previously in the section 7. Case studies: Cao et al. (2008b); Nguyen et al. (2008); Tuyen et al. (2012, 2018); Bisignano et al. (2011); Romanelli et al. (2012) - together represent a feasibility study for a project that could be immediately begun in Vietnam, within the framework of international cooperation, like the joint project cooperation presently in progress in China under “Application research of the neo-deterministic seismic risk assessment (NDSHA) method in China Seismic Experimental Site” -

<http://www.ief.ac.cn/ylaw/index.html> -

which is part of “China Seismic Experimental Site - Natural” - *laboratory of earthquake science for seismic disaster resilience*. Exchange and Collaboration:

<http://www.ief.ac.cn/home/index.html>

9. Discussion and Conclusion

“Errors are not in the art but in the artificers”

- Issac Newton

Our world-wide experiences (expressed in terms of *unacceptable* losses) of now more than half-a-century of equating earthquake risk models with earthquake hazard (or likelihood of an earthquake) have proven unreliable and prompted the development of data driven hazard estimation to replace model driven PSHA.

Building upon the familiarity and long experience of successful practice with Deterministic Seismic Hazard Assessment, NDSHA, a robust and intrinsically data driven evaluation, now convolves a comprehensive physical knowledge of: (i) the seismic source process; (ii) the propagation of earthquake waves; and (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 spacial 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 estimated magnitude M_{max} (plus some multiple of its accepted global standard deviation σ_M). NDSHA is a data driven assessment, since it 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. Therefore, it provides both robust and safely conservative hazard estimates for engineering design and mitigation decision strategies. Importantly, these are broadly and systematically accomplished without invoking the *chimeric* (illusory) and physically rootless Hazard Curve: “annual frequency of

earthquakes” and “earthquake return period” - generally depicted as a “475 yr. earthquake” or the more rare “2475 yr. earthquake.”

The validity of NDSHA estimates of the last 20 years and the description of the perspective and planned activity is documented in the section 7. Case studies. A series of papers that reviews and updates the NDSHA research and the results obtained so far in Africa, America, Asia and Europe – now provides a collection of evidences that hopefully will induce responsible people and authorities to consider more reliable procedures for SHA evaluation like NDSHA - and is the topic of the forthcoming book “Earthquakes and Sustainable Infrastructure: neodeterministic (NDSHA) approach guarantees prevention rather than cure”. Edited by Panza G., Kossobokov V., Laor E. and De Vivo B. for Elsevier (2021 in press).

10. Nomenclature

CE Characteristic Earthquake introduced to artificially justify the frequent exceptions to the log-linear GR law observed when considering study areas of limited extension.

CN Intermediate-term (several months) and middle-range (few 100s km scale) interpretive algorithm to be used for the implementation of low-key preventive safety actions.

DGA Design Ground Acceleration.

GPS / GNSS Global Positioning System / Global Navigation Satellite System.

GR Gutenberg-Richter relation - valid as a log-linear law only at global scale.

I_{EMS} European Macroseismic Intensity Scale issued in 1998

European macroseismic scale

https://en.wikipedia.org/wiki/European_macroseismic_scale.

I_{MAX} Maximum observed macroseismic intensity - as a rule coincident with epicentral macroseismic intensity.

I_{MCS} Macroseismic Intensity Scale as defined by Mercalli, Cancani and Sieberg; also indicated $I(MCS)$.

I_{MM} Modified Mercalli Macroseismic Intensity Scale - see also MM.

M Magnitude.

M Magnitude Threshold - lower magnitude bound for seismogenic nodes

M8 Intermediate-Term (several mos.) and Middle-Range (few 100s km scale) interpretive algorithm to be used for the implementation of low-key preventive safety actions.

m_b body waves magnitude.

MCE Maximum Credible Earthquake.

M_{design} Cellular Magnitude at a given site tentatively set equal to the maximum observed or estimated earthquake magnitude M_{max} + some multiple of its accepted global standard deviation σ_M | $M_{design} = M_{max} + \gamma_{EM} \cdot \sigma_M$.

MIBACT Ministero per i Beni e le Attività Culturali e per il Turismo, Italy.

MM Modified Mercalli Intensity scale (Wood and Neumann, 1931).

M_{max} Maximum Observed or Estimated Earthquake Magnitude.

Ms Surface Waves Magnitude.

MSZ Morphostructural Zonation.

Mw Magnitude derived from Seismic Moment M_0 acting at the fault.

NDSHA Neo-Deterministic Seismic Hazard Assessment.

NDSHA-MCSI (or more simply MCSI) NDSHA Maximum Credible Seismic Input - can be defined (both at bedrock and considering site specific characteristics) as RS; or as a set of Accelerograms .

P "Annual Probability of Exceedance".

PGA Peak Ground Acceleration.

PGD Peak Ground Displacement.

PGV Peak Ground Velocity.

PSA Pseudospectral Acceleration.

PSHA Probabilistic Seismic Hazard Analysis /Assessment.

RS Response Spectrum.

SA Spectral Acceleration.

Sd Spectral displacement.

SHA Seismic Hazard Assessment.

Vs30 Average Seismic Shear-Wave

Velocity from the surface to a depth of 30 meters.

γ_{EM} Tunable Safety Factor related to the partial factor γ_q ; in standard practice for the so-called “ultimate limit states”, and for typical actions like those of wind or snow, $\gamma_q = 1.5$. See M_{design} above.

γ_q Currently accepted Safety Factor (Eurocode Paradigm), in order to get the design value for variable actions, applied to the characteristic value of an action Q_k , so that the design value applied for the action is $Q_d = \gamma_q Q_k$.

σ_M Standard Deviation of Magnitude at global scale.

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