On the geological hazards that threaten existing and proposed reclamations of Manila Bay

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The Philippine Reclamation Authority (2011) has identified 102 near-shore reclamation projects covering 38, 272 hectares in Luzon, Visayas and Mindanao. Of these, 38 projects with an aggregate area of 26,234 hectares are intended to reclaim virtually the entire near-shore zone of Manila Bay (Figure 1). The ongoing rush to execute several of these projects is alarming in how little its proponents seem to understand the littoral environment, and their seeming indifference to the hazards it poses.

Many of the issues that will be raised here have been presented to the general public in a Philippine Star article (Rodolfo 2013a). Subsequently, these arguments were presented with detailed scientific documentation (Rodolfo 2013b) as written testimony at a Public Hearing held on 18 November 2013 regarding a peninsula of three closely linked islands, collectively called Manila Solar City, proposed by Manila Goldcoast Development Corporation. Originally scheduled to be held at the DENR compound in Quezon City, the Hearing was instead held in Binondo, Metro Manila. It was poorly covered by the media, which were not informed of that change in venue, one of several strange circumstances.

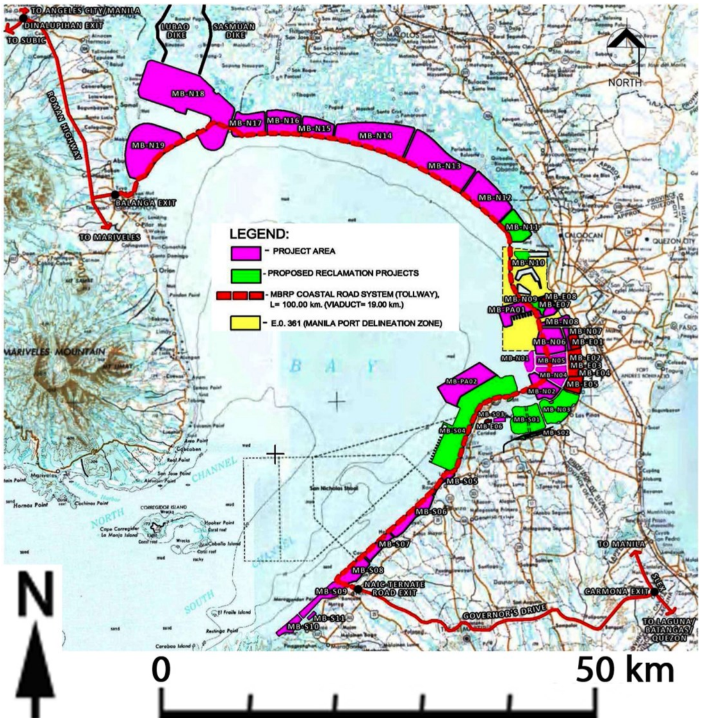

Figure 1. The Manila Bay sector of the National Reclamation Plan. From Philippine Reclamation Authority (2011).

The document to be discussed at the hearing was called an Environmental Impact Statement (EIS) by Technotrix Consultancy Services (2013), which had prepared it on behalf of the project proponent. Interestingly, the announcement of the hearing by the Department of Environment and Natural Resources (DENR) (2013) had characterized the report as an Environmental Impact Assessment (EIA), but EIS and EIA are significantly different, EIS being much more stringent. The hearing officer was not a DENR representative; he was a consultant hired by Goldcoast. The Table of Contents of the “EIS” provided to the public listed sections on subsidence and liquefaction, but the

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actual pages for these sections were missing. Also missing were the figures that were supposed to show ground acceleration in soft and medium soils. Subsidence, liquefaction and seismic ground acceleration are critical hazard factors.

These issues are worrisome examples of lax adherence to due diligence. It is not the purpose of a scientific article to deal with matters under the purview of governmental procedures, but if a thorough evaluation of the physical environment into which the project situates itself is not performed, its hazards threaten many people, as well as its own very existence. And if shortcomings are pointed out and corrective measures are taken, criticism will have served its rightful purpose.

The Solar City project raises specific examples of the reasons why the entire idea of reclamation is wrong, but the objections we will explore here apply as well to any other segment of the bay-shore being considered for reclamation. Three geological reasons make near-shore reclamation a very bad idea that poses lethal risks to many people: land subsidence, storm surges, and earthquake-induced enhanced ground shaking and liquefaction.

Land subsidence

Continuing rapid and accelerating subsidence of the coastal lands bordering the bay is worsening both floods and high-tide invasions. Global warming has raised sea level by about 3 mm/y from 1993-2009, while the seas surrounding the Philippines rose between 7 and 9 mm/y due mainly to unequal heating of the ocean (from data presented by Nicholls and Cazenave (2010)). Philippine authorities now generally accept this rise and worry that it must be aggravating Metro Manila flooding, but have difficulty accepting that over-pumping of groundwater is causing Metro Manila to subside one or two orders of magnitude faster (Figure 2).

The coastal plains surrounding northern Manila Bay are underlain by sediment columns many hundreds of meters thick, mainly river-delta muds with lesser layers of sand and gravel. Under natural conditions, such sediments ‘autocompact’ as they accumulate; the weight of new deposits over each mud layer squeezes water out of it and compresses it. Accordingly, the land surface subsides a few millimeters per year (Soria et al. 2005), at rates only of the magnitude of global sea-level rise. Subsidence from groundwater overuse, however, is much more rapid.

How excess use of groundwater causes land subsidence has long been well understood (Galloway et al. 2001). Groundwater is stored in and recovered from sandy and gravelly *aquifer* (‘water bearer’) layers sandwiched between *aquitards,* clayey layers that are much more porous and contain significantly more water. Grains of aquitard clay, being microscopic, have much collective surface that presents high frictional resistance which *retards* the through-flow of water (whence *aquitard*). Deltaic sediment columns are supported in part by pore-water fluid pressure. Extracting water from an aquifer transfers support to its framework of sediment grains, which is somewhat compressed, commonly causing the ground to subside a little. If extraction is not excessive, the compression and subsidence may be fully reversed when precipitation recharges the aquifer. When an aquifer is exploited excessively, however, its fluid pressure is reduced below that in the adjacent aquitards, from which it sucks water, reducing its volume and thickness. Importantly, this reduction and the resulting loss of surface elevation are permanent.

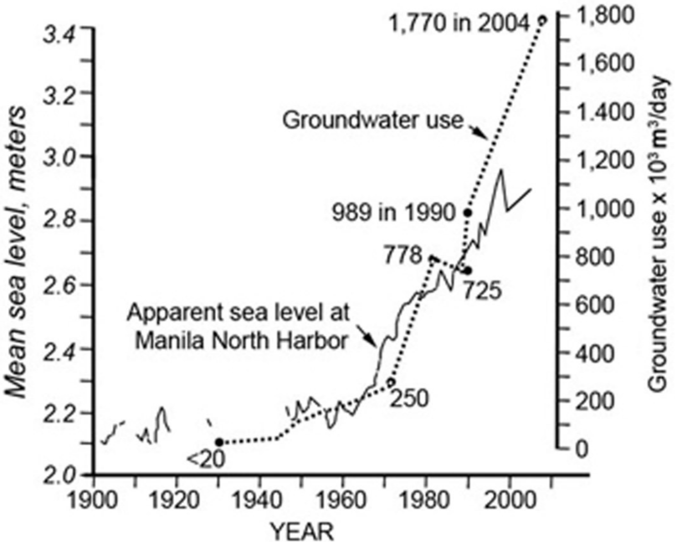


Figure 2. Groundwater withdrawal in the Manila region (discontinuous solid curve) accelerated in in the 1960s and was accompanied by land subsidence (dotted curve) that is an order of magnitude faster than sea level rise from global warming. Modified from Rodolfo and Siringan (2006).

We have documented that Metro Manila’s coastal areas are sinking as fast as 9 cm/y (Rodolfo et al. 2003, Siringan and Rodolfo 2003, Rodolfo and Siringan 2006). Subsequently, the Volcano-Tectonics Laboratory at U.P Diliman’s National Institute of Geological Sciences (Lagmay 2011, Eco et al. 2013) has analyzed Persistent Scatterer Interferometric Synthetic Aperture Radar data from satellites to verify subsidence over wide areas of Metro Manila, with the proposed reclamation areas experiencing up to 6 cm/y (Figure 3). Caloocan, an industrial area that uses large volumes of groundwater, subsided 8 cm/y in 2004 and 2005. Similarly, a French group that employed space-borne Differential Interferometric Synthetic Aperture Radar (DInSAR) has reported as much as 15 cm/y of localized subsidence in Metro Manila (Raucoules et al. 2013).

The Department of Public Works and Highways has long ignored or minimized the problem of land subsidence in planning their expensive but ineffective flood-control projects (Rodolfo and Siringan 2006). It would not be surprising if reclamation planners also ignore subsidence to minimize costs and maximize profits, but thereby enhance the risks. Furthermore, the increased pressure from the weight of new buildings in re-

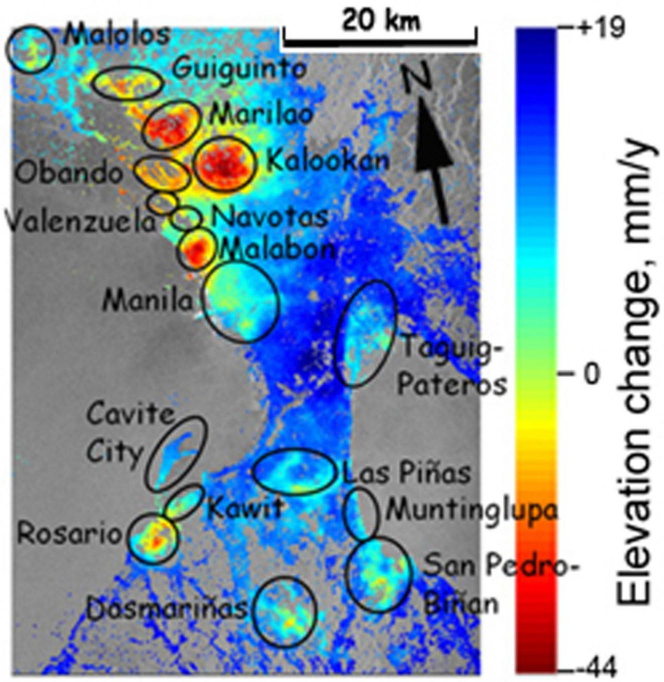


Figure 3. Manila Bay subsidence in mm/y from 2003 to2006, as determined from satellite-borne Permanent Scatterer Interferometric Synthetic-Aperture Radar (PSInSAR). From Lagmay (2011) and Eco et al. (2013).

claimed areas can also be expected to speed up the compression of the substrate and the resulting subsidence, as is occurring in Shanghai (Zhang et al. 2002), where Damoah-Afari et al. (2010) have estimated that this artificial loading contributed 30 to 40 percent of the subsidence that exceeded a meter from 2000 to 2010.

Land subsidence, lowering the surface closer to sea level, delays runoff from rains and enhances both flooding and tidal incursions. The lowered land also becomes increasingly threatened by our second hazard, the storm surges that have often inundated coastal Manila Bay in the past, as recently as 2011during Typhoon Pedring.

Typhoon-generated surges and waves

Powerful but complex, storm surges (Bode and Hardy 1997, Hubbert and McInnes 1999, U. S. National Hurricane Center 2012) are becoming increasingly strong and more frequent as our climate changes. They are still poorly recognized hazards, not understood even by people who should, as exemplified by the Goldcoast project EIA/EIS (Technotrix Consultancy Services 2013 p. 2.2-24, p. 3-10), which erroneously treats surges as regular storm waves.

In January 2013, at the behest of President Aquino, Project Noah submitted a research proposal to DOST to develop a system to identify, quantify and map the storm surge threat to Philippine coasts (Malano et al. 2013). Approved in May 2013 and funded the following July, it describes storm surges in detail. Excerpting from that document:

"The National Hurricane Center of the United States defines *storm surge* as water height above predicted astronomical tide level, and *storm tide* as water height above mean sea level. Storm surges are oscillations of the coastal water level from forcing from the atmospheric weather systems that range in period from a few minutes to a few days. This definition excludes normal wind-generated waves and swell, which have typical periods of only several seconds.

"Storm surges normally occur when water is raised by strong landward winds as hurricanes or typhoons move toward the coast. A secondary cause that may account for 5 percent of the rise is the low pressure at the typhoon eye, enabling the ocean surface there to stand higher than the surrounding areas. Depending upon the shape of the coastline and slope of the sea floor and adjacent coastal plains, storm surges can inundate the coastline and extend several kilometers inland. Usually, the maximum height of the storm surge occurs near the point of landfall of a typhoon or a storm. In areas where there is a significant difference between high and low tide, storm surges are particularly damaging when they occur at the time of a high tide. This increases the difficulty of predicting the magnitude of a storm surge because it requires weather forecasts to be accurate to within a few hours.

"Nearshore bathymetry also influences the heights of storm surges. If it is shallow, there is no space for deeper water currents to carry away excess water, which must accumulate against the coast. Thus, Manila Bay and other bays and gulfs, particularly those with large river deltas, can be expected to experience larger surges than shorelines adjacent to open ocean or steeper continental shelves such as those off the east coasts of the Philippines. Flat or gently sloping land almost invariably meets gently sloping near-shore seafloors, maximizing the extent and intensity of inundation from storm-surge runout."

The Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA) has gathered anecdotal reports of typhoon surges up to 4 m high affecting the coastal areas targeted for reclamation (Figure 4). Depending on how long the typhoon winds last, and the timing and heights of the normal tides, a storm surge and the flooding it causes can last from hours to days.

The havoc that storm surges wreak is magnified by huge waves that ride atop them. Videos of Typhoon Pedring's storm surge and gigantic waves pounding Roxas Boulevard into rubble on September 27, 2011 are very instructive. These are available on the internet at youtube.com/watch?v=KVqOVR9lytk and youtube.com/watch?v=UlhncBQE8-A.

Viewers are not really watching storm surges; after all, a single surge typically takes hours and even days to occur. The

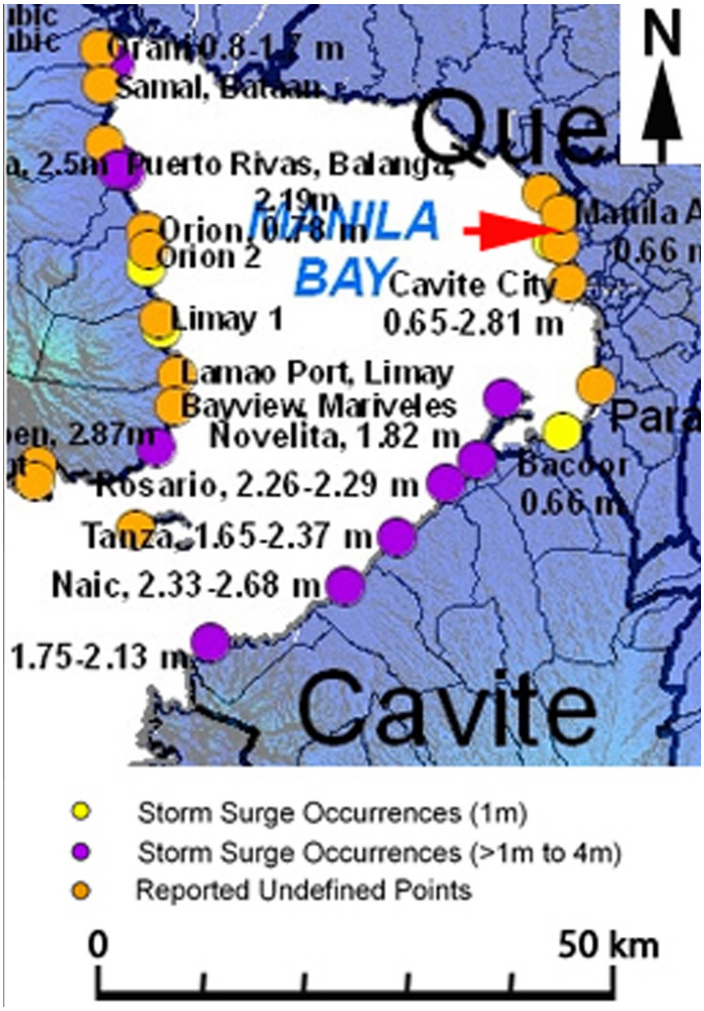


Figure 4. Manila Bay portion of the PAGASA compilation of historical storm surges. Red arrow indicates Goldcoast site. Surges in the vicinity are “undefined” but include where typhoons Patsy in 1970 and Ora parked seagoing ships on Roxas Boulevard.

storm surge propagated across Tacloban by Typhoon Yolanda in November 2013 was unusual not only in its strength, but also in its short duration of only about an hour because of the exceptional speed with which the typhoon travelled. In the case of the Pedring surge, Project Noah has determined that it was only 1.8 m high and lasted about 36 hours. During the short periods of the footages, the surge has already raised the water level and is flooding inland, but it does not change in height while we watch. What excites our awe are the gigantic storm waves riding atop the surge, following each other every several seconds, smashing against the breakwater and sending huge plumes up higher than the tallest coconut trees along the boulevard.

Storm waves are one of Nature’s most destructive forces. No one has said it better than Captain D. D. Gaillard of the U.S Army Corps of Engineers more than a century ago (1904, p. 124-125):

“No other force of equal intensity so severely tries every part of the structure against which is exerted, and so unerringly each weak place or faulty detail of construction.

“The reason for this is found in the diversity of ways in which the wave may be exerted or transmitted; for example: (1) The force may be a static pressure due to the head of a column of water; or (2) it may result from the kinetic effect of rapidly moving particles of the fluid; or (3) from the impact of a body floating upon the surface of the water and hurled by the wave against the structure; or (4) the rapid subsidence of the mass of water thrown against a structure may produce a partial vacuum, causing sudden pressures to be exerted from within.

“These effects may be transmitted through joints or cracks in the structure itself; (a) by hydraulic pressure, or (b) by pneumatic pressure, or by a combination of the two; or (c) the shocks or vibrations produced by the impact of the waves may be transmitted by means of the materials of which the structure is composed.”

We do not have sufficient wave data with which to design appropriate shoreline defenses, without which they should not even be considered at all. It is simply not possible to defend them successfully from forces that are not thoroughly understood. The U.S. Navy, with its fleets worth many billions of dollars at stake, is the organization most dedicated to studying Manila Bay as a possible haven during typhoons. Its U. S. Naval Research Laboratory (2012) reported that “Quantitative information on wave height data for Manila Harbor or Manila Bay is not readily available.” It could only report a few anecdotal data: that winds from the north-northwest funneled through the Central Valley can generate 3 m waves, and that a U.S. Navy evaluation team reported waves 3-5 m high in Manila Bay in Feb 2012. This was most likely related to an unnamed tropical depression that lasted from February 17-20, with maximum winds of only 55 km/h.

A set of empirical equations and a Sverdrup-Munk-Bretschneider nomogram derived from them (Figure 5) are somewhat dated, but still yield good first-approximation forecasts as well as “hindcasts” of wave heights – and therefore their energies (Hale and Greenwood 1980, Sadeghi 2008). They combine the three main, common-sense factors that determine how high a wave can grow under the wind: the wind speed, its duration (how long it blows), and its “fetch” -- how far the wind blows over the ocean surface to make the waves. The nomogram tells us that a 200 km/h wind blowing across Manila Bay from the southwest would propel waves more than 5 m high against the bay-shore in only three hours. These waves would be riding atop any storm surge generated by the winds and tides. Little surprise, then, that storm surges and waves lifted large ocean-going freighters and parked them on Roxas Boulevard during Typhoon Patsy in 1970 and Typhoon Ora in 1972 (Brand and Blelloch 1976) (Figure 6).

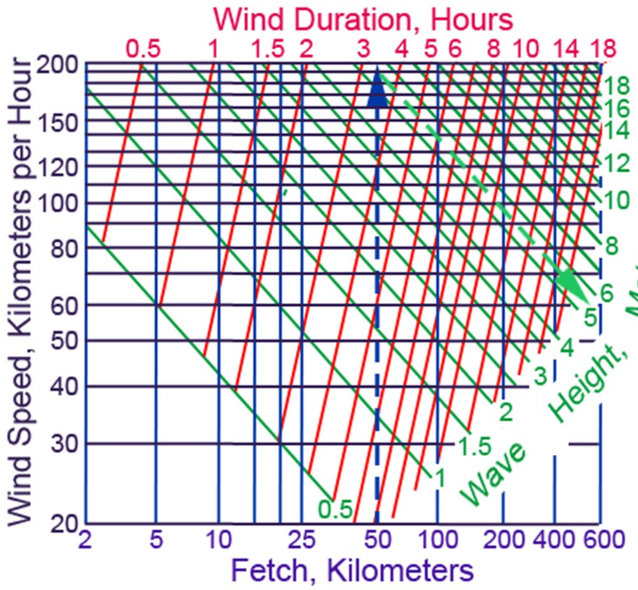


Figure 5. A Munk-Sverdrup-Bretschneider nomogram estimates that a 200-kilometer southwest wind blowing 50 kilometers across Manila Bay for 3.5 hours would generate waves 5.6 meters high (about 18 feet). These waves would ride atop any storm surge being generated by the wind and tide.

Storm surges and climate change

One of the most troubling aspects of the Goldcoast "EIS" (Technotrix Consultancy Services 2013 p 1-19 to 1-21 and 2.3-1, 2.3-5) is that it limits its treatment of the implications of climate change to temperatures and rainfall data. It mentions "extreme events" only in the context of rainfall and flooding. It says nothing about possible changes in the frequency and strength of typhoons, and the surges and storm waves they generate. These are the most powerful forces that Nature impels against coasts and man-made structures, exceeded only by earthquake-generated tsunamis, ground shaking and liquefaction.

Chang and Fu (2002, p. 642) reported that "…there appears to be a transition during the early 1970s from a weak storm track state prior to 1972/73 to a strong storm track state subsequently. Decadal mean storm track intensity during the 1990s is about 30% stronger than that during the late 1960s and early 1970s." The trend has continued and appears to be accelerating; Webster et al. (2005) have argued convincingly that weaker typhoons - those of Categories 1, 2 and 3 - have not been increasing in frequency, but the strongest ones, those of Categories 4 and 5, have increased from 16 or 17 percent in 1970-1974 to about 35 percent in the period 2000-2004. Emanuel (2005) has reported that western North Pacific typhoons have increased the power they dissipated from 1949 to 3003 by about 75 percent. This is not only because typhoons are more frequent; they became both more intense and longer lasting. Furthermore, annual average storm peak wind speeds over both the North Atlantic and North Pacific have also doubled. Emanuel et al. (2008) reiterated these findings for the northwest Pacific and Elsner et al. (2008) reported similar results for the period 1981-2006.

Certainly, the sequence of Ruping (Mike), November 1990; Uring (Thelma), November 1991; Kadiang (Flo), October 1993; Rosing (Angela), November 1995; Loleng (Babs), October 1998; Winnie, November 2004; Reming (Durian), November 2006; Frank (Fengshen), June 2008; Ondoy (Ketsana), September 2009; Pepeng (Parma), October 2009; Juan (Megi), October 2010; Pedring (Nesat), September 2011; Washi (Sendong), 2011; Pablo (Bopha), 2012; and Yolanda (Haiyan), 2013 gives Filipinos the strong impression that typhoons are increasing both in strength and in frequency.

Many of these notable storms wreaked much of their death and damage by driving seawater against the shores into broad, high surges that flooded far inland - much like tsunamis, but lasting much longer, flooding and sweeping away everything in their paths. On 7 November 2103, Super Typhoon Yolanda (Haiyan) tragically and emphatically continued the trend of increasing typhoon strength by devastating the Visayas. Again, one of the typhoon's main tools of destruction was the storm surge. Much of Tacloban was obliterated by surges reported as 5 m high, with storm waves riding atop them. The Goldcoast proposal specifies no adequate way to defend itself against today's typhoon surges and storm waves, much less those of the future.

Reclamation proponents and opponents alike should know that the US Navy has not regarded Manila Bay as a safe refuge from typhoons for over three decades. Quoting Brand and Blelloch (1976): "Manila Bay has had a reputation for sheltering sailing vessels from the seas of tropical cyclones since its discovery by early sailors. However, the effects of typhoon Patsy in November 1970 and typhoon Ora in 1972 have irreparably damaged that reputation… During Patsy, which passed over Manila, high winds and seas sank 21 fishing boats near the North Harbor. Larger vessels dragged anchor or broke loose. Six of them were driven aground or smashed against Roxas Boulevard. Ora repeated this tragedy [two] years later when another six oceangoing were swept into the breakwater…" (Figure 6).

Figure 6. Ocean-going ship lifted and stranded on Roxas Boulevard by Typhoon Ora, 1972 (Brand and Blelloch 1976).

Goldcoast's islands are fundamentally unsound

Another instance of the lack of awareness of basic marine geology is the "Solar City" project: three islands that together comprise a peninsula. Any geology student knows that building a peninsula is asking for trouble, because wave refraction works unceasingly to render shorelines straight (Figure 7).

A wave far enough offshore, running in water too deep for the wave to be experiencing friction with the sea floor, will tend to be reasonably straight and regular in shape (Figure 7A). The height of the wave is what governs its energy. Thus, every unit width W, or parcel, of the wave contains the same amount of energy.

As every wave moves shoreward, it eventually must enter water shallow enough for it to experience friction with the seafloor, which begins to slow it down (Figure 7B). If it approaches a crooked shoreline, the part approaching a headland will reach shallow water first and slow down, while the parts approaching bay shores continue undeterred for a while before they, too, begin to feel bottom and slow.

The result is increased shoreward bending or *refraction* of the wave. Thus, every parcel W that reaches a bay shore will have been stretched out, diminished in height and weakened before it breaks. But parcels reaching a headland have been shortened and their energies have been concentrated to attack a narrower piece of shore. This is why headlands are eroded back by concentrated wave energy. The sediment produced is transported by longshore currents into the gentler water at bay shores, where it is deposited. Left to her own devices, Nature eventually makes a straight shoreline consisting of eroded headlands and filled bays (Figure 7C).

Now imagine replacing the natural headland with an artificial peninsula (Figure 7D). Goldcoast proposes to challenge Nature, to change the shoreline by jutting out into the sea with an artificial erection that refraction-focused waves will immediately begin to attack.

The earthquake hazards: Ground shaking and liquefaction

Seismologists have known for a long time that ground motions during earthquakes are amplified in bay mud and artificially reclaimed sites (Aki 1993). In the San Francisco and Oakland areas of California, observed differences in horizontal acceleration between sites underlain by hard rock or by bay mud and artificial fill were 100-200 percent (Earthquake Engineering Research Institute 1990).

Coastal areas, whether underlain by natural deposits like those of the Pasig river delta or artificial reclamations, also experience seismically-induced *liquefaction*. This is true for California's Bay area as well as Manila Bay. An article by Seed et al. (2003) is an excellent state-of-then-art exploration of the phe-

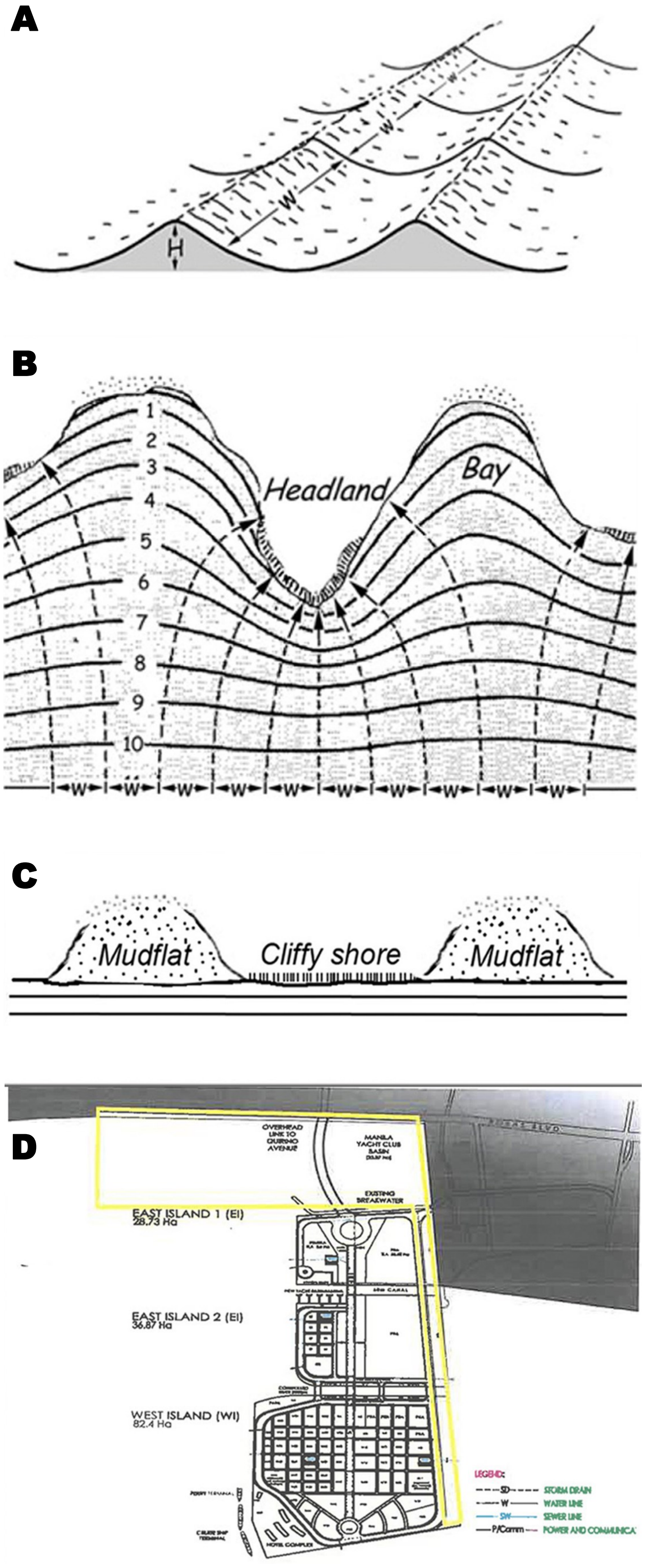


Figure 7. Nature works ceaselessly to straighten shorelines. See text.

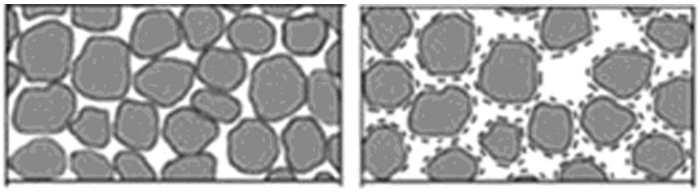


Figure 8. Left: Under normal conditions, grains of sediment rest on top of each other, and the spaces between them are filled with water. **Right:** Shaking during earthquake prevents grains from resting top of each other. The shaking mixture of sediment and water behaves as a "slurry" like freshly mixed concrete, a liquid without strength. Buildings on the sediment sink or topple.

nomenon. All bay-fill materials, natural or man-made, are made up of pieces of rock ranging in size from tiny particles of clay to large boulders, the spaces between them occupied by water. Under normal conditions, the solid particles are in contact, so that the lower ones bear the weight of other grains above them, as well as the weights of any buildings on top of them. During the minute or so that an earthquake lasts, however, the shaking breaks the contact between grains. Together, the solids and water behave as a liquid without strength (Figure 8). Buildings sink into it or topple.

When our Philippine Institute of Volcanology and Seismology (Phivolcs) team surveyed and assessed the damage to Dagupan City in 1990, we were struck by the fact that at many gasoline stations, underground storage tanks had popped up and were sitting on broken concrete floors. Gasoline tanks full of gasoline are much less dense than water-saturated sediment, and so during liquefaction, the tanks floated up so strongly that they forcibly broke their way through the concrete up to the surface. There is a lesson for the Goldcoast project in this.

Page 1-34 of Technotrix Consultancy Services (2013) states that the Goldcoast reclamation will be contained by vertical walls of sheet-steel piles driven into the bay-floor. The integrity of that containment would be crucial to the survival of the reclamation during an earthquake. But, as that document admits, the area is underlain by unconsolidated sediments that extend down far below the proposed reclamation depth. It is therefore very possible that liquefaction during an earthquake would cause the heavy steel pilings to sink deeply into the bay floor, leaving the reclamation without its containment.

In 2004, the Japan International Cooperation Agency, the Manila Metropolitan Agency and the Philippine Institute of Volcanology and Seismology reported that Metro Manila is overdue for a magnitude 7.2 earthquake (Japan International Cooperation Agency et al. 2004). In each of the three most likely settings for that earthquake (Figure 9), the greatest damage would be to the shore areas being planned for reclamation, because ground shaking and the likelihood of liquefaction are enhanced in unconsolidated or partly consolidated sediment. Very simply, if the fault were generated at the West Valley Fault (Model 8), the project area would experience intensities within the lower limits of Intensity 9 on the Phivolcs Earthquake Intensity Scale (PEIS) (Philippine Institute of Volcanology and Seismology 2008):

"Devastating - People are forcibly thrown to ground. Many cry and shake with fear. Most buildings are totally damaged. Bridges and elevated concrete structures are toppled or destroyed. Numerous utility posts, towers and monument are tilted, toppled or broken. Water sewer pipes are bent, twisted or broken. Landslides and liquefaction with lateral spreadings and sandboils are widespread. The ground is distorted into undulations. Trees are shaken very violently with some toppled or broken. Boulders are commonly thrown out. River water splashes violently or slops over dikes and banks."

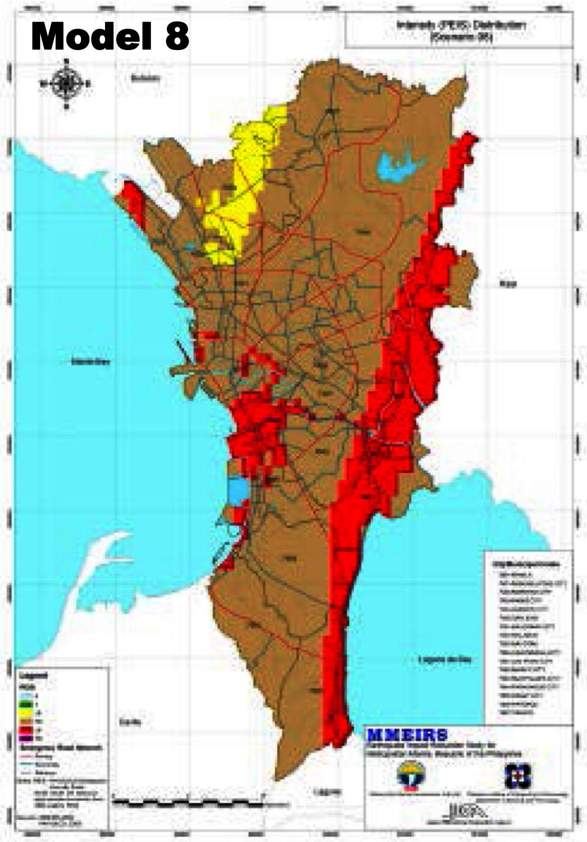
The anticipated intensities for an earthquake generated at the Manila Trench (Model 13) are the mildest, in the **lower** range of PEIS Intensity 8:

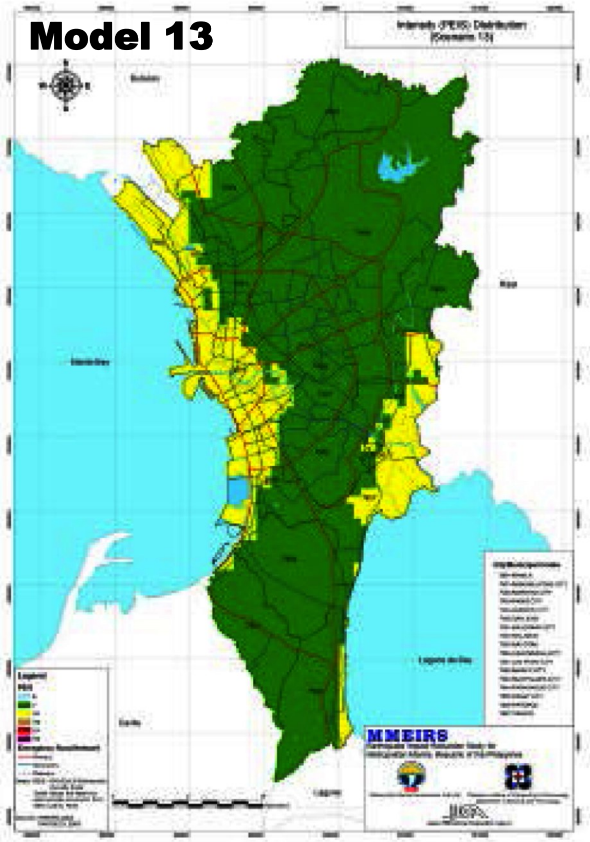
"Very Destructive - People panicky. People find it difficult to stand even outdoors. Many well-built buildings are considerably damaged. Concrete dikes and foundation of bridges are destroyed by ground settling or toppling. Railway tracks are bent or broken. Tombstones may be displaced, twisted or overturned. Utility posts, towers and monuments may tilt or topple. Water and sewer pipes may be bent, twisted or broken. Liquefaction and lateral spreading cause man-made structure to sink, tilt or topple. Numerous landslides and rockfalls occur in mountainous and hilly areas. Boulders are thrown out from their positions particularly near the epicenter. Fissures and fault rupture may be observed. Trees are violently shaken. Water splash or slop over dikes or banks of rivers."

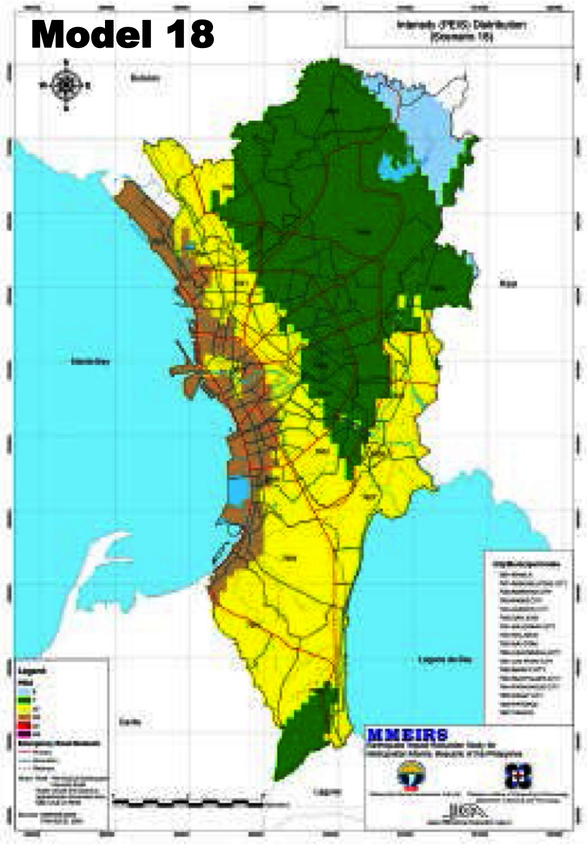
The third scenario (Model 19) is a hypothetical recurrence of the Magnitude 6.5 earthquake in Manila Bay in June 1863. Predicted intensities are in the higher range of Intensity 8. The intensities ascribed to these three most probable scenarios alone should categorically prohibit any reclamation in Manila Bay.

It is important to realize that reclaimed areas in Manila Bay would not require an earthquake to occur nearby to suffer serious damage (Figure 10A). In 1968, Manila was hard hit by a magnitude 7.3 earthquake in Casiguran, Quezon**,** 225 km away (Su 1969, Osome et al. 1969). Many structures that were built on river deposits near the mouth of the Pasig River in Manila were destroyed. The six-story Ruby Tower in Binondo collapsed from amplified ground shaking, liquefaction, or both, killing 260 people.

We also must be mindful of the lessons taught by the great Ms 8 Luzon earthquake of 1990 (Figures 10B, 10C, and 10D). Its epicenter was at Rizal, Nueva Ecija; the coastal Pangasinan city of Dagupan, 100 km away, suffered widespread liquefaction, which caused many buildings to topple, sink into the ground, or become tilted and unusable (Adachi et al. 1992).







Legend

PEIS

🟦 6
🟩 7
🟨 L8
🟫 H8
🟥 L9
🟪 H9

Emergency Road Network

— Primary
— Secondary
-+-+- Railways

Notes: PEIS - PHIVOLCS Earthquake Intensity Scale
Scale values are based on approximate conversion from MMI scale to PEIS

Sources: MMEIRS,2003
PHIVOLCS, 2003

Figure 9. The three most likely scenarios for the future major Metro Manila earthquake. Model 8: earthquake at the West Valley Fault. Model 13: earthquake generated on the Manila Trench to the west. Model 19: Recurrence of the Magnitude Ms 6.5 June 1863 earthquake in Manila Bay (From Japan International Cooperation Agency et al. (2004), Fig. 2.1.7, p. 2-9).

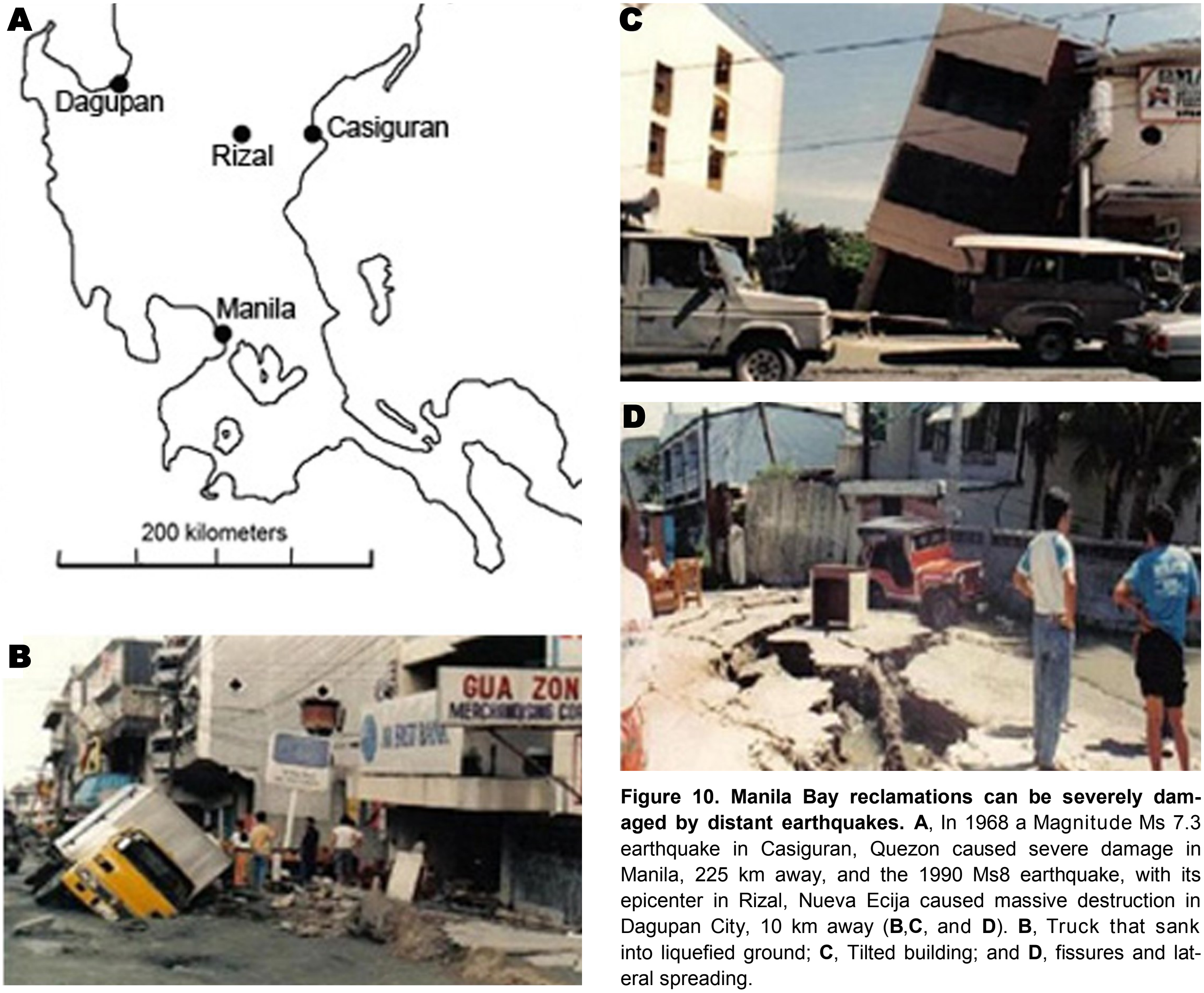


Figure 10. Manila Bay reclamations can be severely damaged by distant earthquakes. A, In 1968 a Magnitude Ms 7.3 earthquake in Casiguran, Quezon caused severe damage in Manila, 225 km away, and the 1990 Ms8 earthquake, with its epicenter in Rizal, Nueva Ecija caused massive destruction in Dagupan City, 10 km away (**B**,**C**, and **D**). **B**, Truck that sank into liquefied ground; **C**, Tilted building; and **D**, fissures and lateral spreading.

"Successful" reclamations?

Technotrix Consultancy Services (2013, p.1-51 to 1-53) defended the Goldcoast project by discussing "successful reclamations" elsewhere. Other proponents of reclamation may reiterate these arguments, and it is appropriate that the examples be evaluated here. The first is Manila's Roxas Boulevard. The demolition of the Roxas breakwater by Typhoon Pedring's storm-surge in 2011 was a classic demonstration of what stronger typhoons and surges can do to a structure built on reclaimed land. It is also an important reminder that structures that had withstood oceanic forces for decades are facing increasingly stronger forces today.

The other example of a "successful" Manila reclamation is the area on which the Cultural Center of the Philippines and Mall of Asia were built. This reclamation, however, has not yet been tested by a major earthquake quake such as the one predicted by Japan International Cooperation Agency et al. (2004).

The section then lists 33 other cities in the world with "successful" reclamations (Table 1). Of these, 30 do not experience serious earthquakes. The three closest to the Philippines are located in China only in areas where seismicity is low.

The list includes San Francisco Bay, California, Mexico city, and Nagoya, Japan. The left panel of Figure 11 is an old San Francisco map, modified by Romans (2010) to show landfills in pink. The right panel of Figure 11 shows that the reclaimed areas in San Francisco and Oakland routinely suffer the most damage during every earthquake, mainly from liquefaction (Baise et al. 2006, Romans 2010. See also Knudsen 2000).

Mexico City experienced liquefaction that sank and toppled

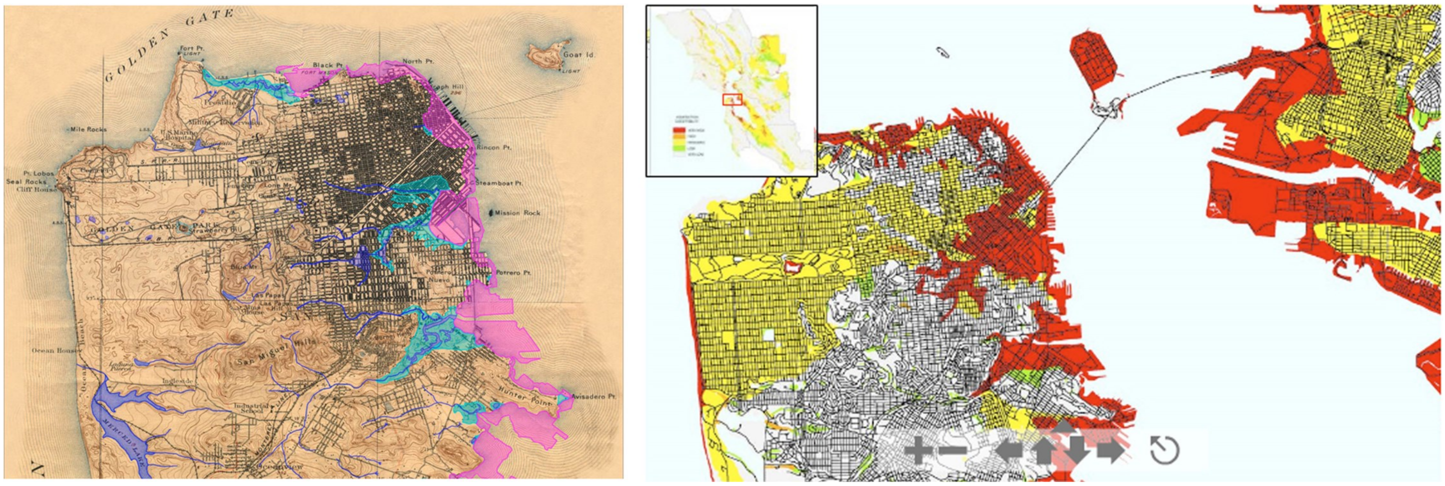


Figure 11. Reclaimed areas in the San Francisco Bay area are the most susceptible to earthquake damage. From Romans (2010).

Table 1. Sites listed as having successful reclamations by Technotrix Services (2013).

Site	Comments
Singapore	Not seismic
Hong Kong, China	Not seismic
Netherlands	Not seismic; devastated by storm surge in 1953
Rio de Janeiro, Brazil	Not seismic
Dublin, Ireland	Not seismic
Saint Petersburg, Russia	Not seismic
New Orleans, Louisiana USA	Not seismic; serious storm surge in 2005
Montevideo, Uruguay	Not seismic
San Francisco Bay, California USA	Reclamations routinely suffer seismic damage
Mexico City, Mexico	Severe liquefaction, 1985 Ms 8.1 earthquake
Panama City, Panama	Not seismic
Helsinki, Finland	Not seismic
Cape Town, South Africa	Not seismic
Chicago, Illinois USA	Not seismic
Hassan II Mosque, Morocco	Not seismic
Barcelona, Spain	Not seismic
Boston, Massachusetts USA	Not seismic
Manhattan, New York USA	Not seismic
Jersey City, New Jersey USA	Not seismic
Zeebrugge, Belgium	Not seismic
Brest, Belarus	Not seismic
Toronto, Canada	Not seismic
Montreal, Canada	Not seismic
Fontvielle, Monaco	Not seismic
La Condamine, Monaco	Not seismic
The Fens, England	Not seismic
Haiko Bay, Hainan, China	Not seismic
Macau, China	Not seismic
Nagoya, Japan	Serious seismicity; prone to ground-motion, liquefaction
Inchon, Korea	Not seismic
Beirut, Lebanon	Not seismic
Mumbain, India	Not seismic
Shenzhen, China	Not seismic

continued

continuation of Table 1

multistory buildings during the 1985 Ms 8.1 earthquake, its epicenter 300 km away (Beck and Hall 1986, Campillo et al. 1989). Masaki et al. (1988) have evaluated the seismic hazard of Nagoya, Japan, by analyzing three serious earthquakes that occurred there in 1891, 1944 and 1945, each of which killed thousands of people, mainly from amplified ground motion and liquefaction. Major loss of life and damage from a future Ms 8 earthquake is expected.

The Netherlands does not experience earthquakes, but a catastrophic North Sea storm surge in 1953 killed 1,835 people, and 70,000 more were evacuated. Sea water flooded 1,365 km² of land, including about 9 percent of Dutch farmland. About 30,000 animals were drowned and 47,300 buildings were damaged; 10,000 were totally destroyed. Total damage: US$ 500 million

(Gerritsen 2005). Billions of Guilders and Euros have been spent on massive flood-control and anti-surge engineering works that continue today, more than half a century after the disaster.

Some final comments: Our history of ignoring science while building projects that fail

In the 1980s, poorly designed lahar dikes were being built at Mayon Volcano despite the scientific objections I raised to them. Those dikes continued to be built until Supertyphoon Reming breached them all in 2006, killing 1,266 people who had sought safety by living behind them (Paguican et al. 2009).

During the 1990s, lahar-dike builders repeated the same mistakes on a much larger scale at Pinatubo Volcano. Again, informed scientists including myself objected to no avail. In October 1995, lahars generated by tropical storm Mameng breached a badly constructed dike and totally destroyed Barangay Cabalantian in Bacolor, Pampanga, killing hundreds of people.

During the 2000s, the Department of Public Works and Highways built numerous costly but ineffective flood-control structures in Central Luzon and Metro Manila's Kamanava district. No objections raised by Academician Fernando P. Siringan and me made any difference. Year after year, they fail, and more money is spent on cosmetic repairs.

In 2008, a legislative initiative was launched to activate the Bataan Nuclear Power Plant. None of the available, detailed geology of Bataan and its offshore surroundings made a difference to the planners. Only the catastrophic Japanese earthquake and tsunami that devastated Fukushima in 2011 halted that effort. But that project is still being pushed by wealthy but scientifically uneducated proponents. "A little knowledge is a dangerous thing," people say; we might add: "Too little knowledge coupled with much money can be a **very** dangerous thing."

Today, it seems that science is again being blithely ignored by the financial interests and government authorities promoting the various reclamation projects. Will we never learn? In truth, however, if the wishes and opposition of enough people prevail so reclamations do not proceed, some of the greatest beneficiaries will be its wealthy proponents, even if they do not realize it now. For they will have been saved from the squandering of much money. And their souls will have been spared the burden of so much needless death and destruction.

CONFLICT OF INTEREST

The author declares no conflict of interest.

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