StEER: Structural Extreme Event Reconnaissance Network

SUNDA STRAIT TSUNAMI (INDONESIA)

PRELIMINARY VIRTUAL ASSESSMENT TEAM (P-VAT) REPORT

Anak Krakatau ("Child of Krakatoa") presumed to have caused the tsunami in Sunda Strait
(Photo Credit: SummitPost.org)

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Executive Summary

A series of tsunami waves hit the shorelines of Sunda Strait, Indonesia, without warning around 9:30 PM local time on Saturday, December 22nd, 2018. The Sunda Strait Tsunami was almost certainly the result of a southwest flank collapse on the Anak Krakatau volcano, which has been erupting continuously since June 2018. Satellite imagery confirms a significant loss of land on the southwest side of the volcanic cone, while tsunami simulations confirm that this event would have resulted in waves similar to what was observed along the shores of Sunda Strait.

The primary damage to built infrastructure consisted of complete destruction of light-framed timber and bamboo houses and kiosks along the shoreline. Unreinforced masonry buildings in close proximity to the shoreline experienced partial to complete collapse. Damage did not extend more than a few rows of buildings from the coastline, though this often included the coastal road that ran close to the shore. Floating debris from damaged buildings and vehicles is suspected to have increased damage to adjacent buildings through debris damming and impact loads. Fortunately, debris and fallen utility lines on the coastal road were cleared quickly to allow access for emergency response teams. Utility lines were being reinstated within days of the tsunami.

One of the more tragic aspects of this disaster is the lack of warning available to communities and the numerous visitors on the beaches of West Java for the Christmas long weekend. Because the tsunami waves were not generated by an earthquake and the waves made landfall after dark, there were almost no warnings for the majority of the coastline. At the time of writing, the death toll stood at 431 with another 15 persons still missing, 7,200 injured and more than 46,000 people displaced. The Indonesia tsunami warning system is based on seismic signals and ocean buoys located along the subduction zone to the South of the chain of Indonesian islands. Although the buoys are currently inoperational, they are designed to trigger a warning if a tsunami is generated by seismic activity. As this tsunami was most likely caused by a flank collapse of the Anak Krakatau volcano, no such activation would have occurred. At the time of writing this report, residents along the Sundra Strait are being warned to stay away from the coastline because of the ongoing eruptions at Anak Krakatau and the potential for additional tsunamis. Installation of wave gages on the shorelines of the three uninhabited islands surrounding the volcano might provide a more reliable early warning system than the current seismic monitoring and ocean buoy system.

This **Preliminary Virtual Assessment Team (P-VAT) Report** provides an overview of the hazard characteristics and coastal impacts associated with this event by collocating publicly-reported information. As the primary product of StEER's response to this event, this P-VAT Report will help to inform and support other research teams seeking to learn from this disaster.

StEER Response Strategy

The objective of StEER's response to the Indonesia Tsunami (Sunda Strait, Indonesia) is to identify whether or not there are structural engineering lessons to be learned. StEER will also recommend other areas of study that may be able to benefit from this event. Given the lack of evidence of structural damage to engineered buildings, bridges and other structures, StEER's response will be limited to a **Virtual Assessment Team (VAT).** The VAT will focus on compiling relevant information from public sources and social media immediately after the event, complementing efforts underway by other organizations such as the Earthquake Engineering Research Institute (EERI) Virtual Earthquake Reconnaissance Team (VERT). While StEER does not plan to deploy a Field Assessment Team (FAT) for this event, it is willing to collaborate with others who visit the site and are able to collect data on structural effects of the tsunami. The result of such a collaboration would be captured by a more detailed **Early Access Reconnaissance Report (EARR)**. If additional information indicates that there may be lessons of a structural engineering nature, StEER may revisit the possibility of a representative joining a field survey team.

The first product of the StEER response to the Sunda Strait Tsunami is this **Preliminary Virtual Assessment Team (P-VAT) report**, which is intended to:

1. provide an overview of the tsunami, particularly relating to the volcanic activity presumed to be the source of the tsunami waves,
2. investigate the effect on coastal communities given the lack of warning prior to this event, and
3. summarize the preliminary findings relating to damage caused by the tsunami along the shores of Sunda Strait.

It should be emphasized that all results herein are preliminary and based on the rapid assessment of publicly available online data within 5 days of the event. Damage assessments discussed herein are based largely on the judgement of the authors without access to additional aerial imagery and ground-truthing.

Tsunami Details

A series of tsunami waves hit the shorelines of Sunda Strait without warning around 9:30 PM local time on Saturday, December 22nd, 2018. Sunda Strait lies between the Indonesian islands of Sumatra and Java (Figure 1). The tsunami waves are suspected to have resulted from a submarine landslide associated with the current volcanic eruption at Anak Krakatau ("Child of Krakatoa"). This was deemed to be the first tsunami event in Indonesia that was not preceded by seismic activity and the government agencies are still further investigating the cause. A GIS map developed by the government officials can be found at: http://gis.bnpb.go.id/arcgis/apps/webappviewer/index.html?id=0e72c7324ed948a09af8e6b0cb17e3e9.

SOURCE: Maps4News/HERE

Figure 1: Map showing location of Anak Krakatau in the Sunda Strait between Sumatra and Java Islands, Indonesia (Credit: Associated Press)

The original Krakatau Volcano exploded in 1883 with devastating consequences. Over 36,000 deaths occurred when large waves struck the surrounding coastlines (Wikipedia, 2018a). Anak Krakatau ("Child of Krakatoa") emerged above sea level in August 1930 and has grown to a current height of 300 meters above sea level. Since June 2018, Anak Krakatau has erupted frequently (Figure 2). A number of videos have been posted online showing various eruptions at Anak Krakatau in the past few months:

- https://twitter.com/DudunZizou/status/1076614592820727809
- https://twitter.com/David_shapira/status/1076785233863892992
- https://twitter.com/David_shapira/status/1076829700876656642
- https://twitter.com/eha_news/status/1076622762997895169

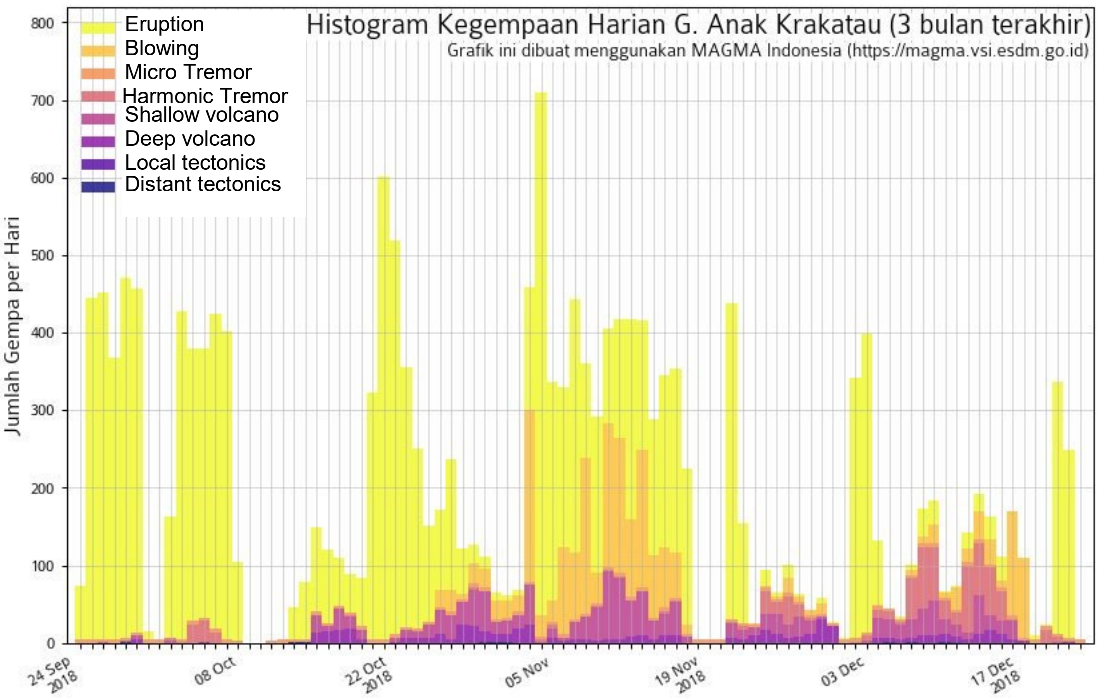


Figure 2: Daily seismic histogram of Krakatau for the last 3 months (Source: https://twitter.com/Sutopo_PN/status/1077006183922204672)

On December 22nd 2018 it is believed that the southwest flank of the volcano collapsed into the sea, resulting in the tsunami waves that affected the adjacent shorelines (Figure 3 and Figure 4). It is estimated that a 2 square kilometer area of the island was involved in the flank collapse (GSI, 2018).

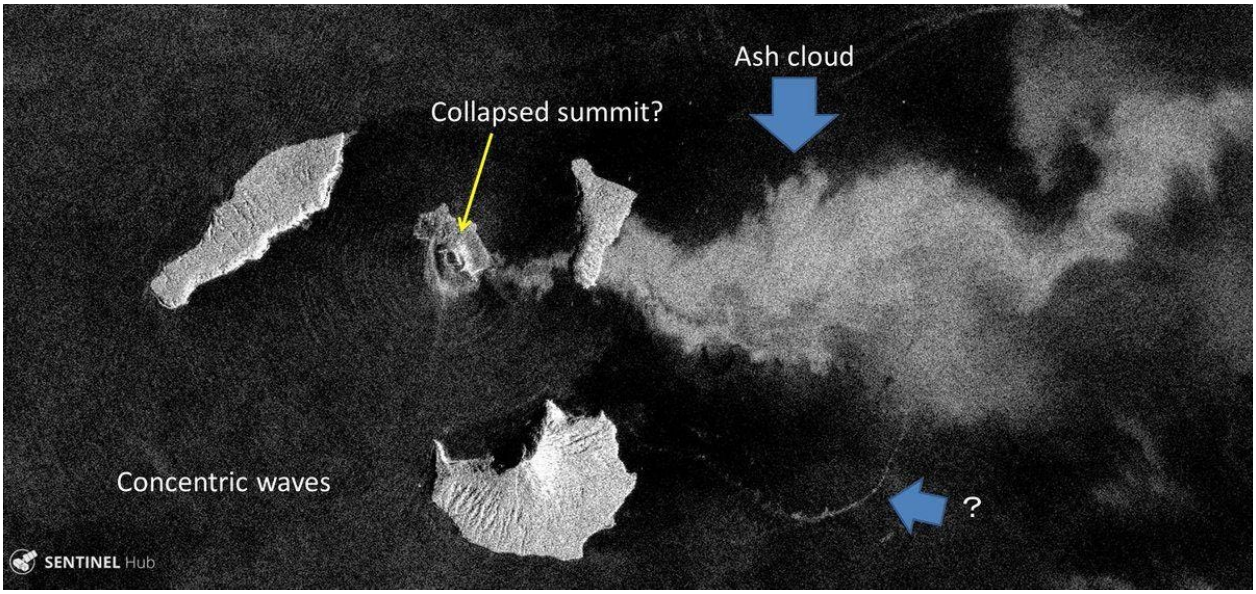
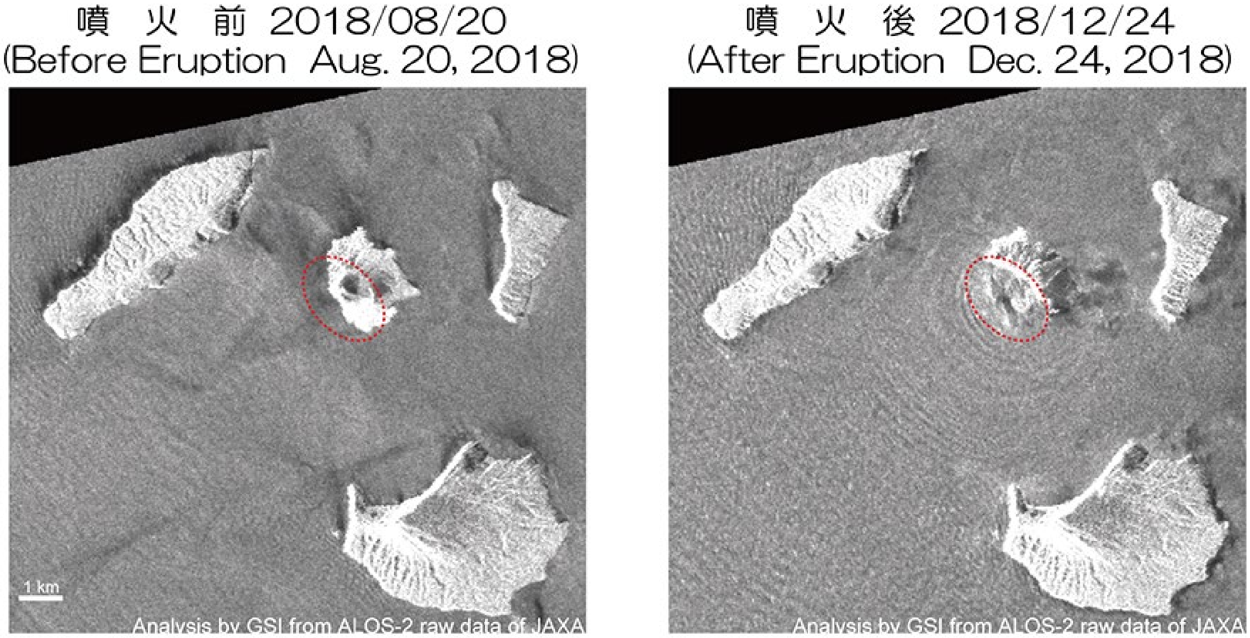


Figure 3: Satellite image taken on December 22nd, 2018, after the collapse, possibly showing one of the tsunami waves (Image: Sentinel 1, annotations by R. Natsuaki @flyingwktk / twitter) (Wikipedia, 2018b)



噴 火 前 2018/08/20
(Before Eruption Aug. 20, 2018)

噴 火 後 2018/12/24
(After Eruption Dec. 24, 2018)

Figure 4: Comparison of Anak Krakatau before and after the flank collapse. Synthetic Aperture Radar (SAR) images analyzed from ALOS-2/PALSAR-2 data. ALOS-2 launched by Japan Aerospace Exploration Agency in 2014. (Credit Geospatial Information Authority of Japan (GSI, 2018))

A subsequent post by the head of public relations for the Indonesian National Board for Disaster Management, P.N. Sutopo, on December 28, 2018 indicates that the original estimate of the height of Anak Krakatau of 338 metres has been reduced to 110 meters. The volume of material lost is estimated as 150-170 million m^3 (0.15-0.17 km^3). The remaining volume of the volcano cone is estimated as 40-70 million m^3 (0.04-0.07 km^3).
(https://twitter.com/Sutopo_PN/status/1078661984277585920)

The volcano is still very active as illustrated by a video captured by Captain Mykola of Susi Air at around 4 PM local time during a reconnaissance flight to observe tsunami damage on December 23rd, 2018 (see https://twitter.com/Sutopo_PN/status/1077045675290812416). Figure 5 shows three images captured from this video showing a large explosion at Anak Krakatau, potentially leading to additional smaller tsunami waves. The volcanic ash was also reported to affect the surrounding areas up to 12 km radius.

Figure 5: Three sequential images (top to bottom) from video of violent explosion of Anak Krakatau at around 4pm on December 23rd, 2018, the day after the damaging tsunamis (Credit: Capt. Mykola from Susi Air)

Tide gage records on both sides of the Sunda Strait indicate the arrival time and amplitude of the tsunami waves (tides.big.go.id). The exact locations of the tide gages have not been determined, and wave heights might be larger or smaller at other locations along the shoreline depending on local bathymetry.

The tide gage records at sites outside of the Sunda Strait (Krui in Figure 6 and Binuangeun in Figure 7) show almost no signal from the tsunami waves. Similarly, the tide gage at Bengkunat (Figure 6) does not appear to show a tsunami wave signal; the long spike at 1:00 am on Dec. 23rd is likely an errant reading.

Tide gages inside Sunda Strait, not directly exposed to tsunamis generated by a Southwest flank collapse on Anak Krakatau, show disturbance from the tsunami waves, but they do not exceed the spring tide level experienced earlier that evening (Kota Agung and Pelabuhan Panjang in Figure 6).

Although located North and East of Anak Krakatau, the tide gages at Ciwandan, Banten, (Figure 7) and Marina Jambu (Figure 7) registered more significant tsunami wave heights that just exceeded the prior spring tide elevations. The single spike in the Marina Jambu record is assumed to be an errant reading.

Tsunami wave arrival times are all approximately 21:30 as reported by eyewitnesses at various locations. All records start with an initial positive wave, which is typical of landslide-generated tsunamis and confirms the eyewitness accounts that the water did not recede prior to the first wave.

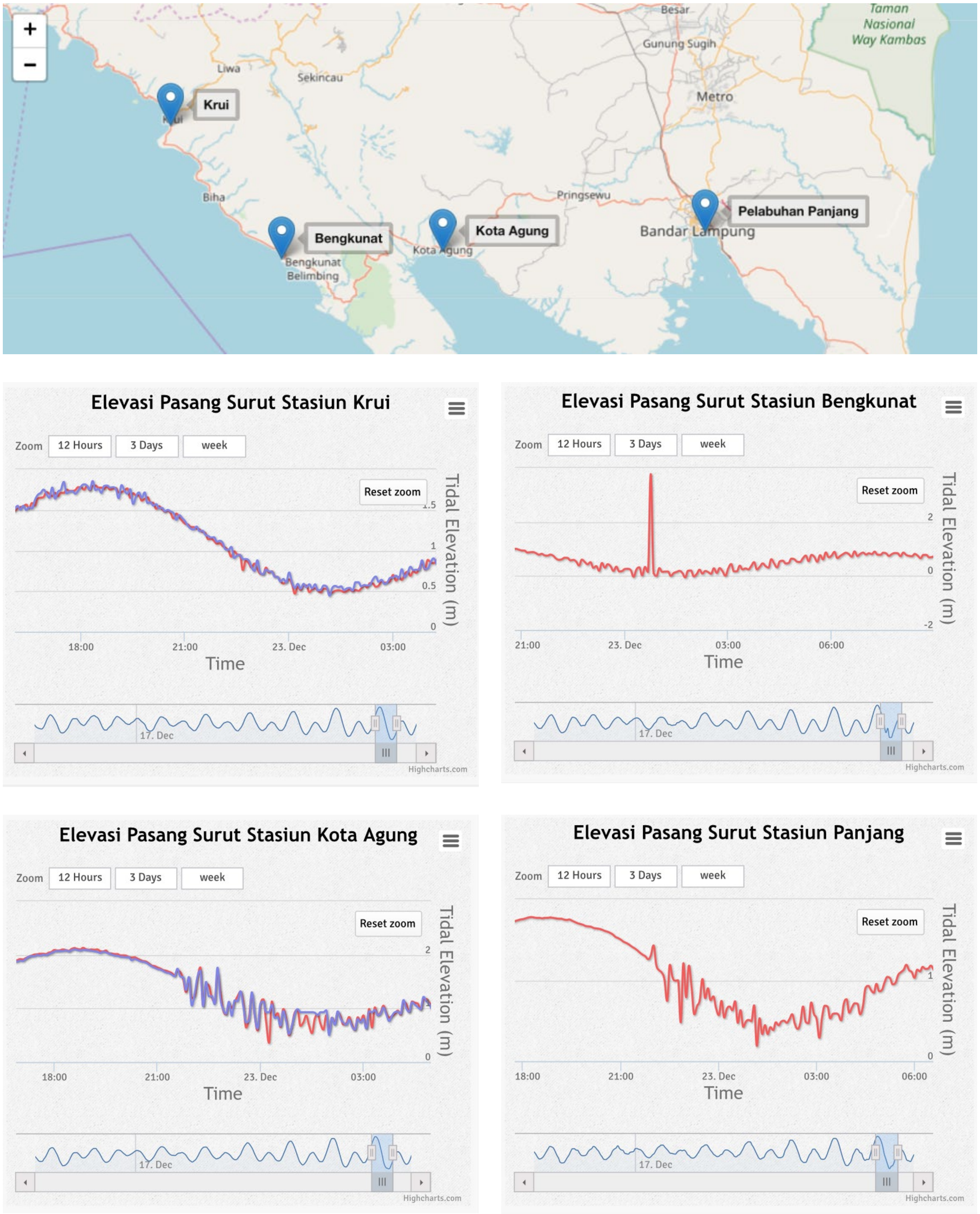


Figure 6: Tide station records on south end of Sumatra Island during time of tsunami (Source: Jason Patton / tides.big.go.id)

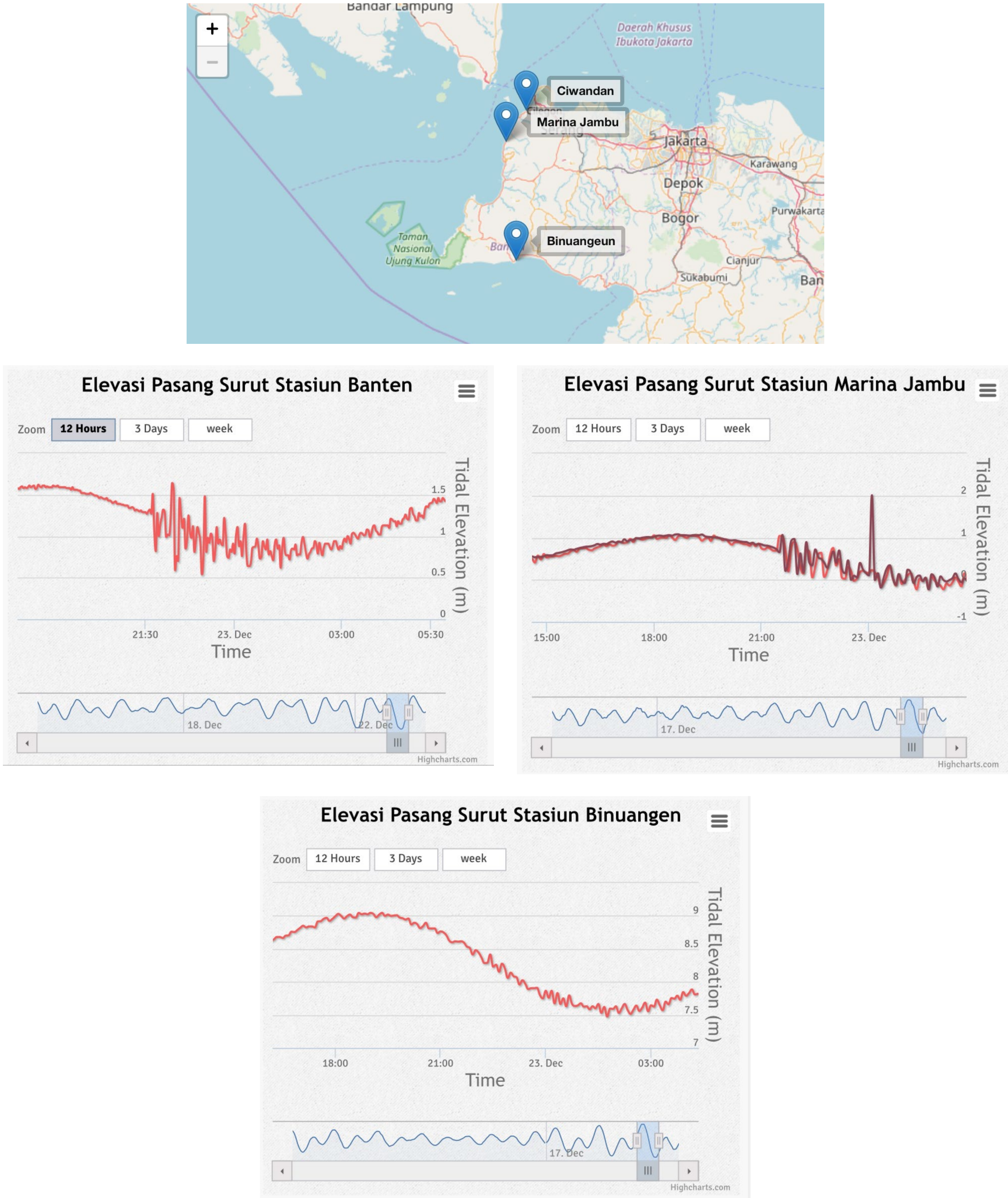


Figure 7: Tide station records on west end of Java Island during time of tsunami (Source: Jason Patton / tides.big.go.id)

An article published in 2012 investigated the potential for tsunami waves generated by a flank collapse of Anak Krakatau Volcano (Giachetti et al., 2012). This study assumed a flank collapse involving 0.28 cubic km of material with an assumed relative density of 1.5. Figure 9 shows the area included in their study and some of the locations where estimated offshore wave heights were output. Figure 10 verifies that they assumed a significant portion of the Southwest flank of Anak Krakatau would collapse as a landslide triggering a tsunami. Figure 11 displays the maximum wave heights predicted by their model, while Figure 12 reports the predicted offshore wave heights at selected coastal locations along the shores of Sunda Strait.

The most significant wave heights are predicted at Carita and Labuhan, both areas that experienced damaging tsunamis during the December 22nd 2018 event. Locations at Panimbang and Kalianda experience slightly smaller waves, while Bandar Lampung, Merak and Anyer experience the smallest waves, similar to the tide gage measurements during the December 22nd tsunami for Pelabuhan Panjang and Ciwandan Banten.

The tsunami on December 22nd was not of the same magnitude predicted by Giachetti et al. (2012); however, the similarity of the resulting wave forms appears to confirm the source of the December 22nd tsunami as a Southwest flank collapse of a lesser volume than assumed in the 2012 study.

In their 2012 paper, Giachetti et al., conclude that:

> *"Our numerical simulation shows that a partial destabilization (0.28 km^3) of Anak Krakatau Volcano towards the SW would possibly be dangerous on a local scale (tourist and fishing activities around the volcano) or even on a regional scale (coasts of Sumatra and Java). This event would trigger an initial wave of 43 m that would reach all of the islands in the Krakatau Archipelago in less than 1 min, with amplitudes ranging from 15 to 30 m, and would be extremely dangerous for boats in the Krakatau Archipelago. Waves would then propagate in a radial manner across Sunda Strait at an average speed of 80–110 km h^{-1}, the first wave reaching cities on the western coast of Java after 35–45 min, with a maximum amplitude of between 2.9 (Carita) and 3.4 m (Labuhan). These waves would be considerably smaller than those produced during the 1883 Krakatau eruption (average wave height of c. 15 m around the Sunda Strait).*
>
> *Owing to the high population, the concentration of road and industrial infrastructure along some parts of the exposed coasts of Java and Sumatra, and the low elevation of much of this land, the tsunami might present a significant risk. However, as the travel time of the tsunami is several tens of minutes between the Krakatau Archipelago and the main cities along these coasts, a rapid detection of the collapse by the volcano observatory, coupled with an efficient alert system on the coast, could prevent this hypothetical event from being deadly. A tsunami preparedness project was initiated in 2006 by UNESCO and the Indonesian Institute of Sciences (LIPI). However, it should be noted that the ground deformation of the volcano is not permanently monitored, and the available data (e.g. bathymetry) are not sufficient to allow for an accurate assessment of slope instability.*
>
> *The example of Krakatau Volcano illustrates the point that tsunamis generated by volcanic eruptions and flank instability are a neglected hazard. They represent 25% of all the fatalities directly attributable to volcanoes during the last 250 years (Latter 1981; Begét 2000). At least 115 volcanic tsunamis have been observed since 1600 AD (death toll >54 000), with 36 events during the nineteenth century*

and 54 events during the twentieth. Volcanic tsunamis can be dangerous because they can occur with little warning, and cause devastation at great distances. South Asian and South Pacific regions are particularly exposed to volcanic tsunamis because of the high density of active volcanoes located near the coasts (volcanic island arcs). Systematic monitoring of flank instability and the integration of tsunamis into volcanic hazard assessments (e.g. maps, evacuation routes) would reduce the impact of future events."

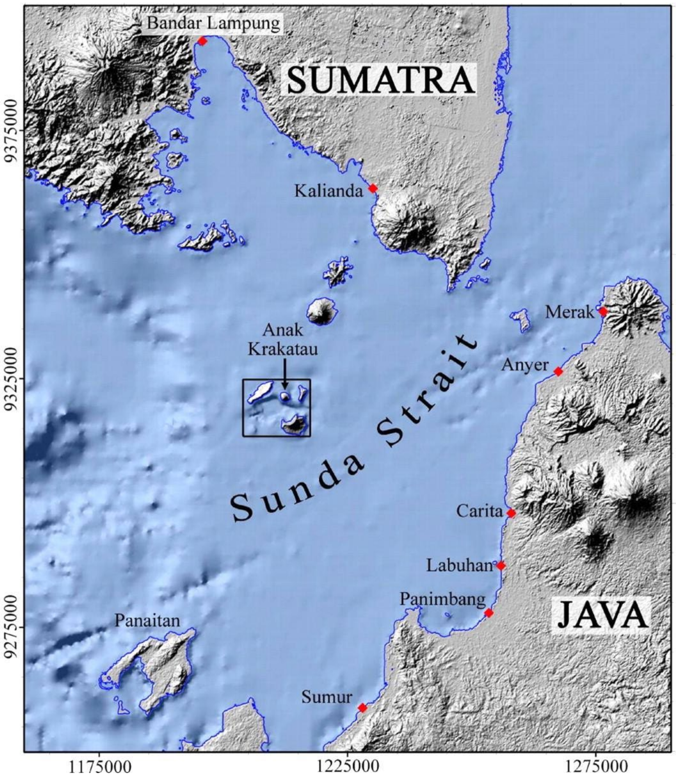


Figure 8: **Study area for tsunami simulation from Anak Krakatau flank collapse (Giachetti et al., 2012)**

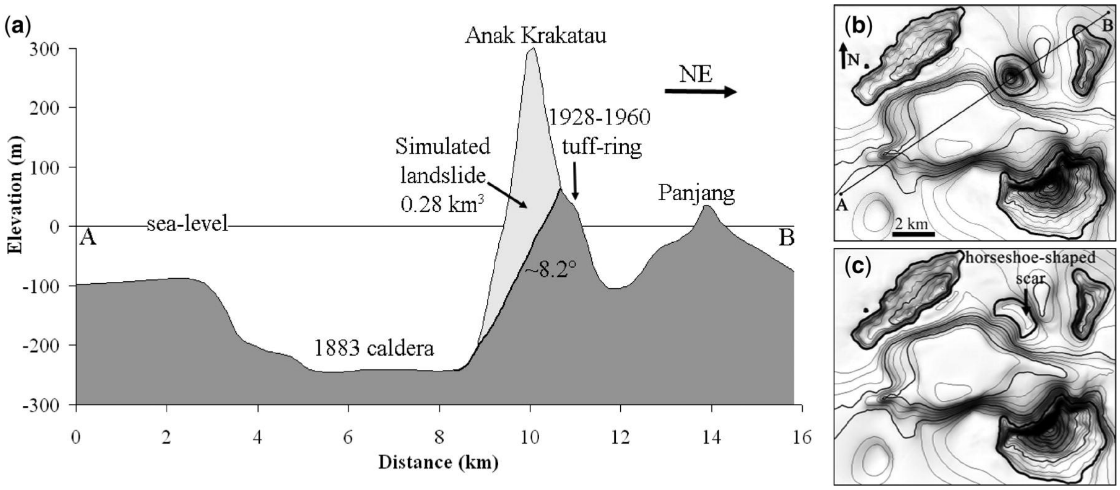


Figure 9: **Assumed Anak Krakatau flank collapse resulting in simulated landslide (Giachetti et al., 2012)**

The wave height predictions exceed those observed during the December 22nd event, indicating that the landslide was probably smaller than their assumption in 2012. Nevertheless, their conclusions provide a valuable suggestion for development of an early warning system triggered by volcano flank collapse.

A current study being performed under an NSF collaborative project (GEO-17-56665) - NERC (Natural Environment Research Council) on “Caldera-forming eruption-generated tsunamis” has confirmed the SW flank collapse as the likely source of the December 22nd tsunami. The researchers participating it this effort are: Profs. Annette Grilli and Steve Carey of the University of Rhode Island; Prof. David Tappin and Dr. Samantha Engwell of the British Geological Survey; Dr. Simon Day of University College London; Dr. Steven Ward of UC Santa Cruz; and Dr. Sebastian Watt of the University of Birmingham.

By performing inverse ray tracing from tide gage records, Grilli et al. (2018) were able to identify the source as the SW side of Anak Krakatau. They estimate the shape and volume (about 0.20 cubic km) of the flank collapse as a viscous flow with an assumed relative density of 1.9. The resulting wave propagation is visualized in Figures 13 and 14. It is evident that wave gages installed on the three uninhabited islands surrounding Anak Krakatau would be able to provide advance warning of the volcanic initiation of any future tsunami waves.

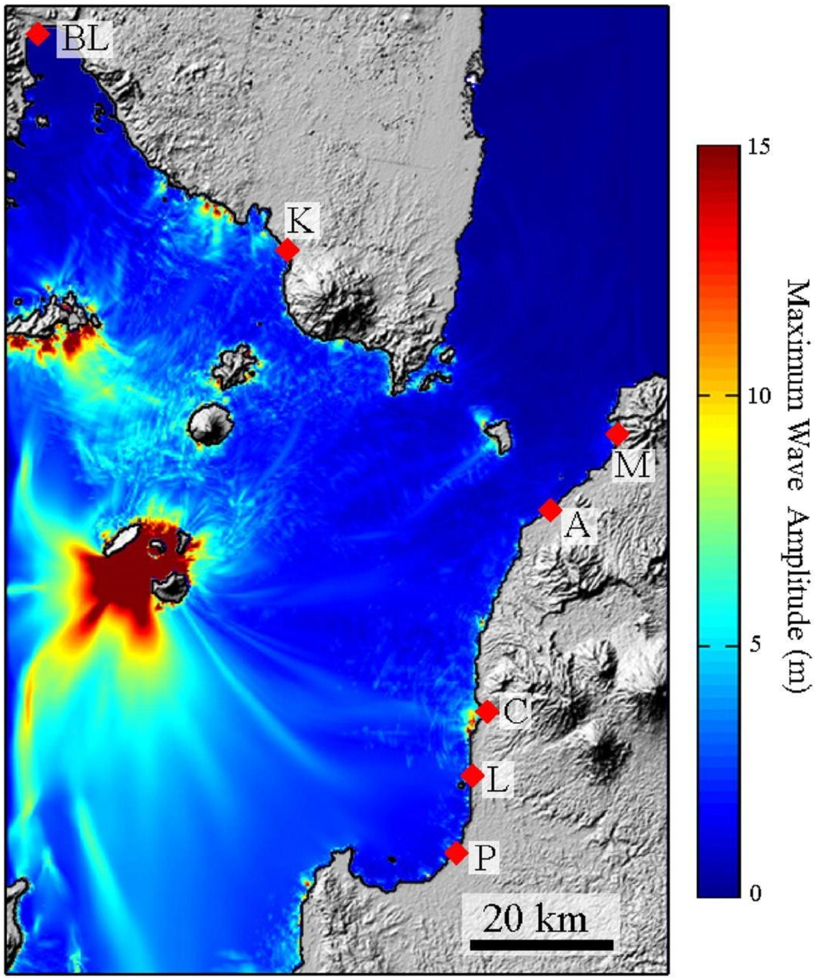


Figure 10: **Maximum wave amplitude (m) predicted by simulation of Anak Krakatau flank collapse (Giachetti et al., 2012)**

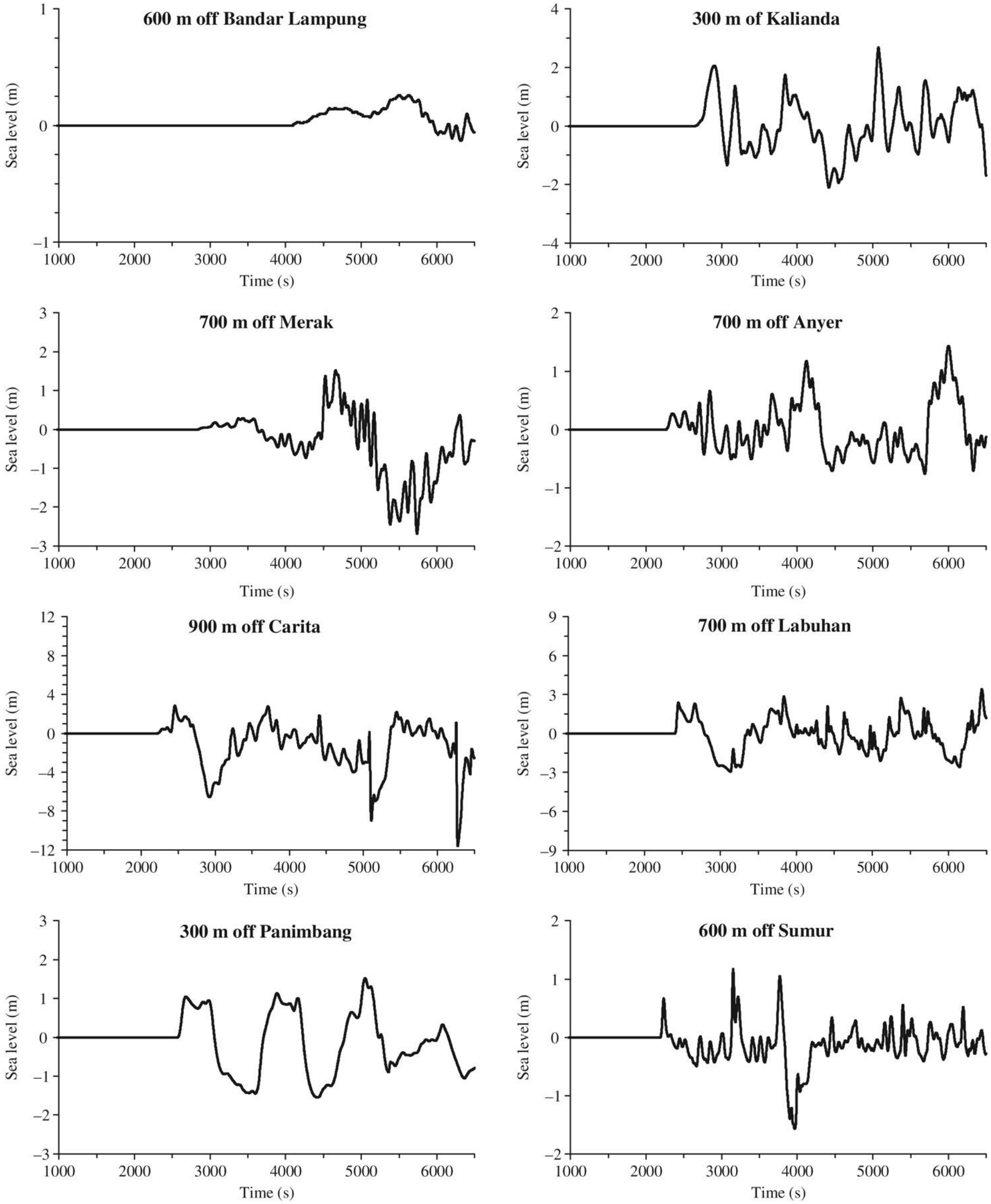


Figure 11: **Simulated off-shore sea-level profiles (m) for eight main coastal cities based on assumed flank collapse (Giachetti et al., 2012)**

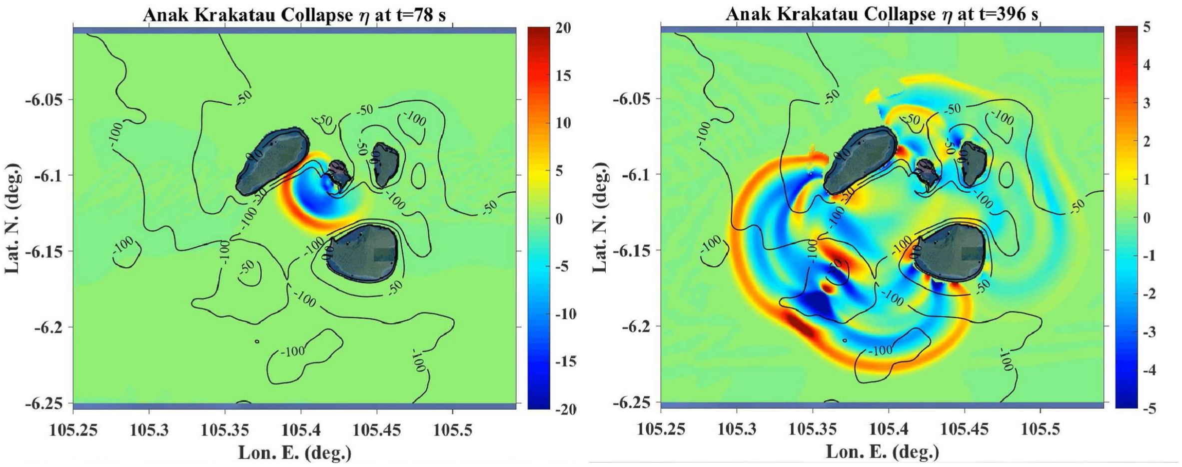


Figure 12: **Images captured from simulation by Grilli, et al. (2018) as landslide-generated tsunami waves travel between islands surrounding Anak Krakatau (Note amplitude scale varies)**

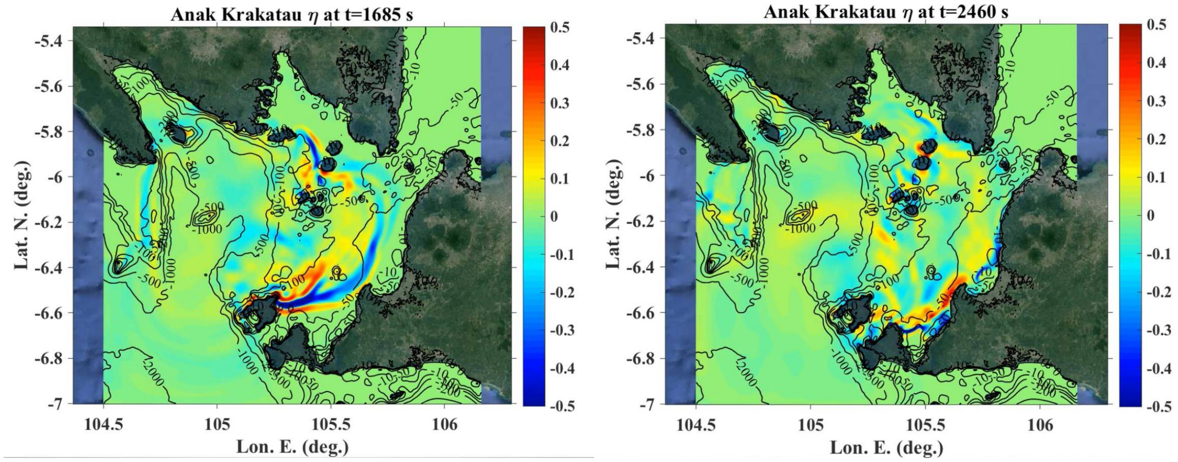


Figure 13: **Images captured from simulation by Grilli, et al. (2018) as landslide-generated tsunami waves make initial (approx. 28 min.) and second landfall (approx. 41 min.) on West Java coastline.**

Warning and Evacuation

The Indonesian tsunami warning system is based on seismic records and ocean buoys (which were placed after the 2004 Indian Ocean Earthquake and Tsunami with 22 reportedly not functioning since 2012). Since there was no seismic activity, and the ocean buoys are not located close enough to Anak Krakatau for reliable early warning initiation, there was no warning for residents and visitors in the affected coastal areas. Following the event, the government plans to place four tsunami-detection buoys over the next three years on the coasts of Sumatra and Java to detect wave heights. These buoys will act as the early warning system for tsunamis induced by volcanic activities, in addition to earthquakes

(https://twitter.com/Sutopo_PN/status/1076999908270301184).

Figure 14 depicts the location of Tanjung Lesung beach resort where many locals and tourists were enjoying the long Christmas weekend. Based on the simulations by Grilli et al. (2018), it would been the first location on West Java to experience the tsunami waves. A video posted at numerous outlets shows the moment the tsunami wave strikes a beach party where a rock band "Seventeen" was playing on stage. (A copy of this video is available at Nowthisnews: https://twitter.com/nowthisnews/status/1076931197362679808).

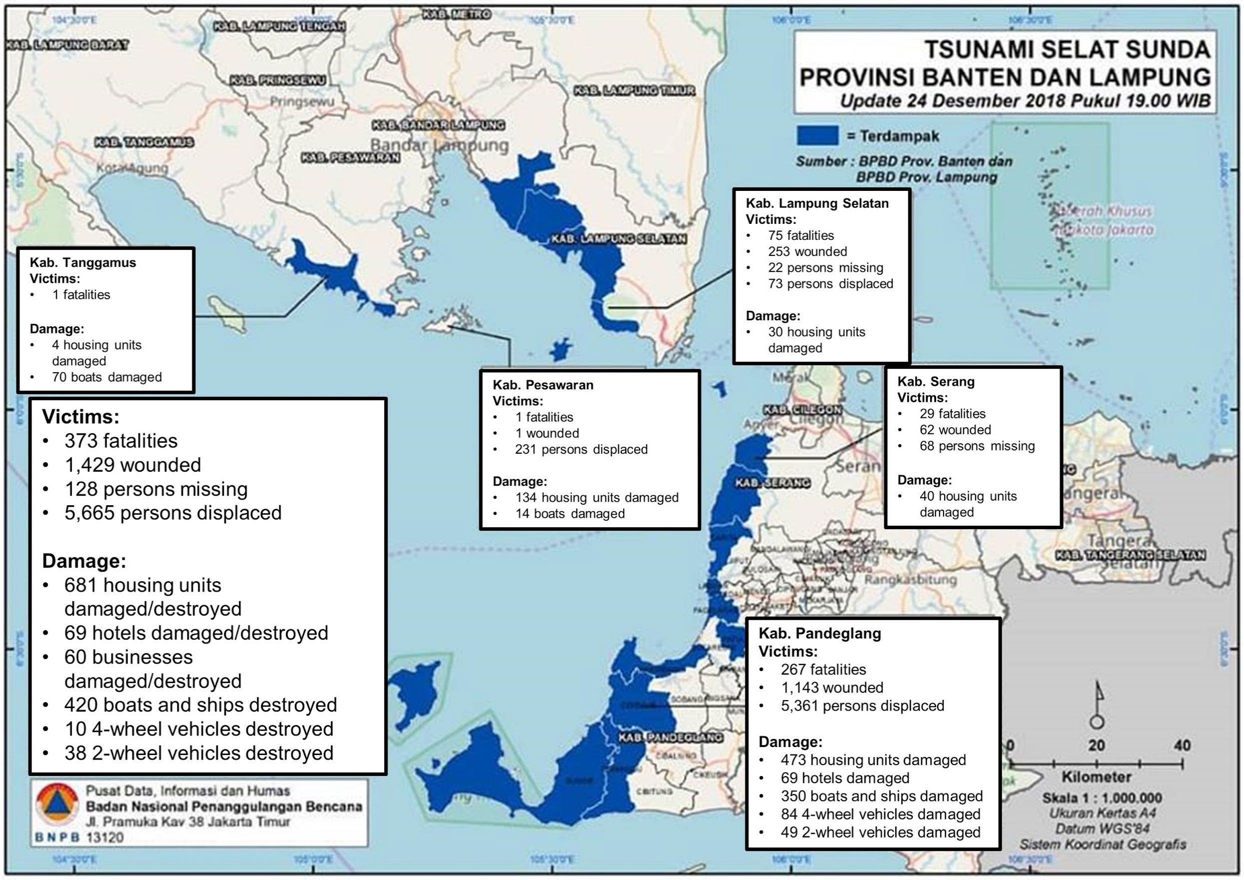
Figure 15 shows a frame from this video shortly before the tsunami wave strikes the beach party, while the second frame shows the wave overturning the stage. The wave continued through the audience resulting in at least 31 deaths. The lead singer survived but the band's bassist and road manager were found dead. Three other band members were still missing at the time this report was authored, while at least 29 party attendees died and another 13 were still missing (Nowthisnews, 2018).

Figure 14: **Map showing location of Tanjung Lesung beach resort (CNN, 2018)**

Figure 15: Rock band "Seventeen" playing on stage at a beach concert in Tanjung Lesung beach resort (left) and the stage overturned by the tsunami wave (right) (Images from video posted by nowthisnews)

Casualties

The current number of reported casualties at the time of writing this report (December 28th, 2018) is 431, along 7,200 injuries, 15 persons unaccounted for, and more than 46,000 people displaced by the tsunami. Figure 17 shows the distribution of casualties and damage as of December 24, 2018 when the counts were somewhat lower.



Kab. Tanggamus
Victims:
- 1 fatalities

Damage:
- 4 housing units damaged
- 70 boats damaged

Victims:
- 373 fatalities
- 1,429 wounded
- 128 persons missing
- 5,665 persons displaced

Damage:
- 681 housing units damaged/destroyed
- 69 hotels damaged/destroyed
- 60 businesses damaged/destroyed
- 420 boats and ships destroyed
- 10 4-wheel vehicles destroyed
- 38 2-wheel vehicles destroyed

Kab. Pesawaran
Victims:
- 1 fatalities
- 1 wounded
- 231 persons displaced

Damage:
- 134 housing units damaged
- 14 boats damaged

Kab. Lampung Selatan
Victims:
- 75 fatalities
- 253 wounded
- 22 persons missing
- 73 persons displaced

Damage:
- 30 housing units damaged

Kab. Serang
Victims:
- 29 fatalities
- 62 wounded
- 68 persons missing

Damage:
- 40 housing units damaged

Kab. Pandeglang
Victims:
- 267 fatalities
- 1,143 wounded
- 5,361 persons displaced

Damage:
- 473 housing units damaged
- 69 hotels damaged
- 350 boats and ships damaged
- 84 4-wheel vehicles damaged
- 49 2-wheel vehicles damaged

Figure 16: **Map posted by P.N. Sutopo, Indonesia's emergency response spokesperson (Source: https://twitter.com/Sutopo_PN/status/1077092955389812736)**

Damage to Structures

As reported by ABC News on December 24th, P.N. Sutopo stated that more than 600 housing units and at least 69 hotels were damaged or destroyed by the tsunami. On December 26th, these numbers increased to 924 housing units, 73 hotels/inns, and 60 food stalls. The majority of the damage occurred in the coastal regions on the west coast of Banten Province. The extent of the damage and loss of life was likely mitigated by the relatively low population density in the regions with the highest tsunami impacts. Figures 17 and 18 show that the population density on the west coast of Banten Province is relatively low, and satellite imagery reveals large sections of forests and unpopulated regions along the coast. However, many of the beaches along this coastline are popular during holidays, such as the long weekend leading up to Christmas.

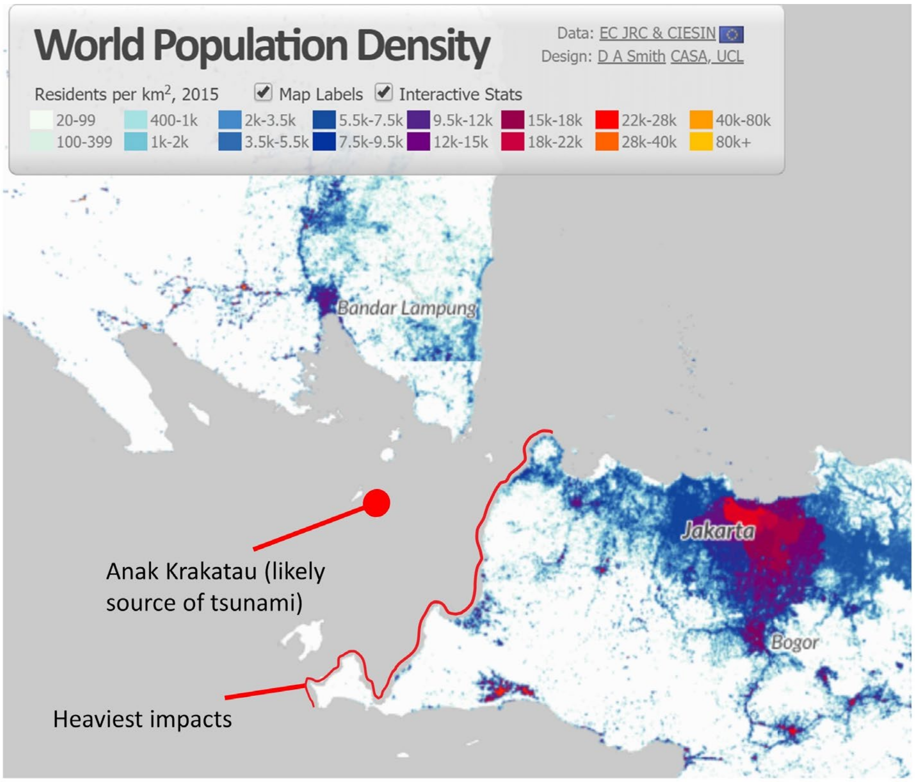
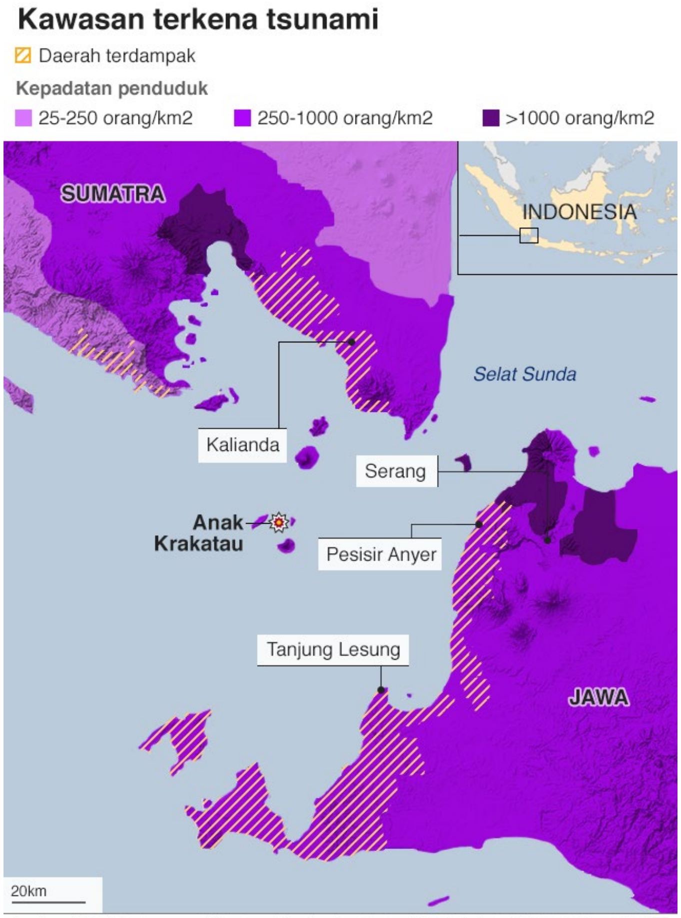


Figure 17: Map showing the population density and coastal region with highest impacts from the tsunami (Credit: Duncan Smith, CASA UCL, Urban Data Visualization)



Sumber: NASA Socioeconomic Data and Application Center (SEDAC), data BNPB, 2015

Figure 18: Population density surrounding the Anak Krakatau volcano, identified as the likely source of the tsunami (Source: BBC)

At the time of writing this P-VAT report, the authors have limited knowledge of seismic and tsunami design requirements on Sumatra and Java. The majority of damage appears to have been to non-engineered timber and bamboo framed or unreinforced masonry buildings close to the shoreline. Although some coastal hotels reported non-structural damage, the authors are not aware of any "engineered" buildings, bridges or other structures that collapsed or suffered structural damage during this event.

Damage on West Shore of Java

Most of the damage was limited to the first few rows of buildings along the shoreline exposed to the tsunami waves. The wave amplitudes and periods were not large enough to result in extensive inland inundation. Figures 19 and 20 show cleanup operations along the West coast of Java, consisting mainly of debris from bamboo, timber and masonry single story structures. Figures 21 and 22 illustrate damage to masonry structures immediately adjacent to the shoreline, presumably due to hydrodynamic wave loading. Figure 23 depicts the contribution of floating debris, including vehicles, to enhanced hydrodynamic loads due to debris damming, and impact loads.

Figure 19: Debris clean-up underway in the Sumur district of Pangdeglang, Banten Province, Indonesia. Photo by Veri Sanovri/Xinhua via Newscom and ABC News.

Figure 20: Clean-up efforts underway along the coastline of Carita district, West Java (Credit: Associated Press / Fauzy Chaniago)

Figure 21: Damage to masonry structure on the shoreline (Credit: Associated Press / Fauzy Chaniago)

Figure 22: Damage to masonry structure on shoreline (Credit: Associated Press / Fauzy Chaniago)

Figure 23: **Floating debris, and particularly vehicles, appeared to enhance the hydrodynamic and impact loading on structures.**

The coastal roadway along the West coast of Java was obstructed by fallen utility lines and debris deposits (Figure 24). This roadway was cleared soon after the event to allow emergency responders to access communities along the shoreline. A video showing the debris from building damage in Pandeglang is available at

https://twitter.com/Sutopo_PN/status/1077149010203357184.

Figure 24: The coastal roadway along the West edge of Java was obstructed by debris and fallen utility lines, but was cleared quickly to allow access to most communities along the coast.

Damage on South Shore of Sumatra

Two aerial videos along the South shore of Sumatra, posted by P.N. Sutopo, document only limited damage to buildings directly on the shoreline (the first video is available at: https://twitter.com/Sutopo_PN/status/1077741487645806593). The coastal roadway does not appear to be damaged or blocked over the region covered by the videos, which is shown in Figure 25. Figures 26 through 29 isolate various locations along with shoreline both in Google Earth and with stills captured from this video.

Figure 25: **Extent of aerial videos surveying damage on the South shore of Sumatra, and aerial photos taken of communities on Sebesi Island.**

Figure 26: Google Earth (left) and aerial video (right) images of damage to coastal buildings on the South shore of Sumatra (5.82414S, 106.600E)

Figure 27: Google Earth (left) and aerial video (right) images of damage to coastal buildings on the South shore of Sumatra (5.8208S, 105.5967E)

Figure 28: Google Earth (left) and aerial video (right) images of damage to coastal buildings on the South shore of Sumatra (5.80825S, 105.58756E)

Figure 29: Google Earth (left) and aerial video (right) images of damage to the timber decking on Canti Pier and boats in a small harbor in Kalianda on the South shore of Sumatra (5.800S, 105.5844E)

The second aerial video (see https://twitter.com/Sutopo_PN/status/1076721942437085184) features an adjacent stretch of shoreline along the Kalianda coast of Sumatra. Figure 30 depicts damage to coastal structures, while Figure 31 focuses on the Kalianda Bawah harbor with some boats intact but others washed on shore or sunk in the harbor.

Figure 30: Google Earth (left) and aerial video (right) images of damage to coastal buildings and coastal platforms in Kalianda on the South shore of Sumatra (5.7506S, 105.587E)

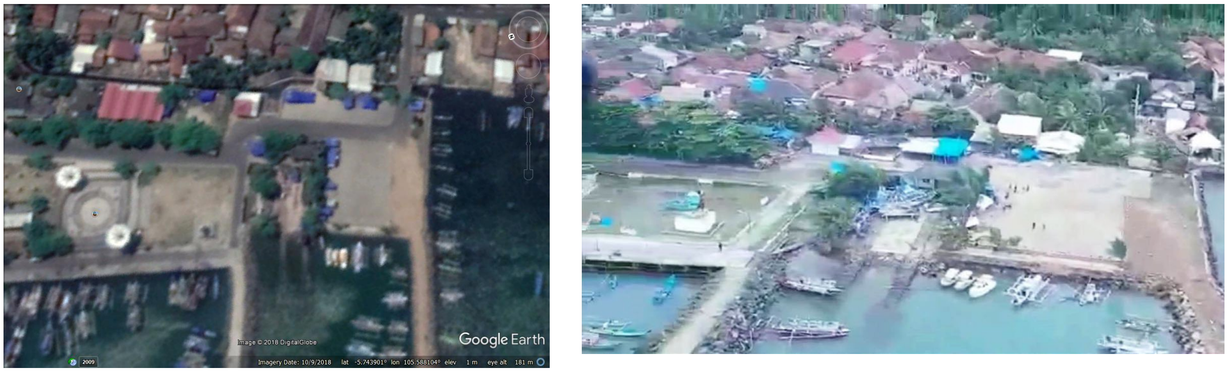


Figure 31: Google Earth (left) and aerial video (right) images of damage to boats in Kalianda Bawah harbor on the South shore of Sumatra (5.744S, 105.588E)

Damage on Sebesi Island

P.N. Sutopo reports that two people died and 40 houses were damaged by the Sunda Strait tsunami on Sebesi Island (https://twitter.com/Sutopo_PN/status/1077762078121684992). Aerial images captured some of this damage to coastal homes (Figure 32) and a pier (Figure 33). Two new buildings (with blue roofs) that were not evident in Google Earth images from August 2017, along with a modified pier (Figure 34) appear to have survived without damage.

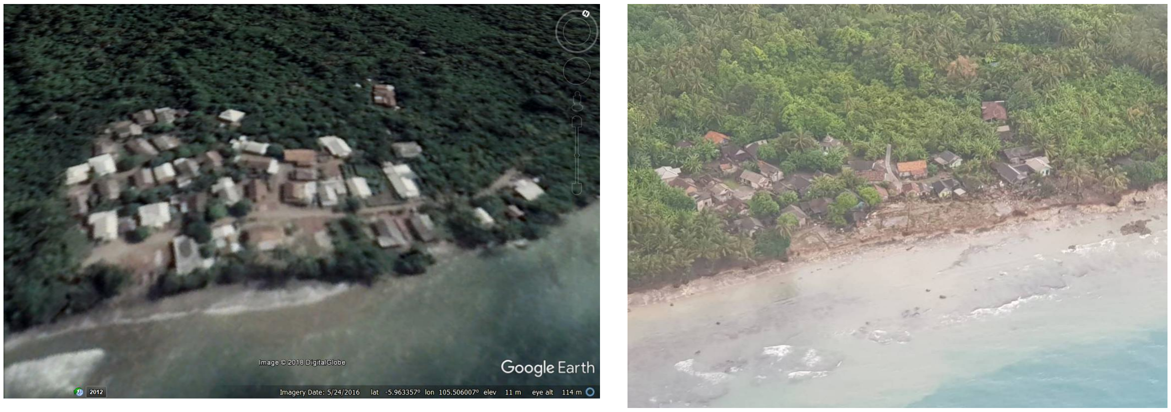


Figure 32: **Google Earth (left) and aerial photo (right) of damage to coastal buildings on the Southeast shore of Sebesi Island. Image 1 location in Figure 25 (5.9635S, 105.50607E)**

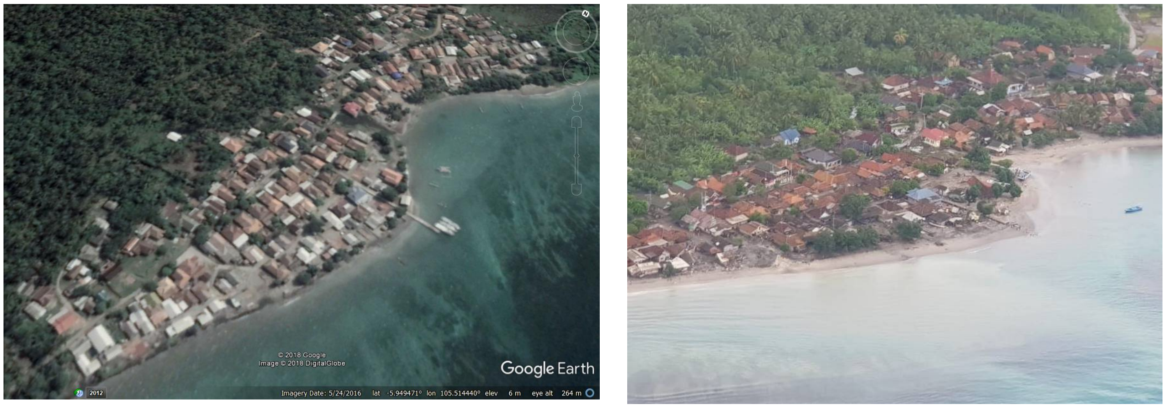


Figure 33: Google Earth (left) and aerial photo (right) of damage to coastal buildings and pier on the Southeast shore of Sebesi Island. Image 2 location in Figure 25 (5.9593S, 105.55151E)

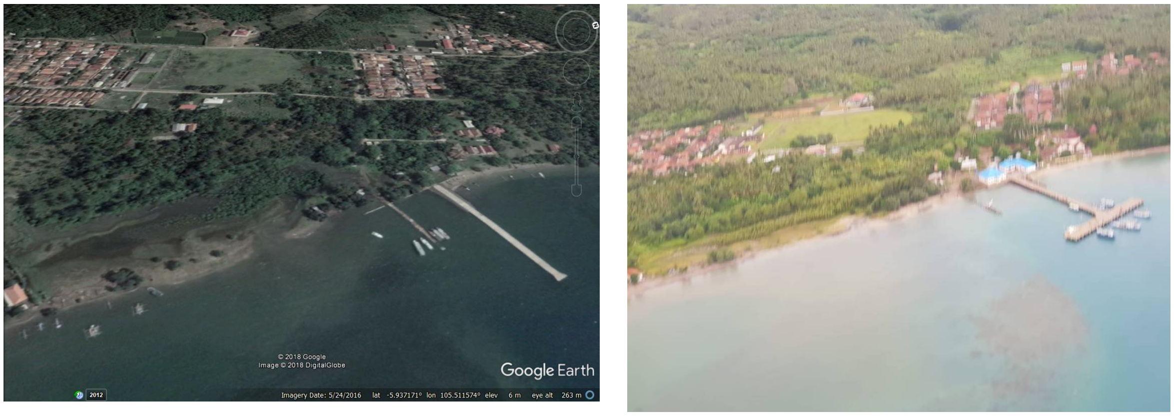


Figure 34: Google Earth (left) and aerial photo (right) showing undamaged pier and new buildings (with blue roofs) built since August 2017 (Date of latest Google Earth image) on the East shore of Sebesi Island. Image 3 location in Figure 25 (5.93615S, 105.51168E)

Damage to Lifelines

Roadways

The main roadways connecting the cities of Serang and Pandeglang in the Province of Banten were disconnected following the tsunami. However, no further detail is available at this time.

Ports and Harbors

Two ports, Merak and Bakauheni, which are located in the proximity of the tsunami area were reported to be working as normal. However, the activity was reported to be low after the event.

Power distribution system

Damage to power distribution poles and lines occurred along stretches of the coastal road on West Java. Crews were quick to replace poles and reinstate the transmission lines. P.N. Sutopo posted images of this repair work on December 23rd, the day after the tsunami (Figure 35).

Figure 35: Crews installing new power transmission line poles the day after the tsunami (Source: https://twitter.com/Sutopo_PN/status/1077091875448737792)

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About StEER

The National Science Foundation (NSF) awarded a 2-year EAGER grant (CMMI 1841667) to a consortium of universities to form the Structural Extreme Events Reconnaissance (StEER) Network. StEER's mission is to deepen the structural natural hazards engineering (NHE) community's capacity for reliable post-event reconnaissance by: (1) promoting community-driven standards, best practices, and training for RAPID field work; (2) coordinating official event responses in collaboration with other stakeholders and reconnaissance groups; and (3) representing structural engineering within the wider extreme events reconnaissance (EER) consortium in geotechnical engineering (GEER) and social sciences (SSEER) to foster greater potentials for truly interdisciplinary reconnaissance. StEER also works closely with the NSF-supported Natural Hazards Engineering Research Infrastructure (NHERI) RAPID facility and cyberinfrastructure Reconnaissance Portal to more effectively leverage these resources to benefit StEER missions.

StEER relies upon the engagement of the broad NHE community, including creating institutional linkages with dedicated liaisons to existing post-event communities and partnerships with other key stakeholders. While the network currently consists of the three primary nodes located at the University of Notre Dame (Coordinating Node), University of Florida (Atlantic/Gulf Regional Node), and University of California, Berkeley (Pacific Regional Node), StEER aspires to build a network of regional nodes worldwide to enable swift and high quality responses to major disasters globally.

StEER's founding organizational structure includes a governance layer comprised of core leadership with Associate Directors for the two primary hazards as well as cross-cutting areas of Assessment Technologies and Data Standards, led by the following individuals:

- **Tracy Kijewski-Correa (PI),** University of Notre Dame, serves as StEER Director responsible with overseeing the design and operationalization of the network.
- **Khalid Mosalam (co-PI),** University of California, Berkeley, serves as StEER Associate Director for Seismic Hazards, leading StEER's Pacific Regional node and serving as primary liaison to the Earthquake Engineering community.
- **David O. Prevatt (co-PI),** University of Florida, serves as StEER Associate Director for Wind Hazards, leading StEER's Atlantic/Gulf Regional node and serving as primary liaison to the Wind Engineering community.
- **Ian Robertson (co-PI),** University of Hawai'i at Manoa, serves as StEER Associate Director for Assessment Technologies, guiding StEER's development of a robust approach to damage assessment across the hazards.
- **David Roueche (co-PI),** Auburn University, serves as StEER Associate Director for Data Standards, ensuring StEER processes deliver reliable and standardized reconnaissance data.

StEER's response to the Sunda Strait Tsunami (Indonesia) preceded the formation of its official policies, protocols and membership, which are still in active development. All policies, procedures and protocols described in this report should be considered preliminary and will be refined with community input as part of StEER's operationalization in 2018-2019.

StEER Event Report Library

2018

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