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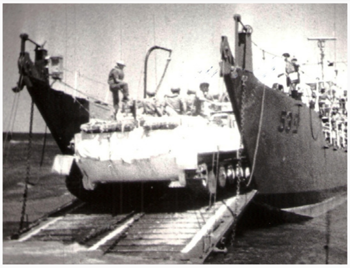
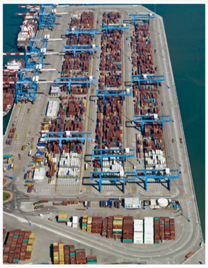


15. Tsunami in the Mediterranean

Dov Raz

Introduction

The concentration of Israel's population and critical infrastructures (electricity production, desalinization, etc.) along its coast, together with the history of earthquakes in the Eastern Mediterranean, increase the risk of severe damage from a tsunami.

A tsunami, or "harbor wave" in Japanese, is one the most unpredictable and destructive natural phenomenon in the world. The shocking scenes in the aftermath of recent tsunamis in India (2004), Indonesia (2004, 2018) and Japan (2011), which are burned into our memories, cost thousands of lives and caused massive destruction to coastal cities and infrastructure.

The goal of this chapter is briefly surveying the theoretical background and causes of a tsunami, the regional history of tsunamis and the potential for damage to the State of Israel as a result of a major tsunami. It also examines what actions can be taken in order to improve Israel's readiness for a tsunami.

Theoretical background

Like any wave, a tsunami is essentially a disturbance of energy moving through the water. In the case of ocean waves, which are known as "wind waves" because it is the wind that moves the water, the energy of the wave moves through the upper layer of the water only, that which is influenced by the wind. The accumulated energy in wind waves is influenced by three parameters: the wind's fetch, duration and strength. Also, in the case of swells, which are essentially distant "remnants" of wind waves after the wind has died down, the energy travels only in the upper layer of the water. In contrast to these waves, the energy of a tsunami wave is created as the result of a sudden and violent disruption and it travels in the water at depths of sometime hundreds and even thousands of meters. The length of a tsunami can reach hundreds of kilometers and its wave frequency can be tens of minutes. The speed of the wave is enormous and can reach hundreds of kilometers per hour. However, in the open sea its influence is almost negligible, as it reaches a height of only a few dozen centimeters in most cases and therefore is almost undetectable. These physical characteristics are what makes the tsunami so destructive (Salamon et al., 2014).

There are a variety of factors that can lead to the creation of a tsunami. The main one is a major earthquake, whose epicenter is located in the ocean. The second most common reason is a landslide on the continental shelf, whether it is caused by nature or by man. Other much less common causes are undersea volcanic eruptions, nuclear explosions, sliding icebergs and even a meteor crashing (Salamon et al., 2014).

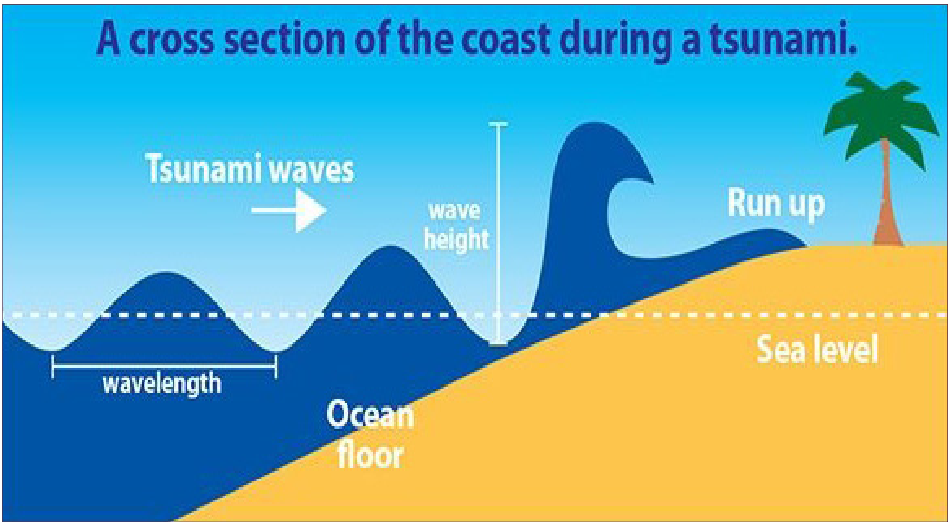

Figure 1: Illustration of a tsunami hitting the shore

The basic traits of a wave that make it so destructive when it hits land are the wave's speed and the fact that the energy is accumulated over the entire height of the water column. As the wave approaches land (Figure 1), the water becomes increasingly shallow and as a result the speed of the wave is accelerated to several meters per second and its length narrows to several dozen kilometers. The energy, which is preserved according to the Law of Conservation of Energy, starts to "push" the water upward to a height that can reach several meters. The intensity of the damage and the extent of flooding as a result of the wave is dependent on its power, on the gradient of the shore and on the topography of the shore (steep/flat) (Salamon et al., 2014).

In general, the contact with the shore initiates a rapid drawback of the water, which is reported often as a "disappearance of the water". The waterline can withdraw dozens of meters in some cases, followed by a high tide that rises the waterline significantly, creating an inundation that sweeps away everything in its path, depending on the characteristics of the wave and the shore. In rare cases and under certain shore conditions, the waves created can break at a height of several dozen meters. There can be a succession of waves that lasts hours or even a full day, during which there is flooding and then retreat of the water every few hours (Salamon et al., 2014).

Characteristics of a tsunami created by an earthquake

As mentioned, the most common cause of a tsunami is an earthquake. The movement of the earth's tectonic plates "pushes" the water upward (Figure 2) which causes the wave to propagate at 360 degrees perpendicular to the longitudinal axis of the earthquake. In such a scenario, the characteristics of the wave are the classic ones described above – a wave length of up to hundreds of kilometers and a frequency of several dozen minutes. These characteristics lead to the diffusion of energy over a very large area and therefore the force with which it hits the beach will be uniform and characterize by long wave lengths (Salamon et al. 2014).

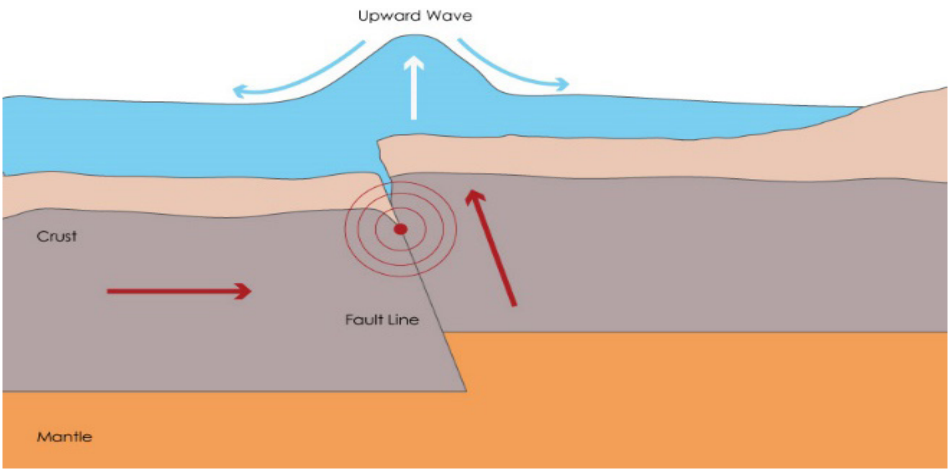

Figure 2: Creation of a tsunami by an earthquake

Characteristics of a tsunami as the result of a landslide

In the event of a landslide, the characteristics of the wave are somewhat different. The force of the wave (Figure 3) is dependent on the width, the volume and the speed of the landslide. This is a localized source of energy that moves along the seabed on a slope along a front of several hundred meters and therefore the greatest force is created along the landslide's axis of movement and diminishes laterally from the source of the landslide. A wave caused by a landslide is shorter in length than one caused by an earthquake (Salamon et al., 2014).

The expected damage from a tsunami

The immediate and most visible damage is of course the flooding on dry land, but that is not the only type of damage and other secondary phenomena are liable to cause serious damage to infrastructures along the coast. In the case of a large wave that starts close to the shore, the speed and flow of the water can reach a speed of 3–5 meters per second (Figure 4). The speed of the water alone can cause serious damage to buildings, infrastructure, movable property, etc. The sweeping away of movable objects (vehicles, garbage, boats, etc.) which are then smashed against buildings and structures can cause serious damage to infrastructure, beyond the direct damage to the objects themselves.

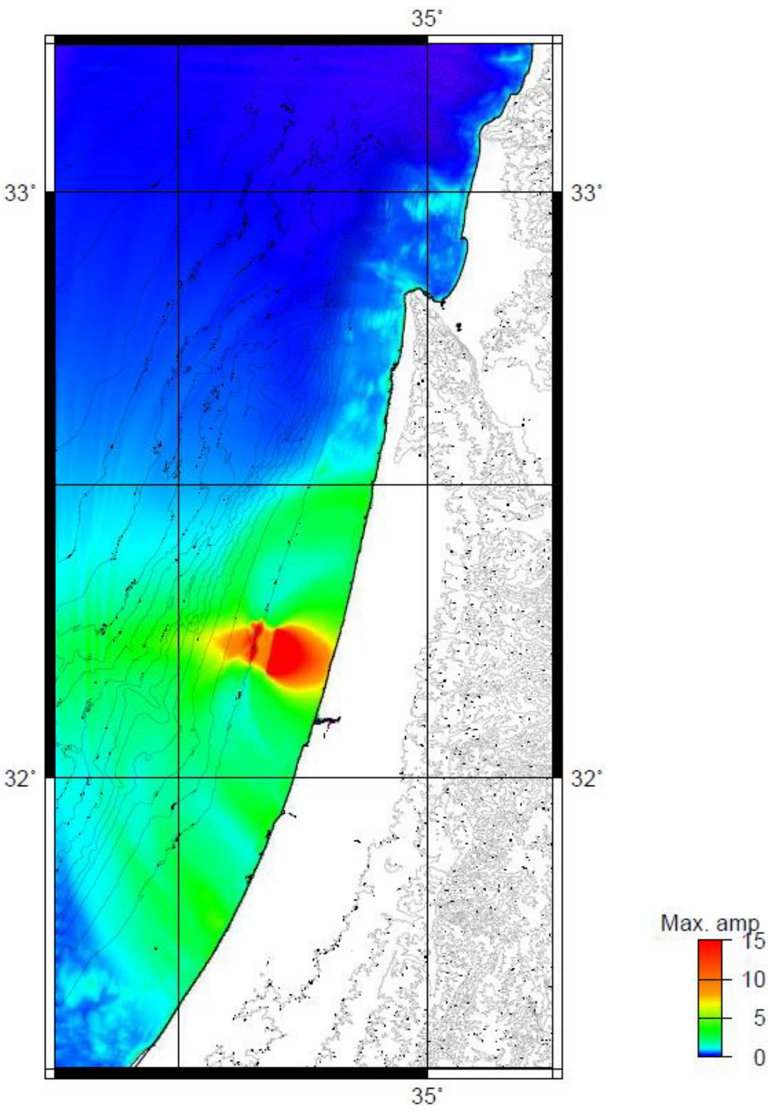

Figure 3: Depiction of a tsunami's force as a result of a landslide (Salamon et al., 2014).

There are other phenomena which are caused by the drawback that occurs prior to the flooding of the tsunami. The drawback of the water is liable to endanger harbors due to the sharp drop in the water level, which in turn leads to a lowering of the float level of any ship moored in the harbor that can cause damage to the harbor infrastructure as the result of broken moorings, damage to the piers or the smashing of vessels weighing hundreds of thousands of tons against the piers. There are a number of types of shore facilities that pump in seawater, such as power plants and desalinization plants, which are liable to be exposed to an interruption of intake due to the drop in the water level. Such an event can lead to serious damage and even to the complete destruction of the pumps and other systems, such as turbines for electricity production, desalinization equipment, etc.

Secondary phenomena that can cause long-term damage are the possible seeping of seawater into the groundwater, thus raising its salinity. In addition, the morphology of the coast is liable to change beyond recognition as a result of the shifting of large amounts of sand from dry land in the direction of the sea.

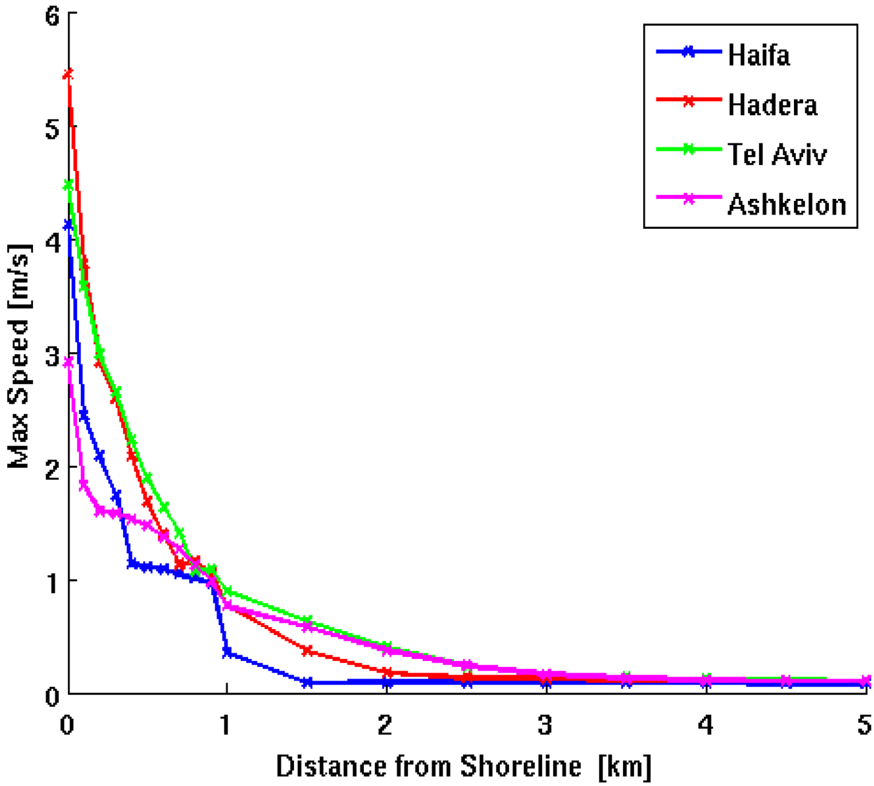

Figure 4: The predicted speed of flow (Galanti, Rosen and Salamon, 2009)

Historical background

The historical record shows that tsunamis have definitely occurred in the eastern Mediterranean. Figure 5 shows the tsunami events in this region during the past several millennia as a result of earthquakes (brown arrow) and as a result of landslides (yellow shading). As can be seen, most of the events that were caused by an earthquake had their source in the Hellenic arc that surrounds Crete and the eastern shore of Greece (Salamon et al., 2009).

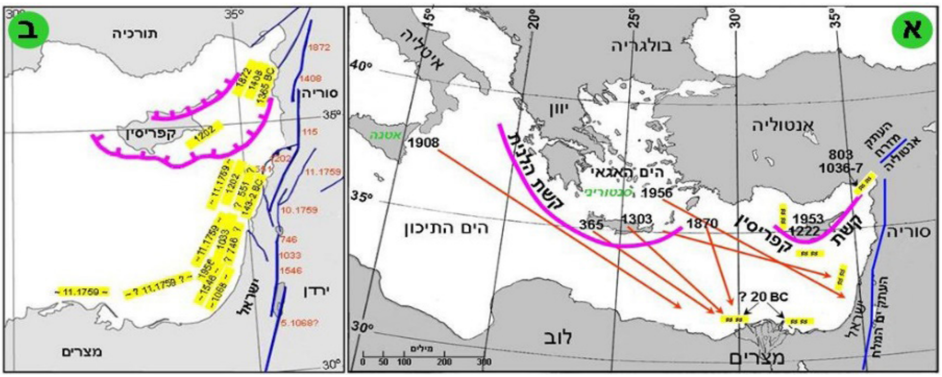

Figure 5: Tsunami events in the eastern Mediterranean (Almagor and Perath, 2012)

These events were analyzed by Salamon and other researchers (Salamon et al., 2009) based on both the historical record and geological and archaeological findings that testify to tsunami events. The analysis shows that tsunami events on Israel's coast occur in average every 200 years and once every 800 to 1000 years there is a large-scale tsunami. In about one-third of the events, there is documentation of damage to port cities and in another third there is documentation of loss of life (Salamon, 2009; Pareschi, Boschi and Favalli, 2007).

There are two events that occurred in Israel for which the documentation includes quantitative data and they can be used as historical references. The first occurred in 1759 and was apparently the result of an earthquake with an intensity of ~6.6 and whose source was in the area of Lebanon and northern Israel. According to the historical record, "the water rose to a height of 2.5 meters in the streets of Acre." However, it doesn't say where the measurement was taken and therefore it is difficult to ascertain the intensity of the wave. The second event was a wave that occurred in 1956 following an earthquake with an intensity of ~7.2, whose epicenter was in the Aegean Sea. It is unclear whether the wave was created as a direct result of the main earthquake or as a result of secondary shocks that occurred 13 minutes later. One way or another, there are researchers who have found evidence of the tsunami in Haifa Bay, but the main documentation comes from the records of water level in the port of Jaffa. The records shows a rise of 28 cm above the common water level, at intervals of 12–15 minutes and for a duration of more than 24 hours following the earthquake (Beisel et al., 2009; Salamon et al., 2009).

The potential damage from a tsunami in Israel

Before discussing the potential damage from a tsunami in Israel, it is worthwhile first discussing when and in what circumstances a tsunami can arise. According to various studies that have been done, there are a number of threshold conditions for the creation of a tsunami on the coast of Israel. The studies looked at scenarios of both an earthquake and a landslide.

An earthquake with the potential to create a tsunami needs to occur in the southeast portion of the Hellenic arc, and with an intensity of 7 or more on the Richter scale. In addition, the epicenter must be relatively shallow – up to a depth of 100 km below sea level. According to the historical record, it is estimated that at least two of these types of events have occurred with an intensity of 8 or more and with a frequency of once in 800–1000 years. Landslides must occur on the continental shelf or in the Nile Delta and the epicenter must be less than 100 km from the coast and with an intensity of 6 or more. The historical record shows that 8 such events are known of, with a frequency of once every 250 years.

Two reports by Israel Oceanographic and Limnological Research (Galanti, Salamon and Golan 2014; Galanti, Rosen and Salamon, 2009) analyzed the potential damage to infrastructure along Israel's coast. The extent of damage is of course dependent on the force of the tsunami, the coastline, the situation of the sea at the time of the event, the time of day and other parameters. Since the evidence of past events does not provide sufficient quantitate data, the analysis was based on computer models. The baseline event is based on a tsunami that occurred in 1303, in which an earthquake with a force of approximately 8 in the vicinity of the Hellenic arc caused a broad tsunami in the eastern Mediterranean. Although the researchers did not carry out a full analysis of the damage over the entire coast, they did consider a number of areas of particular importance, such as heavily populated areas, important infrastructure facilities, important maritime facilities (such as the natural gas platforms in the South), etc.

As can be seen in Figure 6, the predicted flooding in the Tel Aviv area is quite extensive. The water level is expected to rise in certain areas up to a maximum of ten meters and to inundate large areas. In Yarkon Park, which is relatively low, and near the mouth of the river (including the area of the Reading power plant), particularly extensive flooding is expected. In addition to the predicted damage in the Tel Aviv area, the reports predict additional potential damage. For example, in Hadera a cumulative rise and fall in the water level of about 10 meters is expected at the coal pier and a force of tens of tons is expected on its pillars as a result of the expected speed of the water's flow. In addition, severe damage is expected to the intake pipes of power plants and desalination plants due to the drawback/flooding and the sweeping away of movable objects and refuse which may result in the interruption of operations and destruction of the plants.

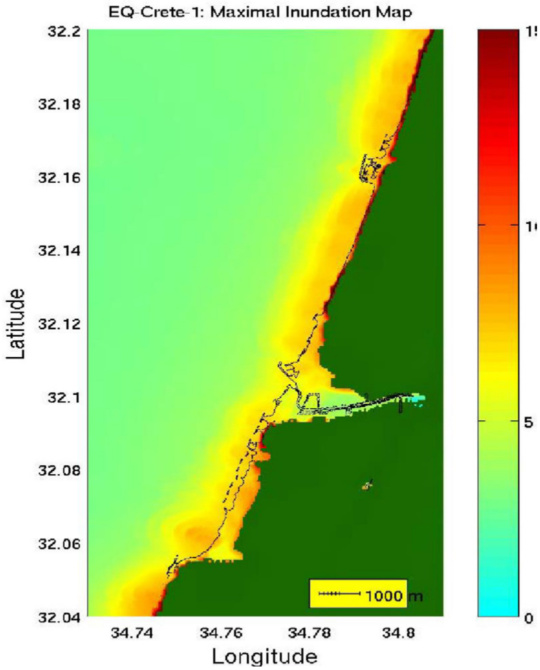

Figure 6: Predicted extent of flooding in the Tel Aviv area (Salamon et al., 2014).

Preparedness for a tsunami in Israel

Preparations in Israel began following a government decision in 2012 to take steps on a national level in order to prepare for a tsunami.[1] The decision primarily concerned the establishment of a national warning center, the *Nachshol Nitzpe* (observed surge), and creation of an ability to provide a warning in real time of a tsunami in the designated areas

1 Government Decision 4738 on June 7th, 2012: "The creation of a national earthquake and tsunami short-term warning system (the *Truah* and *Mayim Adirim* systems)" and at a later stage Amendment 5371 on February 20th, 2013.

using the *Mayim Adirim* (great water) warning system. The purpose of the center is to bring together all of the necessary components needed for the rapid identification and analysis of earthquakes, with the goal of evaluating in real time the level of danger from a tsunami and conveying the information and the warning by means of various media. It is important to mention that the center must deal with a relatively high level of uncertainty since a warning with a high level of confidence can be issued only after measurement of the water level and of parameters that provide evidence of an approaching tsunami. As a result, the plan calls for connecting the center to international warning systems and to establish cooperation and collaboration with various Mediterranean countries. The expected warning time for local earthquakes is only a few minutes and up to two hours for more distant events. Similarly, clear parameters have been set and according to the seismological data of the event a decision will be made as to the type of warning to issue (prepare/activate) and at what level of confidence (Salamon et al., 2014). Some of the preparedness is carried out at the municipal level and in recent years warning signs have been erected in some of the coastal cities (Figure 7) which are intended to mark areas of high tsunami risk and the route by which to escape.

Figure 7: Guidance signs for Tsunami event at the coastal zone of Haifa

In spite of the fact that the discussion of the government decision occurred in 2012 and that a period of three years was allocated to establish the warning system, the contract to build the center and install the warning systems was only signed in 2017 and work is currently expected to be completed by 2020. A report of the Knesset Information Center in 2017 stated that the level of preparedness of the local authorities is still low (Yachimovitch-Cohen, 2017).

Summary and conclusions

It appears that the occurrence of a major tsunami in the eastern Mediterranean is just a matter of time. The danger is amplified by the fact that the frequency of a major tsunami is once every 800 to 1000 years and the last one occurred in 1303. The geographic structure of the State of Israel and the concentration of infrastructure and population along its coast line, increases the potential damage to the point where it may take years for the country to recover from such event. The government decision on this issue which set 2016 as the target for the establishment of a warning center is being carried out at a snail's pace and the center does not yet exist.

Following are the components that are currently lacking in the State's preparedness for a large-scale tsunami:

1. **Raising the level of awareness among the population** – Most residents of Israel are unaware of the signs that have been placed on the beaches, the danger of a tsunami and what they should do in response to a warning.
2. **Implementation of the government decision** – There are gaps between the decision and the pace of implementation and also the domains to which the decision relates.
3. **Dealing with specific infrastructures** – A more in-depth analysis is needed of the possible extent of damage to essential infrastructures and in particular what can be done in order to prevent the damage or at least minimize it.
4. **Procedures for operating/shutting down essential facilities in an event** – If the emergency shutdown of facilities can save some of the infrastructure, then procedures for carrying that out are needed.

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