

TSUNAMIS AND THEIR IMPACT ON HUMAN ACTIVITIES

VALURILE TSUNAMI ȘI IMPACTUL LOR ASUPRA ACTIVITĂȚILOR UMANE

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Abstract: The regions where most of tsunamis originate are Japan, Peru, Chile, the New Guinea and the Solomon Islands. The emergence of tsunamis may be caused by the following factors: 1) earthquakes; 2) volcanic eruptions; 3) rockfalls; 4) landslides; 5) submarine landslides; 6) submarine explosions; 7) meteorological reasons. Damage is caused by: 1) flood due to quick rise of the sea level; 2) dynamic load on constructions; 3) hits by floating wreckages; 4) soil wash-out at foundations by the fast water stream; 5) fluctuations of water level (leading first of all to the damage of vessels moored; 6) dynamic impact of the air wave in front of a tsunami. Tsunamis cause considerable mortality and influence a number of objects and types of human activity: 1) residential and industrial buildings; 2) water transport; 3) plant growing; 4) forestry, etc.

Key words: economic loss, environmental significance, mortality, protection measures, tsunamis

Cuvinte cheie: pierderi economice, semnificație environmentală, măsuri de protecție, tsunami

DISTRIBUTION OF TSUNAMIS

Tsunamis are sea gravity waves of great length, emerging chiefly during submarine earthquakes as a result of extensive bottom areas' shift (up- or downwards) (The Geographic Encyclopedia, 1988, p. 334). In Japanese, the word means "a wave in harbour". The Japanese fishermen's settlements were often destroyed by tsunamis but the fishermen, who were out in the sea at the time, learned about it only on their return home. As their villages were situated on bays' coasts, the fishermen, unable to see the wave in the open sea, concluded that it had emerged just in the bay (Neshyba, 1991).

Tsunamis are a rather common phenomenon by seacoasts. According to N. A. Shchetnikov (1981), their **distribution** (%) to the oceans is as follows: Pacific – 75, Atlantic – 21 (including 12 per cent in the Mediterranean Sea), Indian – 3, Arctic – 1. According to other data, the Pacific Ocean coast accounts for almost 90 per cent of all tsunamis (The Natural-Anthropogenic Processes, 2004), their

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menace being real for 22 Pacific coast countries (Smith, 1992). The coastal regions of Japan, the Hawaiian and Aleutian Islands, Alaska, the Solomon Islands, the Philippines, Indonesia, Chile, Peru and the New Zealand in the Pacific Ocean, as well as the seabords of the Aegean, Adriatic and Ionian seas in the Mediterranean region most often suffer from these waves.

The regions where most of tsunamis **originate** are Japan, Peru, Chile, the New Guinea, and the Solomon Islands. Tsunamis' range of propagation depends on the location of their generating source. For example, for a tsunami to spread for the whole Pacific Ocean, the initiating event should occur on the Kamchatka Peninsula, the Aleutian Islands, the Alaska Bay or the South America coast. In their turn, the Hawaiian Islands being situated in the central part of the Pacific Ocean are subject to all the tsunamis that occur in its basin.

FACTORS CAUSING TSUNAMIS

Tsunamis have been studied by such researchers as S. Tinti, G. Pararas-Garayannis, M.A. Rafig, T. Murty, J.M. Gere, H.C. Shah, B.H. Choi, N. Imamura, C. Goto, K.O. Kim, I. D. Ponyavin, A. E. Svyatlovsky, N. A. Shchetnikov, S. L. Solovyov, B. V. Levin, V. K. Gussyakov, E. N. Pelinovsky et al.

The emergence of tsunamis may be caused by the following factors: 1) earthquakes; 2) volcanic eruptions; 3) rockfalls; 4) landslides; 5) submarine landslides; 6) submarine explosions; 7) meteorological reasons.

Submarine earthquakes are the most frequent cause of tsunamis' emergence. According to some data they account for 90 per cent of such events (The Seismic Dangers, 2000); according to the others, for 99 per cent of tsunamis (Muranov, 1994). But not every submarine earthquake causes a tsunami. It is necessary a certain depth of the centre (the depth over 50 km usually does not cause tsunamis) and a certain mechanism. It is considered that the sea bottom's vertical dislocation is a must (Gere, Shah, 1988).

Volcanogenic tsunamis emerge due to volcanic explosions. The appearing calderas immediately become filled with water that causes a long and high wave. Two tsunamis of this kind are considered the strongest ones. The first one occurred in 1450 B. C. as a result of the Santorin volcano eruption in the Aegean Sea; the second one – on August 27, 1883 during the explosion of the Krakatoa volcano in the Strait of Zond. The wave's height on the Java and Sumatra Islands was 36 – 40 m and the Dutch gun-boat "The Berrow" was carried away by the wave to 3 km from the coast and raised to 10 m high (Dvorzhak, 1989). The wave passed all the oceans at the speed of 800 km/hr; it destroyed more than 5 thousand vessels and killed 36 thousand people. It reached Panama at the distance of 18350 km (Gere, Shah, 1988; Miroshnikov, 1989; Smith, 1992).

Rockfalls and landslides (both underwater and above-water ones) which lead to tsunamis are, in their turn, usually caused by earthquakes. At least two strong tsunamis due to landslides are known. The most known case of the tsunami took place on July 9, 1958 in Alaska; its reason was the falling of a total volume about 300 million cubic meters of ice and rock from the height of nearly 900 m from the Lituya glacier into the bay with the same name (Rezanov, 1984; Shchetnikov, 1981). According to different data, the wave surge was as high as 500-600 m. The most reliable figure seems to be 530 m (The Natural-Anthropogenic Processes, 2004). The second example of this

kind was the tsunami from Norway in 1934. It was the fall-down of a rock of nearly 3 million tons from 500 m height that provoked a 37 m high wave. That tsunami caused multiple human victims and threw several little boats for tens of meters far ashore (Kononkova, Pokazeev, 1985).

There are records of tsunamis caused by **submarine landslides**. For example, during the Alaska earthquake in 1964, they provoked waves that were propagating in fiords on-shores up to 30 m marks (Myagkov, 1995). Another example of this kind is the December 1951 tsunami that caused great destructions on coasts of Puerto Rico and Barbados. An underwater landslide emerged on the slope of the ocean basin of Puerto Rico at calm and a complete absence of seismic shocks (Kononkova, Pokazeev, 1985).

A tsunami caused by an **underwater explosion** took place in 1946. At that time an underwater nuclear explosion with the trotyl equivalence of 20 thousand tons was performed by the Americans in a sea lagoon at 60 m depth. The emerged wave rose as high as 28.6 m at 300 m distance from the explosion site, and at the distance of 6.5 km from the epicenter it was still as high as 1.8 m (Vlasova, 2004).

Meteorological tsunamis are caused by sudden fluctuations of atmospheric pressure. Such phenomena were observed in the Nagasaki Bay (Japan), not far from the Kuril Islands, the port of Lunkow (China), the Ciutadell Bay (the Menorca Island, Spain). Meteorological tsunamis may also cause destructions and human loss in coastal regions ((Rabinovich, Monserrat, 1996).

SOME CHARACTERISTICS OF TSUNAMIS

The destructive power of tsunamis depends on the following factors: 1) the depth of an earthquake's or eruption's center (the less, the more powerful); 2) the center's dimensions; 3) water layer's thickness (the thicker, the more powerful); 4) an earthquake's strength or the mass of the fallen rock; 5) the distance from the place of emergence to the shore; 6) the bottom and shore relief features on the way of the wave's propagation (the less the slopes, the stronger the wave); 7) configuration of the coast line (most dangerous are taper bays and straits).

For evaluating tsunamis evaluation, it is used the A. Imamura – K. Iida Scale. It is based on waves' height and damage caused by them (table 1). Tsunamis' basic parameters according to different authors are listed in the table 2.

Tsunami wave's **speed** is closely connected with the depth. For example, if the wave's speed at the depth of 4,000 m is 720 km/hr, at more shallow plots it will make up: 1,000 m – 360, 720 m – 160, 50 m – 80, and 10 m – 36 km/hr (Seismic Dangers, 2000). Decrease in speed is accompanied by the corresponding enlargement of the wave's height. Wave's length is closely connected with these characteristic. Provided a wave is 200 km long, it will be only 0.5 m high and ships crossing these waves usually do not notice them (Jensen, 1994). A wave's transformation and growth are noticeable only from the depth of about 200 m; they emerge particularly intensively from the depth of 10 – 15 m (Shchetnikov, 1981). In the coastal shallow-water area the wave becomes deformed: its height and the front steepness grow. While nearing the shore, the wave turns over. This very high foaming water flow is what causes the main destructions on the shore.

Contrary to the wide-spread opinion, a tsunami is **not a single but several waves** (usually three or four). The maximum surge height is, as a rule, typical for

the second or the third wave. As a tsunami's height is closely connected with hydrography, its value may greatly differ even in the neighboring areas. For example, in wedge-shaped bays creating a funnel-effect, it increases.

Table 1

Tsunamis Intensity Scale
(The Natural-Anthropogenic Processes ..., 2004)

| Tsunami | | Wave's height, m | Damage caused |
|---------------------|-------|------------------|---|
| Value | Force | | |
| Weak tsunami | 0 | Up to 1 | No destructions on the shore |
| Moderate tsunami | 1 | Up to 2 | Summer constructions on the shore are destroyed, small light boats may be thrown ashore |
| Strong tsunami | 2 | Up to 6 | Destruction of light and damage of solid buildings, damage of embankments. Considerable economic loss and victims |
| Very strong tsunami | 3 | Up to 20 | Tsunami affects a coast line up to 400 km long. Complete destruction of light constructions and buildings and considerable damage of solid ones. Damage of all vessels except the largest ones. |
| Destructive tsunami | 4 | >20 | Bad damage or destruction of constructions and buildings of any type along the 500 km coast line. Multiple victims and huge economic loss. |

Table 2

Tsunamis' basic parameters according to different authors

| Source | Max. propagation speed, km/hr | Wave's max. length, km | Max. height in the open sea, m | Max. surge height, m | Max. period, hr |
|-----------------------------------|-------------------------------|------------------------|--------------------------------|----------------------|-----------------|
| The Geographic Encyclopedia, 1988 | 1000 | — | 5 | 50 | — |
| Gere, Shah, 1988 | 800 | — | — | — | 1.7 |
| Jensen, 1994 | 780 | 200-300 | — | 35 | — |
| Kononkova, Pokazeev, 1985 | 800-1000 | — | — | 40 | 3.3 |
| Kukal, 1985 | 1000 | 150-300 | — | 70 | — |
| Muranov, 1994 | 700-800 | — | — | — | — |
| Myagkov, 1995 | 800-1000 | — | 5 | 100 | — |
| Rezanov, 1984 | 1000 | — | — | 70 | — |
| Shchetnikov, 1981 | 1000 | 400 | 3 | 40 | 2.5 |

On the other side, any shallow-water area near the shore decreases the waves' height. Tsunamis are often preceded by low sea level change. With equal share of probability it may be both water level drop by the seaside, and its rise. It depends

on the part of the wave (a crest or a foot) affecting the given area of the coast, as well as on the direction of the bottom area shift (up- or downwards).

TSUNAMI IMPACT ON HUMAN ACTIVITIES

We may mark out the following **reasons for damage** caused by tsunamis (Gere, Shah, 1988): 1) flood due to quick rise of the sea level; 2) dynamic load on constructions; 3) hits by drifting wreckages; 4) soil wash-out at foundations by the fast water stream; 5) fluctuations of water level (leading first of all to the damage of vessels moored; 6) dynamic impact of the air wave in front of a tsunami.

Tsunamis cause considerable mortality and influence a number of objects and types of human activity: 1) residential and industrial buildings; 2) water transport; 3) plant growing; 4) forestry etc.

Of the six listed factors of tsunamis' impact, the first three mainly lead to **people's deaths**. In every separate case any of them may come to the forefront. Sometimes people got drown because of the fast *water rise*. In other situations they perish mainly due to *residential buildings' destruction*, particularly if the tsunami occurred at night time. Sometimes the main reason is *hits of drifting wreckages* if the coastal territory is littery. In that case objects and equipment, thrown and carried away by the water stream, may cause a mass perish of people. For example, in the case of two tsunamis, the first one registered on January 1, 1996 in Indonesia and the second on July 17, 1998, in Papua-New Guinea, all the human victims were due to concussions with other objects moving in water at high speeds (The Seismic Dangers, 2000).

The performed analysis of **mortality** and **economic loss** due to tsunamis in the 20th century enabled us to estimate the average annual mortality to 100 – 150 people and the economic loss to \$100 million (Govorushko, 2003). As per these figures, tsunamis are far less competitive with their nearest “relatives” – earthquakes and volcanic eruptions. However, the most destructive tsunami in the history of mankind, which occurred in the Indian Ocean by the north-west coast of the Sumatra Island on December 26, 2004, made us revise this conception to a great extent. As its result, 294,743 people from 55 countries perished or were declared missing, more than 5 million people were wounded, about 1 million people found themselves homeless (http://tsun.sccc.ru/tsulab/20041226fat_r.htm). Indonesia, Sri Lanka, India, and Thailand suffered most of all (Rodriguez et al., 2005).

A certain contribution to the economic loss and, evidently, to the death-rate, was made by the *earthquake* initiating the tsunami. At least, residential and industrial buildings were destroyed on the territories which were not subject to the waves. However, the earthquake's aftereffects may be considered unessential. By the Sumatra Island there were five waves, the second and the third ones being the most powerful. The maximum surge height was 15 meters (Kurkin et al., 2005). Hitherto most victims were claimed from the June 15, 1896 tsunami, when after the earthquake in the Japanese lauder, a 30-meter high wave killed 27,122 people (The Reference Book ..., 1994).

Tsunamis' impact on **residential buildings** is typical enough and has been known from a long time. During the archeological diggings of the Ras Shamra settlement (Syria) there were found tablets dated back to two thousand years. They read about an enormously high wave which had ruined the capital of the

ancient state of Ugarit that had been located there (Vlasova, 2004). Actually any tsunami destroys constructions in the area of its activity. The main impact factor is the *dynamic wave load*, as well as *hits by drifting wreckages*. The minor factors are *flooding* and *wash-out of soil* from under foundations.

From this point of view, the most famous are the tsunamis registered in Japan. The March 3, 1933 tsunami by the Sanriku coast (the northern part of the Honshu Island) ruined 9 thousand buildings and the tsunami in the same district destroyed 10,600 houses on June 15, 1896 (The Reference Book ..., 1994).

Influence on water transport is a tsunami's common result, too. Here of cardinal significance are the *dynamic impact of waves* and *water's level fluctuations*. In the first case vessels are thrown ashore, in the second one moored ships are damaged. As a result of a volcanogenic tsunami 5 thousand ships perished (Miroshnikov, 1989). During the tsunami of December 26, 2004, in India alone 31 thousand catamarans and over 9 thousand other vessels were destroyed (Shinde, Gokhale, 2005).

The effect on **plant-growing** and **forestry** is connected with *flooding* and the *dynamic impact of waves*. Due to waves' strokes soil gets covered with sand and silt, and woodlands and fruit plantations are destroyed. Arable lands become worthless and crops perish due to water salinity, but it is less important because of a comparatively short duration of flood. The impact of tsunamis on these types of activity has much in common with the impact of wind-induced surges.

ENVIRONMENTAL IMPORTANCE

Tsunamis have a definite ecological significance as they influence a number of natural components: 1) soil; 2) flora; 3) fauna; 4) surface waters, etc. The influence on **soil** is shown in its erosion, pickling, covering with deposits layers, etc. The influence on **flora** is shown in its damage and complete obliterating. For example, during the February 4, 1923 tsunami in the Pervaya Rechka Valley (the Ust-Kamchatka region) the forest was uprooted for 7 – 8 km long (The Seismic Dangers, 2000). After the tsunami of December 26, 2004 some flat islands, primarily covered with mangrove forests, completely lost their vegetation (Kurkin et al., 2005).

Sometimes tsunamis negatively influence the situation with **marine hydrobionts** but the mechanism of this influence is not known yet. Probably it is connected with acoustic waves. For example, after the tsunami of June 18, 1780, as it was reported in the chronicle, “manufacturers seized going to the Kuril Islands because collectors who sailed there annually, informed that after the earthquake sea beavers had died out completely” (Seismic Dangers, 2000).

Tsunamis lead to change in **temperature conditions** of water mass. In the zone of intensive vibrations of sea bottom, a quick rise of cold abyssal waters frequently happens, which leads to the drop of surface water temperature by 5-6 degrees. The diameter of such temperature anomalies reaches 500 km, and their duration may exceed 24 hours (Koronovsky, Yasamanov, 2003).

FORECAST OF TSUNAMIS

As for tsunamis forecast, it may be divided into **short-term** and **long-term**. A *short-term* (i.e. a tsunami forecast after the earthquake that has already occurred) is developed rather well. It is based on the difference between the seismic waves'

propagation speed in the earth's crust and tsunami waves' propagation speed in an ocean. In comparison with tsunamis, seismic waves' rate of movement is 50-80 times higher (Vlasova, 2004). There exists The Tsunamis' Forecast Service with its center in Honolulu (the Hawaiian Islands). Records from 31 seismic stations and 50 mareographic posts are processed there. From the moment of an earthquake's detection to the waves' arrival only 15-20 minutes may pass, so forecasts should be broadcasted immediately. In cases of distant epicenters a few hours may count for everything. When a tsunami emerges at the opposite coast of the Pacific Ocean, the time of waves' propagation is up to 20 hours.

It should be noted that some earthquakes give rise to "*harmless*" tsunamis, but the warnings are broadcasted all the same. Due to this, people get used to "unjustified" alarms and do not react to important warnings. For example, the emergence of the tsunami due to the May 21, 1960 earthquake under the bottom of the Peru – Chilean chute was informed beforehand, together with indicating the exact time of the wave arrival to different regions of the Pacific Ocean. Nevertheless, 205 people were killed in Japan where the waves had arrived 15 hours later (Kukal, 1985).

Registration of *hydro-acoustic signals* (the so-called T-phase) may help to increase forecast reliability of a tsunami generating by a particular earthquake. An acoustic wave propagating in water from a tsunami's source, moves at 1500 m/sec speed, i. e. 7.5 times faster than a tsunami wave in an ocean. There are already events of registering acoustic waves by means of satellite observations. First it was made while registering a tsunami after the Guam earthquake of 1993 (Seismic Dangers, 2000). A *long-term tsunami forecast* actually refers to powerful earthquakes' forecasts.

PROTECTION MEASURES

We may single out the following **measures of decreasing** tsunamis damage aftereffect: 1) use for human activity such coastal areas where the risk of their emergence is minimal; 2) tsunami-resistance constructional engineering; 3) erection of protective constructions.

To define the *probability of a tsunami emergence* in a given place during a definite period of time and with a specified wave's height, the information on historical events, numerical simulation methods, statistical methods, etc. are used. These measures, to a great extent, are based on the knowledge of regularities of waves' transformation according to characteristic properties of the bottom relief and the coastal line configuration. For example, for harbor's constructions, it is advisable to use ocean-protected bays with narrow gates, while hydro-engineering and coastal constructions are better to locate at shady (closed to the entrance) sides of capes, etc.

Tsunami-resistant construction has two trends: 1) erecting constructions with increased margin of safety; 2) construction with due regard to tsunamis' certain effects. The first trend is rather expensive. The second one may include disposition of buildings with their long side towards a tsunami's passage, the maximum "openness" of ground floors, erecting houses on high pillars, etc.

Erection of *protective constructions* (breakwaters, protective concrete dams, protective banks made of big stones, afforestations, etc.) is rather common but in case of powerful tsunamis it may prove to be useless.

Different aspects of tsunamis' impact on human activity are illustrated by photos 1-8.

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Photo 1. Dynamic impact of waves is one of the crucial destructive factors of tsunamis. The magnitude 9.2 earthquake of March 27, 1964 generated a 31.7 m high wave. The photo shows a 5.2x31 cm plank in a truck tire at Whittier, Alaska. At this area the waves destroyed two saw-mills, a tank farm, a wharf, a railroad depot, and several buildings.

Photo: U. S. Geological Survey.



Photo 2. The magnitude 7.4 earthquake of April 1, 1946, the Aleutian Islands, generated a vigorous tsunami. This picture illustrates a 5.1 m high tsunami advancing on the railroad bridge at the mouth of the Wailuku River near Hilo, Hawaii. A span of the railroad bridge, missing on the photo, was torn away 273 m upstream by the previous wave.

Photo: University of California, Berkeley, the USA.



Photo 3. Tsunami impact on the coastal industrial and civil areas is no news. The photo shows the wave approaching to Oahu Island, the Hawaii. The magnitude 8.6 earthquake of March 9, 1957 occurred 3600 km away from the Hawaii, at Adak Island, the Aleutians. However, the earthquake triggered a tsunami that caused \$5 million property damage for Hawaii St. The highest wave mounted 10.4 m. Located in the central part of the Pacific Ocean, the islands suffer from all tsunamis occurring in the Pacific.

Photo Credit: Henry Helbush.



Photo 4. Water transportation is one of the realms badly suffering from tsunamis. The impact of tsunami on water transportation is mainly exerted through dynamic waves' impact and water level fluctuation that damages berthed vessels. The photo shows the fishing boat configured for catching squid is beached high by tsunami surge at Okushiri Island. Next to it fire-engine is located.
Photo Credit: Dennis J. Sigrist, 1993.



Photo 5. Tsunami impact on motor transportation mainly lies in destruction and damaging of roads at the seashore. Right below, one can see the ruins of tar-concrete road Banda Aceh - Calang, the northwest coast of Sumatra Island, Indonesia. The road, together with the coast area itself, was demolished by the tsunami of December 24, 2004. In the middle of the photo, one can see the new road.

Photo Credit: Elizabeth Babister, October 16, 2006.



Photo 6. Tsunami rarely impacts on railroad transportation directly. A railway accident near Hikkaduwa Station, the southeast coast of Sri Lanka, became one of the consequences of the calamitous tsunami of December 26, 2004 in the Indian Ocean.

Photo Credit: S.S.L. Hettiarachchi



Photo 7. In environmental point of view, tsunami damages or even completely annihilates vegetation. The photo shows stark desolation of the part of Babi Island located 5 km from Flores Island, the Zondian Islands, Indonesia. The island was hit by the tsunami of December 12, 1992.

Photo Credit: Harry Yeh, University of Washington, the USA.



Photo 8. Tsunamis frequently destroy coral reefs. Thus, the severe tsunami of December 26, 2004 that emerged near the northeast coast of Sumatra Island broke off huge blocks of corals and transported them up to 400 m far inland. The photo shows the block of reef limestone dimensioned as 0.9x1.4x2.25 m. The block was thrown into Similue Island as far as 200 m inland.

Photo Credit: N.G. Razzhigaeva, Pacific Geographical Institute, Russian Academy of Sciences, January 2005.