About Regional Standard “Buildings, Structures, and Safety Requirements Under Tsunami Impact”

Dr.Prof. Igor Nudner, Dr. Mark Klyachko,
Dr.Prof. Vasily Maximov & Eng. Vladislav Filkov
RADAR, NPO, Saint-Petersburg, Russia

SUMMARY:
Regional (interstate) standard "Buildings, Structures, and Areas. Safety requirements under tsunami impact" which is in line with a new conception of comprehensive tsunami safety and regulates land use, planning, construction and service activity in tsunami hazard regions is under consideration. The safety requirements concern to coastal lines with a run-up height of more than 0.5 m. The initial parameters of tsunami run-up with probability once per 100 years are studied and given for coastal line of Pacific and Black sea. Tsunami run-up estimation may be get by means of tsunami event scenario producing when characteristics of tsunami wave are assigned using parameters of triggers - underwater earthquake or landslide. Requirements are related to both floating, port & marine construction and to coastal structures. Rules for assigning of loads from non-broken and broken waves on structures of various shape, permeability and streamlining are subjected. Elaborated calculation and designed procedure is represented in details both for new and for existing structures. Besides the formulae to assess the tsunami inundation area are applied, that is required for city planning activity. All of the given formulae are based on a variety of hydraulic tests, on physical and mathematical simulation of long wave propagation and their interaction with water area, structures, and coastal line. These experiments were basically fulfilled by the end of 1980th. Permissible tsunami risk criteria are proposed. Planning and engineering measures of buildings and areas protection against tsunami impact are elaborated and given. For tsunami safety of flat and lowlands special engineering structures are provided to escape tsunami and prevent human losses. Standard is accompanied by supplements among which examples of effective tsunami protection are shown.

Keywords: tsunami impact, marine and coastal structures, tsunami loads, structures, safety requirements

INTRODUCTION & BACKGROUND

It’s after the catastrophic tsunami in 1952 that many specialists in our country became interested in the tsunami safety problem not in its “evacuation” but in the “engineering” aspect. Town-planning methods of solving this problem were implemented under the direction of L. N. Puterman when moving Ust-Kamchatsk to a higher, tsunami-safe place in the beginning of the 1960’s. However, the Resolution of Council of Ministers of RSFSR No. 19 dated 08.01.1964 completely interdicted constructional reclamation of tsunami-safe coasts. Such approaches and decisions do much harm because on the one hand, its sea coasts (especially large river mouths) that are the most attractive for development of economy, trade, which means the most attractive for bigger concentration of construction objects and population. On the other hand, formal prohibition to overbuild tsunami-hazardous regions (THR) does not allow to create and develop construction regulations for protection of onshore and offshore facilities and reduction of economic risk and material damage which has been growing uncontrollably during the recent years, and not only on the Pacific coast.

And yet, from the beginning of the 1970’s, the first engineering problems of interaction of various barriers with waves like tsunami were set and were solved in Research Center on Capital Construction 26 of USSR Ministry of Defense with use of model experiments with active participation of I.Nudner and V.Maximov. Attempts to develop tsunami engineering code and rules to increase the safety of floating, onshore and offshore structures in tsunami hazardous areas (THA) and reduce real economic damage caused by this destructive and unpredictable phenomenon were repeatedly initiated by M.Klyachko since 1982. In 1988, a positive decision for development of such code was finally made, but it was never implemented due to the breakup of the Soviet Union. While executing the order of the Emercom of Russia dated October 28, 1991 on development of program system for promotion of safety of population of RSFSR in conditions of natural, elemental disasters and technological catastrophes, the Far East Association "Reliability and Safety" prepared, among others, the program No. 3 "Tsunami" which in 1993 became part of the program "Protection of coastal territories from dangerous seawater impacts". Due to lack of accuracy in decisions and actions of the federal center and incoordination and inconsistency of interests of Russian Federation subdivisions, this Federal Target Program turned into a territorial program, because federal financing was only allotted in small quantity to Primorsky Krai. In 2000, as a result of collaboration of RDC for antiseismic construction with heads of RFE and other Russian Federation subdivisions, under the auspices of some ministries and agencies and after appeal to President and Prime Minister, there appeared an RF Government Order dated 26.08.00 No. XB 119 – 23942 to the Russian Federation State Committee for Construction, Architectural and Housing Policy in association with the Ministry of Defense of the Russian Federation, the Ministry of Finance of the Russian Federation and Russian Committee on Hydrometeorology to address matters related to development of Federal Target Program for protection of cities, settlements and industrial facilities from tsunami impact (FTP "Tsunami"). RDC for antiseismic construction of the Russian Federation State Committee for Construction, Architectural and Housing Policy as the initiator and author or a new paradigm of tsunami-hazard, by order of Town-planning department, developed a concept, flow diagram and the substantial part of FTP "Tsunami". The Russian Federation State Committee for Construction, Architectural and Housing Policy did not make this FTP independent and included it as part of FTP "Protection of sea coasts from dangerous environment impacts", which, due to awkwardness and inconsistency of the declared excessive financing, was not included by the Government of the Russian Federation in the list of FTP financed from 2002. This issue was only returned to again after the catastrophic tsunami of 27.12.2004 in the Indian Ocean and the corresponding orders of President and Government of the Russian Federation.

Until recently and predominantly now the policy of tsunami disaster prevention and mitigation consists of alarm warning and anticipatory evacuation of population from tsunami-hazardous zones. At the same time, in consequence of economic reclamation of shelf, development of coastal cities, ports, sea HES's and, especially, potentially dangerous facilities which become more and more vulnerable to tsunami impact, the complex tsunami risk is growing considerably. Possible material losses of society are growing quicker, and besides, secondary technological dangers to population of tsunami-hazardous areas are appearing, which arise from fire and explosion hazardous containers with oil products, gas collectors, facilities which process and contain chemically dangerous substances and others. This is why in June 2000, on the International Seminar for tsunami mitigation in Moscow, M.A. Klyachko presented a new conceptual approach to evaluation of tsunami risk consideration to ensure stable development of tsunami-hazardous coasts. The point and content of this approach implies that in addition to the system of alarm warning and evacuation - WADE block (Warning Alert Detectors, Evacuation), which is traditionally implemented and developed in the Pacific Ocean, the standard complex tsunami-safety program must provide for other 3 very important blocks: 1) HITs - (Tsunami Hazard Identification) – determination of tsunami danger; 2) FLEET – (Force & Loads, Tsunami Engineering Evaluation) – tsunami load and impacts and engineering evaluation; 3) TSAR – (Tsunami Safety, Risk Analysis and Reduction) – tsunami risk analysis and reduction for tsunami-safety.

It's important to note that in order to implement the final target block TSAR, it was necessary to preliminarily understand and assign tsunami-risk values acceptable and allowable (normalizable) for a specific community. Then it became possible to develop land-use recommendations and counter measures considering world experience of tsunami counteraction, both town-planning (settlement planning), and engineering – reduction of tsunami impact on buoyant, shelf, onshore and offshore facilities and improvement of resistance of these facilities to tsunami impact.

All substantive aspects were included in the block-program "Tsunami safety" approved in autumn 2001 in Cartagena (Columbia) on the UNESCO session devoted to the tsunami problem, and implemented in the IGS project "Buildings, structures and areas. Safety requirements under tsunami impact".

1. IGS AIMS AND SPHERE OF APPLICATION

Tsunami safety is understood to mean the conditions of onshore and offshore facilities and THA occupied by or adjacent to them, where tsunami impact does not involve danger to life and health of people, cause secondary disasters, or disturb operation of special lifelines and facilities infrastructures, and material/economic losses do not exceed allowable levels.

The standard is designed for promotion of safety of population and territories susceptible to tsunami, and onshore and offshore facilities located in tsunami-hazardous areas.

The standard set obligatory requirements to:

- designing new structures and reclaimed coastal territories;
- reconstruction and capital repairs of existing structures and territories reclaimed earlier;
- preparing of safety declaration and certification of responsible port HES's and onshore potentially dangerous facilities under tsunami impact;
- estimate of consequences of possible tsunami and tsunami-risk analysis;
- designing special structures for vertical evacuation.

The standard considers, first of all, seismogenic tsunamis. However, all estimations and requirements contained in the standard are valid in relation to any waves of tsunami type.

2. APPROACHES AND STRATEGY

Tsunami safety is achieved with the help of package of measures for protection of territories and building and structures. The complex approach to the problem and the system of tsunami-protection measures includes all the 4 program blocks mentioned above: HITs, WADE, FLEET, TSAR. However the standard under question preeminently implements the engineering blocks FLEET and TSAR.

HITs block is represented by Appendix A to the Standards which is obligatory and is made up following the results of general tsunami regionalization works. It introduces the initial parameters of design height of runup with recurrence period of once every 100 years pegged to different water areas, bays and settlements on the Pacific and Black Sea coasts. For non-standard tsunami-hazardous shore, as well as for responsible structure, the design tsunami parameters must be assigned on the basis of the mathematic and physical simulation.

WADE block is only slightly touched in the standard, just as related to development of engineering structures necessary for vertical evacuation of population.

FLEET block for estimation of tsunami impact on structures and territories also implies development of disaster scenarios with consideration of different design events. For each design event, a possibility of occurrence of limit conditions is estimated and risk level assessment is carried out (TSAR block). If the risk level exceeds the allowable value, a decision is taken about preventive engineering and planning measures to protect buildings, structures and areas against tsunami. The decisions taken also reflects the aims of prevention and mitigation of emergences caused by tsunami.

The standard includes the safety criteria, conditions and requirements imposed to harbor (berthing, protecting, and lifting) structures and onshore facilities of industrial and civilian designation. Rules of assignment of loads from tsunami in the forms of boron and solitary wave on structures of different forms, size and streamlining are developed. Rules and requirements are given for analysis of onshore and offshore facilities under tsunami impact. The main engineering and planning methods of protection of buildings, structures and areas from tsunami area listed. The standard is accompanied by examples of HES analysis for tsunami impact and engineering measures for tsunami risk reduction.

The standard uses terms and definitions harmonized with those accepted in the world practice, which are complemented by new notions. The following terms and definitions are accepted in it.

Standard tsunami-hazardous coast – a coast with smooth bathymetry variation and even coastline.
Structures non-streamlined – structures having a significant extension along the wavefront and solid surface (protecting, coast protecting, berthing of gravitation type, etc.).
Structures permeable – structures made of rod elements of lattice or truss construction.
Structures poorly permeable – onshore structures with upstream faces having separate apertures, holes (dwelling and process buildings, separate onshore buildings, etc.).
Structures streamlined – hydrotechnical engineering structures of short extension along the wavefront (lighthouse, bridge footings, etc.).
Structures through – hydrotechnical engineering structures having a series of free standing or lattice poles (piers, flyovers, etc.).
Tsunami close – a tsunami, the propagation time whereof from the source to the coast under consideration is less than 3 hours.
Tsunami designed – a tsunami with a specified altitude of vertical offset with average repeatability of once every 100 years.
Tsunami distant – a tsunami, the propagation time whereof from the source to the coast under consideration is no less than 3 hours.
Tsunami-hazardous area (THA) – a coastal zone (water area and territory) with a possibility of occurrence of tsunami waves with offset altitude of 0.5m or more and repeatability of no less than once every 500 years.

Tsunami-hazardous areas are divided into the following types:
A – areas where only distant tsunamis are possible (Pimorsky Krai, Magadan region);
B – areas where close tsunamis are possible (Kuril Islands, Kamchatka).

Hydrotechnical engineering structures (HES) considered in the standard include:

- coast protection (non-harbor), protecting structures;
- HES’s of shipbuilding and shiprepairing organizations;
- HES’s of navigation equipment;
- free standing service and support berths;
- ice protection structures.

HES’s, depending on their height, social and economic responsibility and consequences of possible emergencies are divided into four classes.

For all HES’s located in tsunami-hazardous areas, tsunami safety certification must be executed according to the following criteria:

- by social and economic significance level – life-support infrastructures which must operate uninterruptedly.

Tsunami safety – condition of onshore and offshore facilities and tsunami-hazardous areas occupied by or adjacent to them, where tsunami impact does not involve danger to life and health of people, cause secondary technological disasters, or disturb operation of special vital infrastructures, and material/economic losses do not exceed allowable levels.

Tsunami safety depends on numerous factors including the degree of the tsunami-hazardous zone urbanization, probability and extent of secondary disasters, readiness of the tsunami-hazardous zone for the emergency, etc.

For the practical purposes the tsunami safety should be subdivided into 4 levels: high (TS1); average (TS2); low (TS3); unacceptable (TS4).

The levels of tsunami safety are provided by the parameters shown in the table 1.

Tsunami safety of the territory is evaluated with the help of scenarios of probable disasters that are developed for each design event, that is provided for in the programming unit TSAR. The design event is a combination of loads where the tsunami impact load is taken as a super load. For each hydrotech-

nical structure or onshore facility it is necessary to consider several design events. Each combination contains constant loads, imposed loads of frequent repeatability and tsunami load.
At the first it is recommended to take the level TS3 for developing countries and the level TS2 for developed countries as a criterion for the acceptable tsunami risk.

Table 1. Basic indicators of tsunami safety

Level TS	Safety indicators			
	Individual risk	Index of social vulnerability	Disaster magnitude	Secondary techno-disasters
TS_1	$\leq 10^{-6}$	<0.5	≤3.5	
TS_2	$\leq 5 \cdot 10^{-6}$	≤0.5	≤4	-
TS_3	$\leq 10^{-5}$	<0.75	≤4.5	-
TS_4	$\geq 10^{-5}$	>0.75	>4.5	-

Tsunami safety is ensured with the help of the package of measures to protect territories and structures. The package of tsunami protection measures includes the following:

- evaluation of tsunami hazard on the basis of general and detailed microzoning, purpose of design loads and impacts;
- warning about tsunami, population warning, and evacuation;
- inspection and certification of tsunami safety, securing of tsunami resistance of offshore and onshore facilities;
- inspection of tsunami safety and engineering protection of the territories in general.

Slow development of construction of tsunami protective (mitigating impacts) structures and special zoning of shore territories.
Maximum possible withdrawal of potentially hazardous facilities from the tsunami-hazardous zone.

3. ABOUT DESIGN OF STRUCTURES UNDER TSUNAMI IMPACT

The compulsory, irrespective of the proportioning results, constructional measures to secure tsunami resistance of offshore and onshore facilities, include the following: creation of tsunami resistant constructions, whose sizes, shapes, structures, and materials are minimally subject and maximally resistant to hydrodynamic impact (framed structures, streamlined forms, water-repellent materials, flexible and damping devices, etc.). The design of structures for tsunami resistance is compulsory for the important constructions and at the same time the design standards of maritime hydrotechnical structures must be used.

The design of structures for the tsunami impact must be carried out on the basis of loads depending on the design of height of runup $H_{100,}$ taken for the zone being considered (Appendix 1 to the standard) for:

1) all structures, besides temporary ones, for the design tsunami;
2) HES of increased extent of responsibility for the maximum design tsunami.

General maps (1:1000000-1:100000), detailed maps (1:100000-1:25000), and local/object maps of tsunamimicrozoning (>1:25000) are used in depend of importance of design targets. Tsunamimicrozoning maps must be carried out by application of physical and mathematical simulation.

Serviceability of the structure is detemined by the limit state occurrence which is assigned in advance depending off operation condition: operation is impossible, hindered/limited, or inexpedient.
For the structures, located on the THA of A type, combined action of tsunami and earthquake is not considered.

For the structures, located on the THA of B type, when considering the tsunami impact, one must take into account permanent deformations of foundations and structural elements stipulated by earthquake impact.
During the relevant justification of the most important structures on the territories of B type one can consider the simultaneous impact of aftershock inertial earthquake load and the tsunami impact.
When designing maritime hydrotechnical structures for the tsunami impact one must take into consideration the situation stipulated by the decrease in the design sea level, as well as by subsoil erosion and outflow processes.
The parameters of the design event under consideration are determined for each particular construction type taking into account local conditions. The values of the parameters specified (value of the decrease in the design level, filtration rate etc.) are determined by the methods of physical and (or) mathematical simulation.
The buildings, located in tsunami-hazardous zones, should be designed taking into account hydrodynamic impacts on the load-bearing structures and foundations. If it is impossible to provide structural strength and sustainability of the building under the impact of tsunami, its operation is not permitted.
It is recommended to make lower floors the buildings, located in the flooding zone, open, living accommodations should be located above the ground floor. The life-support system elements (emergency generators, electrical distribution units and motors of lifts) must be located on the floors not exposed to the flood hazard.
Secondary impacts stipulated by the movement of massive objects (fuel tanks, motor transport, industrial equipment, structure elements, ice, etc.) should be minimized, if possible.
The marks of the bottom of bridge superstructures must be higher than the height of runup value with design margin. The bridge footings (both bridge abutments and middle supports) must withstand the tsunami impact.
To protect the territories with the relevant technical and economic feasibility the special structures can be erected (near-shore dams, breakwaters, river dikes).
It is recommended to plant strips of forest and shrubs on tsunami-hazardous shores. In the zones, exposed to the flood, in the near-shore zone one must provide for the construction of framed platforms with bearing parts in the form of space frameworks to secure vertical evacuation.
In flood zones, for the territories, being explored anew, it is not recommended to construct residential buildings.
The transport systems should be designed taking into account the possibility of fast mass evacuation from flood zones.
For the earlier explored territories it is recommended to correct general lay-outs with gradual demolition of residential buildings in flood zones.

4. EXAMPLE OF THE STANDARD APPLICATION

As an example of the standard application we considered tsunami resistance of the port hydrotechnical structures on the Sakhalin island.

The tsunami impact was determined in respect of the following projects:

1. quay made of floating caissons (the Korsakov port);
2. quay made of caisson masonry (the Korsakov port);
3. supports of the bridge-type quay (the Kholmsk port).

The basic data for the design of the tsunami impact on the quays made of floating caisson and caisson masonwork in the Korsakov port are the following:

Water depth d=8m,

Height of runup H_{100}=1.4m,

Wave period T=8min.

According to the methodology, given in the standard, the total wave-impact load on the vertical wall is equal to P=195.7 kN. The load P is applied at the distance of 4.8m from the bottom.

The basic date for the design of the load on the the bridge-type quay supports in the Kholmsk port are taken as follows:

Water depth at the support d=8.5m,

Wave height H_{100}=3.2m,

Support diameter D=4m.

The total wave-impact load on one support 4m wide will amount to 309 kN.

After the loads had been determined, the structure stability against sliding was checked and each of the three projects-representatives under consideration was overturned. In connection with considerable dimensions of the structure the plane stress problem was considered, and the analysis of forces was carried out by 1m of the structure for the retaining walls in the Korsakov port and the buttress 4m wide of the berth bridge conduit in the Kholmsk port. At the same time, for the space structures both the tsunami wave setup with the height h and the decrease in the water level before the wave arrival taken equal to h *and* $2h$ were considered. The calculations showed that, with practically equal loads, the berth N5 in the port Korsakov has lower values of the stability margin factor than the berth N3, therefore the table 3 presents the results of the design of the berth N5.

According to the table B.1 SNiP 33-01-2003 the general-purpose berthing structures less than 20 m high is assigned to the class III.

The load-bearing capacity of the structure and its elements will be provided subject to the following condition

$$\gamma_{lc} F \leq \frac{R}{\gamma_n},$$

where γ_{lc} – combination factor, is equal to:

- 1.0 for basic load combination;
- 0.95 with super load including earthquake load at the level of the strength-level earthquake, with the yearly probability of 0.01 and less;
- 0.85 – with earthquake load of the maximum strength-level earthquake level,

F – general value of the force impact (strength, moment, stress);

R – general value of the load-bearing capacity;

$\gamma_{n\,j}$ – safety factor, equal to 1.15 for the structure of class III.

The berthing structures made of floating caissons and caisson masonwork have sufficient load-bearing capacity against sliding and overturning both during the tsunami waves setup and during the decrease in the water level down to two wave heights.

REFERENCES

Go Ch.N., Kaistrenko V.M., Pelinovsky E.H., Simonov K.V. (1988). A quantitative estimation of tsunami hazard and the tsunami zoning scheme of the Pacific coast of the USSR *Pacific Annual*. Vladivostok. 7-15.

Choi B.H., Pelinovsky E., Riabov I., Hong S.J. (2002). Distribution functions of tsunami wave heights. *Natural Hazards*. **25:1**, 1 - 21.

Dotsenko S.F. (2005).Analysis of observations and methods for calculating hydrophysical field in the

ocean. *Physical Oceanography*. **15:6**, 363 – 369.
Dotsenko S.F., Ingerov A.V. (2007). Spectra of the Black-sea tsunamis. *Physical Oceanography*. **17: 5**, 269 – 277.
Dotsenko S.F., Eremeev V.N. (2008). Analysis of the necessity and possibility of tsunami early warning on the black sea coast. *Physical Oceanography*. **18: 5**, 288 – 296.
ETDB/ATL – Expert Tsunami Database for the Atlantics. Version 3.6 of March 15, 2002. Tsunami Laboratory, Novosibirsk, Russia.
ETDB/PAC – Expert Tsunami Database for the Pacific, Version 4.7 of June 15, 2002. Tsunami Laboratory, ICMMG, Novosibirsk, 2002. http://tsun.sscc.ru/htdbpac.
Goto C., Ogawa Y., Shuto N., Imamura N. (1997). Numerical method of tsunami simulation with the leap-frog scheme (IUGG/IOC Time Project). IOC Manual, UNESCO, N. 35.
Imamura F., Imteaz M.A. (1995). Long waves in two layer: governing equations and numerical model*. Journal of Science of Tsunami Hazards*. **13: 1**, 3 – 24.
Pelinovsky E. (1999). Preliminary estimates of tsunami danger for the northern part of the Black *Sea. Phys. Chem. Earth*. **A24**, 175 – 178.
Pelinovsky E., Zahibo N., Dunkley P., Edmonds M., Herd R., Talipova T., Kozelkov A., Nikolkina I. (2004). Tsunami generated by the volcano eruption on July 12-13 2003 at Montserrat, Lesser Antilles. *Science of Tsunami Hazards*. **22:1**, 44-57.
Ranguelov, B., Spassov, E., and Dotsev, N. (1983). A model of tsunami generation from Bulgarian earthquake sources in the Black Sea Area and prediction of their possible effects. *Bulgarian Geophys. J.* **9**, 91-99.
Ranguelov, B., Spassov, E., and Dotsev, N. (1985). Tsunami danger for the Bulgarian Black Sea Coast*. Bulgarian Geophys. J.* **11**, 6-73.
Ranguelov, B., Spassov, E., Dotsev, N., and Pavlov, I. (1987). Spectra of tsunami in the Black Sea. *Bulgarian Geophys. J.* **13**, 3-58.
Yalciner A.C., Pelinovsky E., Synolakis C., Okal E.A. (2003). NATO Advanced Research Workshop: Underwater Ground Failures on Tsunami Generation, Modeling, Risk and Mitigation". Kluwer.
Yalciner A., Pelinovsky E., Talipova T., Kurkin A., Kozelkov A., Zaitsev A.(2004).Tsunamis in the Black Sea: comparison of the historical, instrumental and numerical data. *J. Geophys. Research.* **109**: C12,, C12023 10.1029/2003JC002113.