

GENERAL SPECIFICATION

SURVEYS

GS EP GEO 507

Tsunami hazard assessment on coastal facilities
--

00	06/2016	First issue
Rev.	Date	Purpose of the revision

Owning entity: DSO/TEC	Managing entity: DSO/TEC/GEO
Other Approving entity(ies):	

General Specification		GS EP GEO 507
Tsunami hazard assessment on coastal facilities		
Rev.: 00	Effective date: 06/2016	Page: 2 of 44

Contents

1. Scope	4
2. Reference documents.....	5
3. Definition & Acronyms.....	5
3.1 Definition.....	5
3.2 Acronyms.....	5
4. Adopted approach.....	6
4.1 First stages	6
4.2 Compliance with project levels	6
4.3 Probabilistic approach.....	7
4.4 Deterministic and scenario based approach.....	8
4.5 Sources characteristics and parametric studies	9
5. Tsunami metrics for design	12
6. Data collection.....	13
7. Calibration phase	17
7.1 Description.....	17
8. Calibration results by level.....	18
8.1 Level 1	18
8.2 Level 2	18
8.3 Level 3	19
9. Tsunami modelling.....	19
9.1 Grid creation	19
9.2 Source modelling	19
9.3 Propagation modelling	20
9.4 Inundation modelling	20
9.5 Impact on structures modelling	21
10. LEVEL 0 study (step 1 and step 2).....	22
10.1 Objective.....	22

General Specification		GS EP GEO 507
Tsunami hazard assessment on coastal facilities		
Rev.: 00	Effective date: 06/2016	Page: 3 of 44

10.2	Step 1: Geographical level screening	22
10.3	Step 2: Identification of historical tsunami records	23
11.	LEVEL 1 study (step 3 to step 6)	25
11.1	Objective:	25
11.2	Step 3: Review of existing tsunami hazard studies or tsunami propagation simulations	25
11.3	Step 4: Identification of tsunamigenic sources in the study area	26
11.4	Step 5: Qualitative evaluation of the effects of a possible tsunami run-up	26
11.5	Step 6: Recommendations	27
12.	LEVEL 2 study	27
12.1	Preparation and set up of modelling phase	28
12.2	LEVEL 2A (Regional tsunami hazard analysis)	28
12.3	LEVEL 2B (Local tsunami hazard analysis)	30
12.4	Total exposure and hazard: aggregating of scenarios for all sources	31
13.	LEVEL 3 study	31
13.1	Objectives	31
13.2	Output	32
13.3	Computation of hydrodynamic forces on structures	32
14.	Early warning systems	35
15.	Reporting and deliverables	35
15.1	Report organization	35
15.2	Report format	37
15.3	Deliverables	37
	Bibliography	38
	Appendix 1	39

General Specification		GS EP GEO 507
Tsunami hazard assessment on coastal facilities		
Rev.: 00	Effective date: 06/2016	Page: 4 of 44

1. Scope

The aim of this General Specification Document is to detail the minimum requirements for the performance of TSUNAMI HAZARD ASSESSMENT (THA) for any structure exposed to tsunamis in coastal regions.

The approach aims at defining and characterizing the potential scenarios of tsunamis to which a project or a site is exposed, in order to produce and quantify several values, parameters and dimensions used in various cases of studies, from preliminary assessment to detailed design of structures and infrastructures.

The approach is compatible with the framework of the French civil works regulation but is applicable worldwide ([API RP 2N](#)).

The successive steps to follow for the integration of tsunami hazard in the design process are:

1. Etude d'Opportunité (opportunity study) = Prospect and preliminary Study
2. Etude de Faisabilité (feasibility study) = Conceptual
3. Etude d'Avant-Projet Sommaire (draft design) = Pre-Project and Basic Engineering
4. Etude d'Avant-Projet Définitif (detailed design) = Detailed Design

This type of study is valid for onshore projects or structures as well as offshore projects limited to the continental shelf. The parts concerning inundation are not relevant for off-structures with no physical connections or link to the coast, and for which only exposition to oceanic waves is concerned.

The approach covers both far field tsunamis origin (with no impact of the triggering mechanism - earthquake in most cases) and near field tsunamis origin in which the source mechanism is affecting the specific project site before the arrival of a tsunami.

In all cases, the earthquake hazard approach ([GS EP GEO 601](#), [GS EP GEO 602](#)) has to be undertaken before the tsunami hazard assessment.

Tsunami can be generated also in large continental lakes and consequently by aerial and submarines mass movements. The present specifications also address industrial sites located along lake shores.

General Specification		GS EP GEO 507
Tsunami hazard assessment on coastal facilities		
Rev.: 00	Effective date: 06/2016	Page: 5 of 44

2. Reference documents

The reference documents listed below form an integral part of this General Specification.

External Documents

Unless otherwise stipulated, the applicable version of these documents, including relevant appendices and addendums, is the latest revision published at the effective date of this document.

Reference	Title
API RP 2N	Recommended Practice for Planning, Designing, and Constructing Structures and Pipelines for Arctic Conditions
ISO 19901-1	Petroleum and natural gas industries - Specific requirements for offshore structures - Part 1: Metocean design and operating considerations

Total General Specifications

Unless otherwise stipulated, the applicable version of these documents, including relevant appendices and addendums, is the latest revision published.

Reference	Title
GS EP GEO 601	Seismic Hazard Assessment for Offshore Structures
GS EP GEO 602	Seismic Hazard Assessment for Onshore Structures
GS EP CIV 203	Design of harbour

3. Definition & Acronyms

3.1 Definition

LEVEL Phase of development of a project from the Prospect study to Detailed Design.

3.2 Acronyms

DART Deep Ocean Assessment and Reporting of Tsunamis (oceanic buoys with pressure sensors)

PTHA Probabilistic Tsunami Hazard Assessment

PMT Probable Maximum Tsunami

SHA Seismic Hazard Assessment

THA Tsunami Hazard Assessment

General Specification		GS EP GEO 507
Tsunami hazard assessment on coastal facilities		
Rev.: 00	Effective date: 06/2016	Page: 6 of 44

TEWS Tsunami Early Warning System
WCS Worst Case Scenario of tsunami for a site

4. Adopted approach

4.1 First stages

Tsunami hazard study involves several disciplines and modelling techniques of Earth sciences due to the different possible triggering mechanisms. Nearly 90% of tsunami sources are earthquakes but mass movements, volcanic eruptions, specific meteorological conditions offshore and very infrequent asteroids fall are known to also produce tsunamis in unusual places, even in continental lakes.

It is recommended not to start the THA before having performed the surveys and studies related to the other hazards, in order to have already significant input data on possible tsunami sources before starting the THA.

For that reason the SHA must be systematically undertaken before the THA. Nevertheless numerous regions in oceans could be out of seismic zones and prone to tsunami impact from far field origin.

4.2 Compliance with project levels

The proposed approach is applicable for:

- New harbour (GS EP CIV 203) or industrial site development
- New facility or site in an existing harbour (GS EP CIV 203) or coastal site
- Re-assessment of hazard for existing plant, harbour (GS EP CIV 203) or facility.

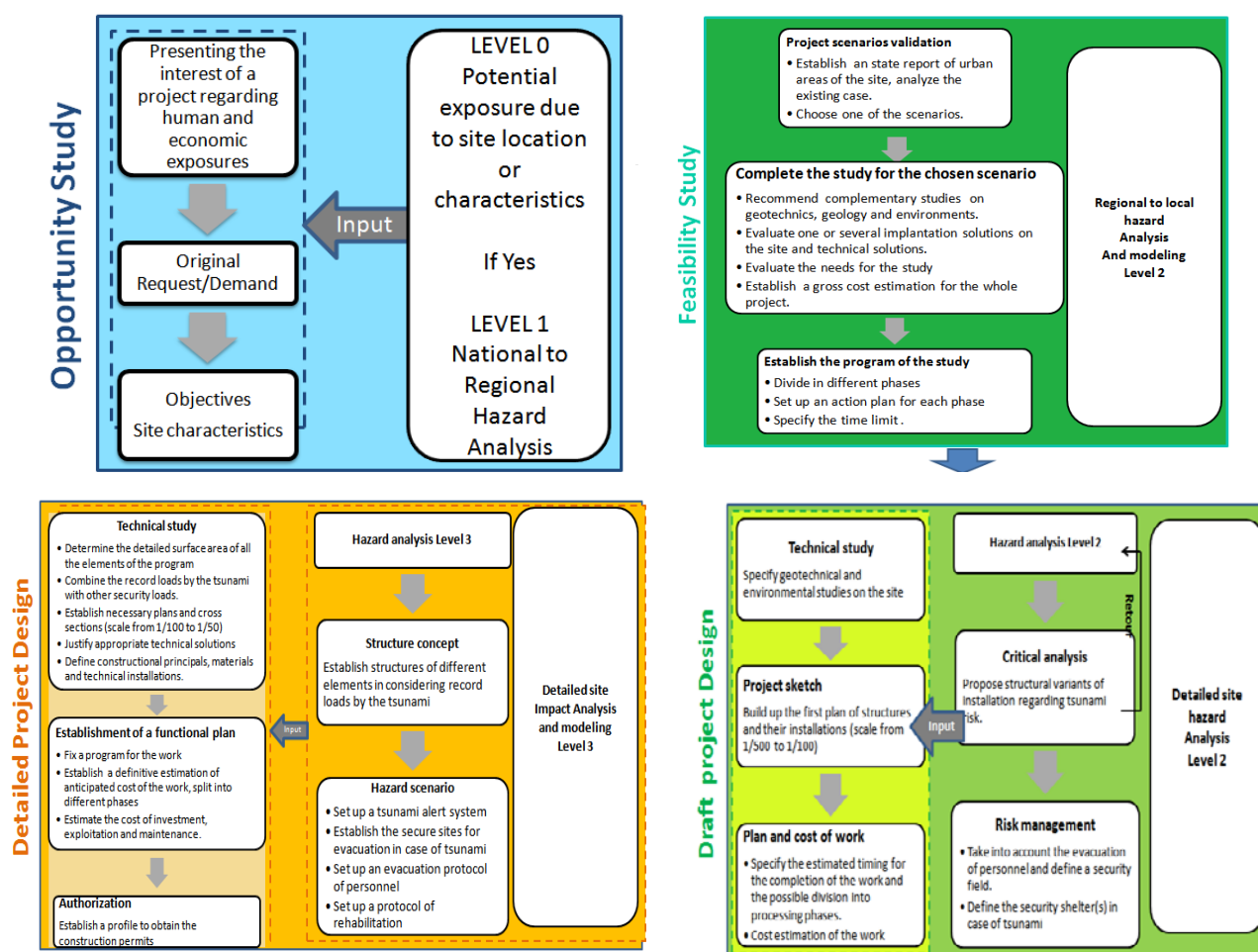
Four levels of technical studies are required:

Table 1 - Description of the different levels

STUDY PHASE	STAGE AND PURPOSE
LEVEL 0 Prospect and Preliminary Study	Is the site exposed to a tsunami hazard or not?
LEVEL 1 Conceptual	What is the range of hazard and coastal wave height to which the site is exposed? Is a further tsunami modelling stage required?
LEVEL 2 Pre-project and basic engineering	What are the impacts of the tsunami on the shores and on the installation? Simulation of extreme scenarios
LEVEL 3 Detailed design	What are the forces applied by the wave on the structures?

Figure 1 represents the study content evolving according to the project stage deployment.

Figure 1 -Frameworks of integration of LEVEL 1 up to LEVEL 3 tsunami hazard studies



4.3 Probabilistic approach

Several seas or oceans such as the Pacific Ocean are exposed to frequent tsunamis compared to others seas. A probabilistic approach of hazard level could be undertaken in some cases when numerous traces of tsunamis are visible or when the source is quite systematically the same, such as a subduction zone.

Since 2004, various countries around the Pacific Ocean have carried out probabilistic tsunami hazard assessment (PTHA) studies.

If a PTHA is available for one site, the available tsunami sources can be kept for the studied site.

The output of such study can be considered, provided that they comply with requirement of each study level proposed in this document of specifications.

If some outputs proposed here are not available in the PTHA, the missing product has to be issued using the required tools and techniques.

General Specification		GS EP GEO 507
Tsunami hazard assessment on coastal facilities		
Rev.: 00	Effective date: 06/2016	Page: 8 of 44

Whatever the sources and return periods covered by the PTHA, a deterministic study complying with the requirement described below has to be undertaken, for the worst possible case tsunami scenario (and whatever the return period).

4.4 Deterministic and scenario based approach

A tsunami is a "rare" phenomenon compared to an earthquake and can also originate from volcanic eruptions or mass movement. As necessary records and data to carry out probabilistic tsunami hazard study are not available everywhere, the common approach promotes deterministic THA based on identification of possible scenarios of tsunamis for the studied site.

In addition, the first step of the study consists in checking the numerical methods against actual observations (see Calibration chapter 7). A comprehensive synthesis of available tsunami data close to the site will therefore be undertaken. In some cases, no exploitable data for a check of the numerical exist. This control can be skipped in this case if the nearest site where model can be checked is very far (several hundreds of kilometres).

4.4.1 Identification of sources

A first review of past known sources should be identified on a bibliographic review based on:

- Regional or national tsunami hazard assessment.
- Global tsunami catalogues and data bases.
- Historical tsunami records.
- Suspected tsunamis clues of any type.

Various types of sources should be screened:

- Major and large earthquakes (offshore, close to shore inland),
- Submarine mass movement or aerial mass movements entering into the sea (rock or ice),
- Volcanic (normal or paroxystic) eruptions with pyroclastic flows, lateral collapse or caldera collapses (ex: Krakatoa 1883) which can be assimilated to aerial mass movement entering into the sea,
- Meteorological tsunamis caused by a particular atmosphere-ocean coupling producing tsunami-like long waves, and then amplified in funnel shaped bays.

Tsunamis caused by meteorites impact in the sea, which are extremely rare and difficult to identify or to define, and which are associated to return periods of several 10⁵ to 10⁶ of years, are excluded of this source hypothesis.

For a given site survey open to sea or in estuaries, any source whatever its distance from the site, should be considered:

- Distant sources – more than 3 hours travel time;
- Regional source – 1 to 3 hours travel time;
- Local sources – 0 to 60 minutes travel time.

General Specification		GS EP GEO 507
Tsunami hazard assessment on coastal facilities		
Rev.: 00	Effective date: 06/2016	Page: 9 of 44

In case of a site exposed in an open ocean or sea, the whole perimeter of the ocean/sea should be considered for potential volcanic, mass movement or earthquake sources with no maximum distance limit between source and target. In case of a site in a lake or a closed sea, all sources around the perimeter of this water body should be investigated as well.

4.4.2 Determination of scenarios

For each source type a set of parameters must be chosen:

- For earthquakes, the maximum possible magnitude according to best knowledge of seismotectonic of the region and fault characteristics (type of fault, reverse, normal or strike-slip), and relevant parameters selected accordingly to account for a maximum impact (some earthquakes being associated with a low rupture and a high slip in the shallower part of the rupture should be considered).
- For mass movement, the detection of future possible mass movement sources is sometimes possible by analogy with similar conditions to past mass movements. A probabilistic approach is frequently too complex or impossible. Where historical evidence and observations presume that a mass movement has generated a tsunami affecting the site, the characteristic of the mass movement should be retrieved or estimated in order to be transposed on other locations close to the site with similar geological and morphological conditions which are susceptible to be the source of new landslides (nearest cliff failures, canyon from source or valley with trend in direction of the site).
- For volcanic eruptions, the assimilation to aerial or submarine mass movement can be accepted, since nearly all cases correspond to fall into water of volcano flanks or lateral collapses. The characteristics of past volcanic events (size, volume, shape) selected in scientific publication and adapted to the local context, should be taken as basic hypothesis for the mass movement.

For each source type, the hypotheses should be presented and justified in the technical offer.

Parametric studies have to be carried out on each identified source for a single site.

4.4.2.1 Worst case scenario

For a given source a worst case scenario must be defined. If a PTHA has already been undertaken on the site, the worst case can be extracted from it. Otherwise, the worst case must be established from a deterministic approach using existing knowledge on each source.

4.4.2.2 Intermediate scenario

Depending on coastal morphology and source characteristics, intermediate tsunamis scenarios may have few inundations effect but can generate strong perturbations in harbours. An intermediate intensity scenario should be proposed (source characteristics) in order to carry out corresponding modelling if required.

4.5 Sources characteristics and parametric studies

4.5.1 Sensitivity study on source characteristics

A site can be exposed to different sources of tsunamis, local, regional or remote (from opposite coast of sea or ocean).

General Specification		GS EP GEO 507
Tsunami hazard assessment on coastal facilities		
Rev.: 00	Effective date: 06/2016	Page: 10 of 44

After determining each possible source for the studied site, a Worst Case Scenario (WCS) has to be determined using the best knowledge of the identified source for each type of source.

In order to account for errors in modelling process due to different kinds of uncertainties and errors (see below) the worst case scenario will be determined by performing successively a sensitivity study on sources parameters (Chapter 4.5.1) and then to local conditions (Chapter 4.5.2):

- Errors on the initial water level
- Errors due to insufficient accuracy or representativeness of the bathymetric and topographic data (one of the main cause of potential errors)
- Uncertainties regarding source mechanisms parameters
- Errors at calibration stage of the model on a recorded tsunami event
- Errors due to inappropriate models.

4.5.2 Parametric and sensitivity study on site conditions

Table 2 - Sensitivity study to source parameters

Parametric and varying source characteristics	
Earthquake sources	When using an earthquake deformation model to simulate sea bottom displacements the following parameters can be considered : 1. Location (latitude, longitude, and depth) 2. moment magnitude, Mw 3. Fault dimensions (rupture length and width) 4. Dip (angle between fault plane and horizontal) 5. Strike (angle between fault plane horizontal and north) 6. Rake (angle between slip direction on the fault plane and horizontal on the fault plane) 7. Slip distribution 8. Shear modulus.

Tsunami hazard assessment on coastal facilities

Rev.: 00

Effective date: 06/2016

Page: 11 of 44

Parametric and varying source characteristics	
Mass movement source Two cases to differentiate: Submarine and sub-aerial mass movements	Submarine mass movements: 1. Location (latitude, longitude and elevation) 2. Dimension and geometry of sliding mass (average length, width, thickness) 3. Slide orientation (directivity) 4. Length of trajectory from starting point to ending point 5. Slide volume 6. Slide speed and acceleration 7. Duration of movement 8. Density, cohesiveness, viscosity of the slide material 9. Coulomb stress. To add for sub-aerial mass movement : 1. Density of slide material 2. Impact Froude number.
Volcanic source The following type of phenomenon are considered: 1. Pyroclastic flow into the water 2. Submarine caldera collapse 3. Submarine explosion 4. Debris avalanches and flank failures	The source parameters for a tsunamigenic pyroclastic flow are for example: 1. Location 2. Elevation with respect to sea level from base to top of volcano). 3. Orientation 4. Density and rheology of the flow material 5. Dimensions of the flow 6. Impact Froude number. The source parameters for a caldera collapse are for example: 1. Location 2. Orientation 3. Caldera dimensions 4. Fixed wall height 5. Cavity depth after the collapse. The source parameters for a submarine volcanic explosion are for example: 1. Location 2. Volcanic Explosivity Index (VEI) 3. Age of last eruptions. The source parameters for tsunamigenic-debris avalanches and flank failures are similar to those for submarine and subaerial landslides.
Meteo Tsunamis	If known on site, use the 100 year return period storm or gales event capable of generating meteo tsunamis.

General Specification		GS EP GEO 507
Tsunami hazard assessment on coastal facilities		
Rev.: 00	Effective date: 06/2016	Page: 12 of 44

After the worst case scenario has been identified, the reference water level used for modelling should be set using additional aggravating factors.

One run should be done for the worst case of source characteristics according to normal conditions of sea (reference case), and then several additional runs should be performed using the following cases:

Table 3 - Sensitivity study to site conditions

Parametric and varying local conditions	
1. Extreme astronomical high (inundation) and low (drawdown) tides	Two runs to perform: extreme low and high sea levels.
2. Extreme known possible storm surge	To be added to initial sea level. At least 100-year return period or other return period according to metocean conditions evaluation.
3. Additional sea level rise due to climate change	A run to perform with previous additional sea level but without sea level rise. A run to perform using maximum value, projection at 100-year ahead of sea level to be added to usual sea level.
4. Friction effects and roughness coefficient	To be used especially if tsunami scenario inundates urban areas in modelling phases at LEVEL 2 and LEVEL 3.

4.5.3 Statistical approach

To be considered only if a validated national study has been performed prior to the survey.

5. Tsunami metrics for design

The output data, documents and maps are described in the following table. Detailed specifications for each product are provided in the appendix.

The specific metrics for values and dimensions being very specific, the tsunami modelling tools must comply with the production of values according to dimensions proposed in Appendix 1 (§ 5 -).

5.1.1 Metrics for tsunami scenarios at Level 1 and Level 2

Table 4 - Output data and presentation for levels 1 and 2

Output document	Type of presentation
Maximum wave elevation at each grid point	Map , graphic colour intensity scale, geographic scale, text block, initial sea level conditions
Maximum flow depth and minimum drawdown	Map , graphic colour intensity scale, geographic scale
Maximum current speed at each grid point	Map , graphic colour intensity scale, geographic scale
Maximum momentum flux at each grid point	Map , graphic colour intensity scale, geographic scale
Maximum Froude number at each grid point	Map , graphic colour intensity scale, geographic scale
Event duration and synthetic and/or recorded tide gauge records	Graphs, location on map
Propagation time	Map and Charts
Sources characteristics description	Include in each map and a text block or a legend describing sources characteristics and values chosen. Specify parameter value presented for parametric study.

5.1.2 Metrics for Level 3 studies: impact on structure

In addition to the outputs of Levels 1 and 2, the following results have to be issued on each structure impacted by the wave:

- Hydrostatic Forces
- Buoyant Forces
- Hydrodynamic Forces
- Surge Forces
- Impact Forces
- Breaking Wave Forces.

6. Data collection

The objective of the data collection is the development of the database from global to local levels, to progress in the successive stages of the project study according to potential tsunami sources.

Tsunami sources can be very distant from studied sites. All required information's should be collected to assess the characteristics of distant sources, which are in general major earthquake along active tectonic margins. Near field tsunami sources can be of any type but more

General Specification		GS EP GEO 507
Tsunami hazard assessment on coastal facilities		
Rev.: 00	Effective date: 06/2016	Page: 14 of 44

frequently earthquakes. Onshore strong earthquakes sources have to be considered as potential tsunami sources when one of the known faults edge is a few kilometres from the sea.

For strong onshore earthquakes close to the coast, submarine landslides source should be seriously investigated also as possible sources.

Some specific morphological and offshore meteorological patterns can give birth to what is called a meteotsunami which is generally described in databases as well.

First investigation should be carried out in:

- Regional or national tsunami hazard assessment studies
- Global tsunami catalogues and data bases
- Historical tsunami records.

Suspect tsunami events should be disregarded when they can be the results of seiches or storm surges.

The data collection is also required to collect and prepare bathymetric and topographic data which are used as input for tsunami modelling tools. Table 5 provides an extensive list of required data at each study level.

Table 5 - Main types of data and input required for tsunami hazard assessment and sources

N°	What	What for	LEVEL 0	LEVEL 1	LEVEL 2	LEVEL 3
1.	Initial site location constraints description	Geographic, topographic, slope, elevation, sea or rivers proximity requirements for the site implantation and function in terms of proximity and link with sea, elevation	X	X	X	X
2.	Bibliographic study and Regional/national studies	Past tsunami identification (rapid review for LEVEL 0 and detailed review for LEVEL 1) / Tsunami source identification and characterization / Previous tsunami hazard study on site	X	X	X	X
3.	Historical tsunamis records	Description of impacts or publications / Tide gauges Records of past tsunamis		X	X	X
4.	Paleotsunami evidence and Data	Identification intensity of past tsunamis on the study site / Can be undertaken regionally at several tens of kilometres from studied site		X	X	X
5.	Topography & Satellite imagery	Basic topo data for: Site characteristics and Initial screening at LEVEL 0, Detailed data required from LEVEL 1, Grids constructions for modelling, Aerial and submarine geomorphology and instabilities, Land use and infrastructures	X	X	X	X