STREST

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REPORT

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SEVENTH FRAMEWORK PROGRAMME

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Abstract

This report provides a harmonised classification (i.e. taxonomy) for the components at risk within the critical infrastructures (CI) of the STREST project, describes the available knowledge on the vulnerability of each component at the beginning of the STREST project, and the dependencies between the components of each CI and between the infrastructures of the CI and other networks. This deliverable covers the following CI: an oil refinery and petrochemical plant (REF); large dams (DAM); major hydrocarbon pipelines (HDRC); gas storage and distribution network (GPN); port infrastructures (HBR); and industrial districts (IDA). The inter- and intra-dependencies that affect the performance of these complex facilities are presented herein, with the most common and crucial being geographical and physical dependencies.

Keywords: taxonomy, classification, components, critical infrastructure, vulnerability, intensity measures, dependencies

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1 Introduction

This focus of this deliverable is primarily on the development of the STREST taxonomy that was necessary to describe the components and systems of the various critical infrastructures (CI) considered in the project with a common language. The proposed taxonomy is presented in Chapter 2. Once, the various components at risk were identified and described, the next critical step that was taken within the project was the identification of fragility/vulnerability characteristics of each component, and the intensity measure types needed to describe the hazards to which they are exposed. This information was collected through vulnerability factsheets, which are presented in Chapter 3. These factsheets included a preliminary identification of the dependencies of the CIs, which was then further elaboration through specific dependency factsheets, presented in Chapter 4.

2 Proposed STREST Taxonomy

The STREST project is covering three macro-classes of critical infrastructures (CI):

A. Individual, single-site infrastructures with high risk and potential for high local impact and regional or global consequences.

B. Distributed and/or geographically-extended infrastructures with potentially high economic and environmental impact.

C. Distributed, multiple-site infrastructures with low individual impact but large collective impact or dependencies.

A number of case studies are being considered for each of these classes of CI, and despite their differences, they all share similar elements that are exposed to risk. In many cases, they include components from different systems, working together to ensure the supply of the CIs' products and/or services. This document presents a proposed taxonomy for classifying the various individual components that can be found within these different systems, such that each critical infrastructure can be described in a harmonized way. It builds upon the taxonomy developed in the SYNER-G project (Hancilar and Taucer, 2013), with new elements for the CIs that were not part of the latter project. In the following section, a brief description of the components of each CI of STREST is provided, followed by the taxonomy.

2.1 ENI/KUWAIT OIL REFINERY AND PETROCHEMICAL PLANT, MILAZZO, ITALY (A1)

An oil refinery or petroleum refinery is an industrial process plant where crude oil is processed and refined into more useful products such as petroleum naphtha, gasoline, diesel fuel, asphalt base, heating oil, kerosene and liquefied petroleum gas.

The oil or petroleum refinery is a very complex system, including many structures and components, linear and punctual elements.

The Refinery of Milazzo was built in the 1950s. The industrial production started in 1961. The refinery of interest processes about 10 million tons of crude oil per year. The refinery produces gasoline and naphtha fuels, kerosene, propylene, gas and fuel oils, liquefied petroleum gas (LPG), and other hydrocarbons which serve as a prime materials for the petrochemical industry.

The refinery consists of the following sections (Cruz et al. 2009):

- Processing: atmospheric and vacuum distillation units, catalytic reforming unit, hydrocracking unit and hydro-desulfurisation unit.

- Storage farm: 127 storage tanks with capacity of over 3.75 million m^3 for prime materials, intermediate products and finished products.

- Port terminals: Two jetties used for loading and unloading tankers of up to 420,000 DWT (Dead Weight Tonnage). The port terminals have a maximum crude oil reception rate capacity of 15,000 tons per hour. It moves about 570 ships per year (max. capacity is 900 ships/yr). Through the two port terminals it moves approximately 12 million tons per year of crude oil and other products.

- Utilities: boilers, cooling towers, and process air.

2.2 LARGE DAMS IN THE VALAIS REGION OF SWITZERLAND (A2)

The Valais region of Switzerland is composed by the Rhone valley and its lateral tributaries, many of which are dammed. Owing to its topography, precipitations and coverage of glaciers at high altitudes, Switzerland is the European country with the highest density of large dams in its territory, providing close to 60% of the electricity supply of the country. Switzerland hosts 25 dams with height over 100m; of these, 7 are in the Valais, including major arch dams like Emosson and Mauvoisin (the highest arch dam in Europe at 250m) and gravity dams like Grande Dixence (the highest concrete gravity dam in the world at 285m, with a 401 mio m^3 retaining capacity) and Mattmark (the largest earthen dam in Europe). In STREST both the individual dams as well as the aggregated risk for the whole region is considered.

The hazard factors for the Swiss dams are those classically affecting large arch or gravity dams, aggravated by the pronounced topography of the Valais region and by the rapidly changing climatic conditions in the Alps: these risks include earthquakes, gravitational instabilities (rock- and land-slides, ground deformation, glacial collapses, mobilization of permafrost sediments) and floods.

2.3 MAJOR HYDROCARBON PIPELINES, TURKEY (B1)

The hydrocarbon pipeline infrastructure system consists of the buried pipeline and secondary support units such as, vessels, tank storage units, critical mechanical, electrical equipment, pigging facilities, block valves etc. The primary component of the overall system is the transmission pipeline. KOERI is responsible for the vulnerability analysis of the buried pipe only, but the other components of the system are reported in the taxonomy for completeness. A schematic overview of the overall oil transport system and the route of the BTC pipe-Turkish section are given below in Figure 1 and Figure 2.

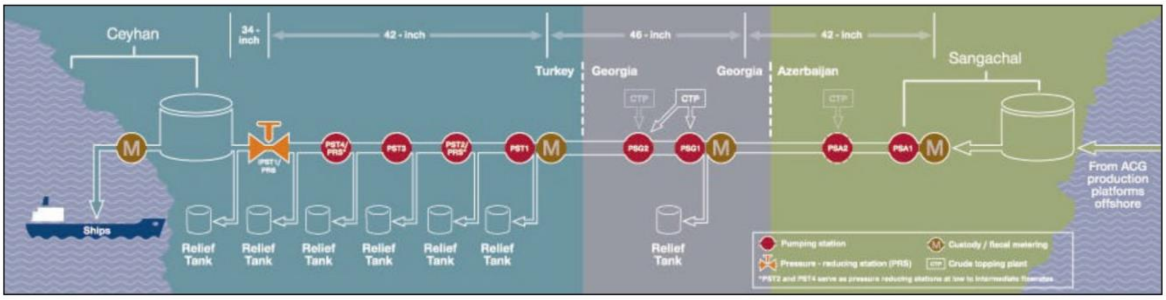

Figure 1 Schematic overview of the overall oil transport system

Figure 2 Route of the BTC pipeline

2.4 GASUNIE GAS STORAGE AND DISTRIBUTION NETWORK, HOLLAND (B2)

This case study is the Gasunie gas storage and distribution network in the Netherlands. On- and off-shore natural gas production and distribution is the key component of the national energy supply in the Netherlands. The gas distribution relies on a major gas pipeline infrastructure, with a total length of over 12,000 km of installed pipes. The production from the Groningerveld gas field and other natural gas fields mostly located in the north east part of the country supply the Dutch economy and major export across Europe, via cross-border long distance gas pipelines (European Natural Gas Round-About). Induced earthquakes have occurred more frequently in the province of Groningen, as result of gas field depletion in the soft soil Delta area. Additionally, Holland has a long history of catastrophic inundations and provides a text-book case of defense, preparation and construction of water infrastructures to protect against future repetition of such events.

The underground gas distribution system of Gas Transport Services (a part of Gasunie) transports the gas from feeding stations under a pressure of 66 bar, sometimes 80 bar. Compressor Stations make part of the system in order to maintain these pressures and corresponding flows. The gas is then led to Measure and Regulation Stations where the pressure is reduced to 40 bar and odorants are added. Next, the gas reaches the Gas Receiving Stations, where a further gas reduction is performed to 8 bar, after which the gas is delivered to clients, such as municipal networks, industry or energy plants.

For the use case a sub-network is selected located in the induced earthquake prone area, directly above the main gas field, as depicted in Figure 3.

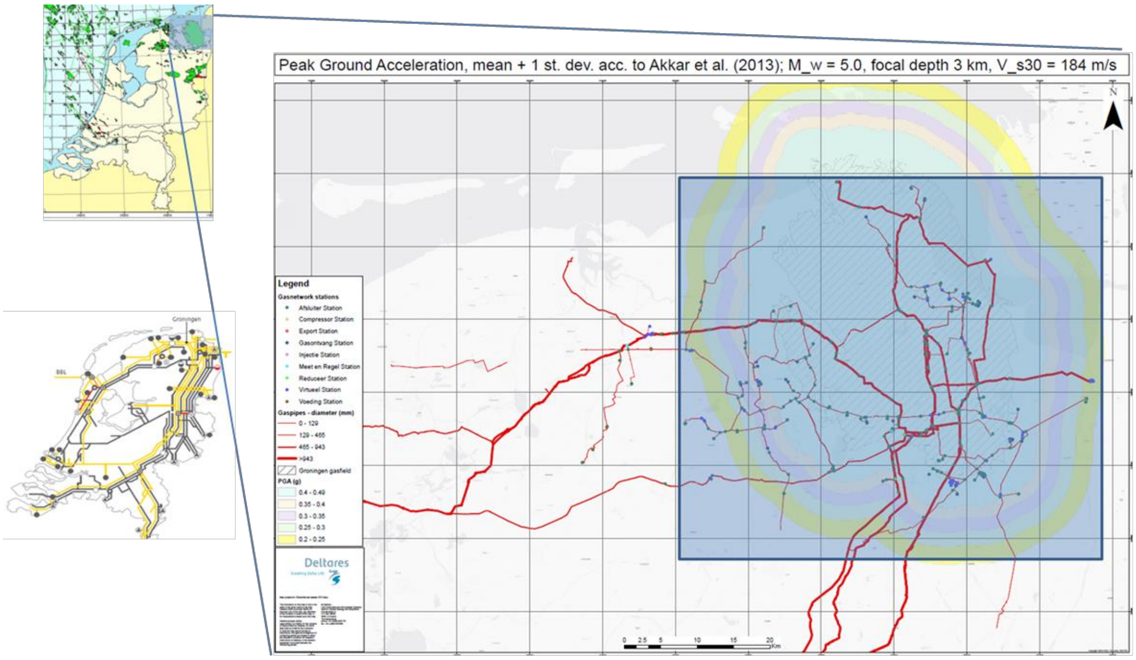

Figure 3 Selected area for main Gas Transport System. Layout of main HP pipeline system (bottom-left), selected area and main gas field (top-left) and detail of selected area and pipeline system (right).

Indicative numbers and type of components within the area are listed below:

Component	Number (indicative)
Valve Stations	426
Compressor Stations	2
Export Stations	1
Municipal Receiving Stations	56
Industrial Receiving Stations	38
Measure and Regulation Station	6
Mixing station	1
Underground storage	1
Reducing stations	5
Feeding stations	16

The components of the system will be confined to those belonging to Gas Transport Services (GTS). As a result, the underground storage and the feeding stations are left out w.r.t. physical modelling of their components.

2.5 PORT INFRASTRUCTURES OF THESSALONIKI, GREECE (B3)

Ports contain a wide variety of facilities for passenger operations and transport, cargo handling and storage, rail and road transport of facility users and cargoes, communication, guidance, maintenance, administration, utilities, and various supporting operations. The main characteristic of these complex systems is the multiple interactions existing within their elements and with the external supplying or/and supplied systems and infrastructures. In this sense, they can be characterized as “systems of systems”. The ports’ functionality is dependent on the functioning of each system/ component, taking also into consideration the interactions between them.

Thessaloniki’s harbor is a major export and transport harbor of Greece, covering an area of 1,550,000 m^2, trading approximately 16,000,000 tons of cargo annually, and having a capacity of 370,000 containers and 6 piers with 6,500m length. Various data are available for the construction, typological and functional characteristics of port facilities, including cargo and handling equipment, waterfront structures, electric power (transmission and distribution lines, substations), potable and waste water (pipelines), telecommunication (lines and stations), railway (tracks) and roadway (roads and bridge) systems as well as buildings and critical facilities.

In **Error! Reference source not found.** the taxonomy of Thessaloniki’s harbor elements is presented, on the basis of the various systems that are present inside the port. Harbor components are identified and classified in categories, given in the column “Component”. The main typological features of each harbor element (component) are given in the column “Typology”. Here, the main typological categories of the components are provided, where available. Except from the main components existent inside Thessaloniki’s harbor, several other systems, with their sub-components, which interact with the port facilities and affect their functionality, like for example roadway system and roadway bridges connecting the port with the urban area and oil facilities in close proximity with the harbor area, are included. It is mentioned that the taxonomy and typology of Thessaloniki’s harbor components, as well as buildings, utility systems and transportation systems existing inside the port or interacting with it, are mainly based on SYNER-G proposals.

2.6 INDUSTRIAL DISTRICTS (C1)

In the STREST project a class of critical infrastructures (CI) made up of distributed, multiple-site infrastructures with low individual impact but large collective impact or dependencies has been identified. In the case studies of Work Package 6, this class of CI is represented by the industrial buildings in the north of Italy, similar to those that were affected by the 2012 Emilia earthquakes. At least 650 industrial buildings in the Tuscany Region will be considered in the case study. A brief description of the common types of buildings in this region is provided herein. The buildings of the STREST project are classified using the GEM Building

Taxonomy v2.0 (Brezv et al., 2013), which is provided in Appendix A. A tool for developing a taxonomy string, which combines the attributes of the taxonomy in a logical sequence, is available here:

http://www.nexus.globalquakemodel.org/gem-building-taxonomy/posts/apply-the-gem-building-taxonomy-v2.0-using-taxt/.

Type 1. Parallel portals with asbestos sheet covering

This typology, more traditional and frequently used, consists of a series of one-storey basic portal frames. Each portal is comprised of two or more columns fixed at the base and a saddle roof beam usually simply supported by the columns or with shear resistant connections. The age of the building is important as there were changes to the seismic design code in Italy in 1996 (DM 16-01-1996) which improved the shear reinforcement and connection design of these buildings.

Figure 4 One type of common industrial buildings in northern Italy

Type 2.Parallel portals with “self-supporting” precast concrete elements

The second common typology consists of one-storey frames linked by perpendicular straight beams, which carry the main roof beams or directly support the large span slab elements. As before, the age of the building is important to understand the probable connection resistance.

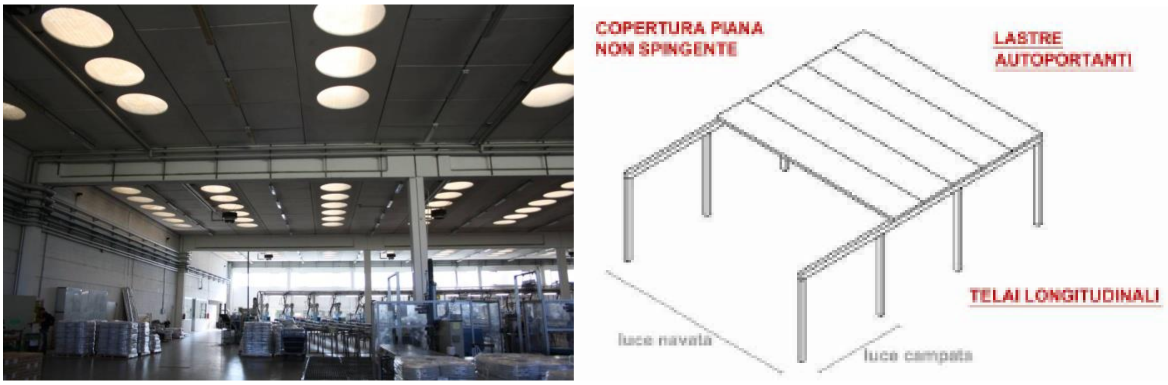

Figure 5 A second common industrial building typology in northern Italy

The non-structural components cannot be described with the aforementioned taxonomy, and thus the following three additional attributes, which are common non-structural elements of these buildings in northern Italy, are added:

- Horizontal panels
- Vertical panels
- Masonry infill panels

The principle contents of the buildings in the region can be classified as:

- Stocks and supplies on shelves
- Industrial racks
- Movable manufacturing equipment

2.7 STREST TAXONOMY

Table 1 presents each component, the CI/system within which it can be found, and then two columns for the classification: the first provides a list of generic typologies, and the second gives a more detailed list of so-called classification parameters. Some elements (such as pumping stations or cranes) can be comprehensively described with a list of generic typologies, and sometimes this can be further expanded using some additional information that can be described using the classification parameters. Other elements (such as buildings and pipelines) instead have a very large number of potential typologies and so generic typologies are not available, and instead they require a classification system based on the classification parameters, such that ad-hoc typologies can be produced.

Table 1 Proposed Taxonomy for STREST critical infrastructure components

COMPONENT	CRITICAL INFRASTRUCTURE / SYSTEM	GENERIC TYPOLOGY	CLASSIFICATION PARAMETERS
Appurtenant structures	**Dam – Hydropower System**	Spillway (Reservoir volume control) Bottom outlet (Reservoir volume control and drawdown)	o Regulated / unregulated o Covered / open o One or multiple o Type (e.g. WES, labyrinth, etc) o Geometry (section and main dimensions) o Location o Outflow capacity o Topographic implantation o Pressure/open-channel flow
Backup power (generator)	**Harbor - Electric Power System**		o Anchored/ Unanchored o Open/ closed type
Breakwaters	**Harbor – Waterfront components**	Gravity structure Piled structure Rubble mound	
Bridge abutments	**Harbor - Roadway System** **Harbor - Railway System**		o Structural type (e.g. stub, partial or full depth, integral abutment) o Geometry of the abutment, i.e. height, width o Soil conditions of foundation o Fill material behind the abutment
Bridges	**Harbor - Roadway System** **Harbor - Railway System**		o Material: concrete, masonry, steel, iron, wood, mixed o Type of Deck: girder bridge, arch bridge, suspension bridge, cable-stayed bridge, moveable bridge o Deck structural system: simply supported, continuous o Pier to deck connection: not isolated (monolithic), isolated (through bearings), combination o Type of pier to deck connection : single-column pier, multi-column piers o Type of section of pier: cylindrical, rectangular, oblong, wall-type o Spans: single span, multi spans o Type of connection to abutments: free, monolithic, isolated (through bearings, isolators) o Skew: straight, skewed o Bridge configuration: regular or semi-regular, irregular o Foundation type: shallow, deep o Seismic design level: no seismic design, low-code, medium-code, high-code

COMPONENT	CRITICAL INFRASTRUCTURE / SYSTEM	GENERIC TYPOLOGY	CLASSIFICATION PARAMETERS
Buildings	**All**	Sheds Office buildings Industrial warehouses Maintenance buildings Compressor stations Control room facilities Passenger terminals Control and clock towers	o Attributes in GEM Building Taxonomy v2 (See Appendix A) o Type of non-structural components on the perimeter: none, vertical panels, horizontal panels, masonry infills o Additional components: none, anchored components, unanchored components
Building contents	**Industrial warehouses**	Stocks and supplies on shelves Industrial racks Movable manufacturing equipment	
Compensation reservoir	**Dam – Hydropower System**		o Volume o Embankments o Floodplain: in/out
Cranes	**Harbor - Cargo Handling / Storage System**	Stationary cranes Rail, tire and track mounted gantry and revolver cranes Mobile cranes	o Crane foundations o Power supply systems
Distribution Circuits	**Dam – Hydropower System**		o Voltage (kV) o Resistance (Ω/km) o Reactance (Ω/km) o Susceptance (S/km) o Voltage ratio o Floodplain: in/out
Electricity Lines	**Dam – Hydropower System** **Harbor - Electric Power System**		o Over ground / underground o Voltage: Low, medium, high o Floodplain: in/out
Fire-hydrant	**Harbor - Fire-Fighting System** **Dam – Hydropower System**		o Pressure o Demand o Operational: yes/no
Gas Pipelines	**Natural Gas - Distribution System** **Oil Refinery - Processing System**		o Location: Buried/Elevated o Burial depth (if buried) o Type of rack/support (if elevated) o Material: PVC, PEAD, cast iron, ductile iron, steel

COMPONENT	CRITICAL INFRASTRUCTURE / SYSTEM	GENERIC TYPOLOGY	CLASSIFICATION PARAMETERS
			o Material strength o Diameter o Wall thickness o Type of connection: Rubber gasket, lap-arc welded, heat fusion. Arc or oxyacetylene-gas welds, screwed, mechanical restrained, etc o Pressure classification: Low/High o Design flow/pressure o One way feed/Bi-directional feed o Type of rack/support (if elevated)
Gravity Retaining Structures	**Harbor – Waterfront components** **Harbor - Earthern/rockfill embankments** **Natural Gas - Distribution System** **Dam - Earthern/rockfill embankments**	Concrete block walls Massive walls Concrete caissons Cantilever structures Cellular sheet pile structures Steel lock-gates Steel plate cylindrical caissons Crib-work quay walls Native soils Rock and sand dike with back land fills Bulkheads Sea walls Breakwaters	o Age of construction o Geometrical characteristics: slope, height, width o Geometry of crossing: underneath, following profile o Filters o Slope protection o Impervious layer/curtain o Drainage system o Foundation o Soil conditions o Water table
Mooring and Breasting Dolphins	**Harbor – Waterfront components**	Monolithic gravity structures Founded on rubble and soil or rock or piles, or pile structures	
Oil / Gas Storage Tanks	**Oil Refinery - Storage System** **Hydrocarbon - Storage System** **Natural Gas - Storage System**	Floating roof tank Fixed roof tank Bullet tank Spherical tank Anchored atmospheric tanks Unanchored atmospheric tanks Buried horizontal pressurized tanks Above ground horizontal pressurized tanks Spheres	o Material: steel, R/C o Construction type: at-grade/ elevated o Anchored/ unanchored components o Roof type (floating/ fixed) o Capacity o Above ground/partially buried/buried o Tank foundations o Shape factor: height vs diameter ratio o Amount of content in the tank: empty, half-full, full.

COMPONENT	CRITICAL INFRASTRUCTURE / SYSTEM	GENERIC TYPOLOGY	CLASSIFICATION PARAMETERS
Oil Pipelines	**Hydrocarbon - Distribution System** **Harbor - Liquid Fuel System** **Oil Refinery - Processing System**		o Location: Buried/Elevated o Burial depth (if buried) o Type of rack/support (if elevated) o Connection type o Material type o Material strength o Diameter o Wall thickness o Type of connection o Pressure classification: Low/High o Design flow o One way feed/Bi-directional feed o Altitude reached o Speed of oil through the pipeline o Capacity
Other Pipelines	**All**		o Buried/elevated
Other Storage Tanks	**Harbor - Cargo Handling / Storage System** **Harbor - Liquid Fuel System**		o Anchored/unanchored o Above ground/partially buried/buried o Containment berms o Tank foundations
Piers	**Harbor – Waterfront components**	Deck slabs on pile caps Structures on columns with auxiliary structures for horizontal force absorption	o Pile caps material: wood, steel or concrete o With / without batter piles
Pipeline Station	**Natural Gas - Storage System**	Valve Stations Compressor Stations Export Stations Municipal Receiving Stations Industrial Receiving Stations Reducing stations Measure and Regulation Station Mixing station Feeding stations	o Open Air/In building o Pressure classification: Low/High o Wall thickness (pipe) o Type of connection (material) o Installations (Anchored/Unanchored) o Station specific main components
Power plant	**Dam – Hydropower System**		o Number of turbines o Type of turbines o Turbines characteristics (power, discharge, head) o Floodplain: in/out

COMPONENT	CRITICAL INFRASTRUCTURE / SYSTEM	GENERIC TYPOLOGY	CLASSIFICATION PARAMETERS
Pump equipment	**Harbor - Liquid Fuel System** **Hydrocarbon - Distribution System**		o Anchored/ unanchored
Pumping Station	**Harbor - Waste-Water System** **Oil Refinery - Waste-Water System** **Oil Refinery - Fire-Fighting System** **Dam – Hydropower System** **Hydrocarbon - Distribution System**		o Small/medium/large o Anchored/Unanchored Sub-components o Floodplain: in/out o Number of pumps o Pump discharge/head
Pumping Plants	**Hydrocarbon - Distribution System**		o Centrifugal o Reciprocating o Power
Refinery process components	**Oil Refinery - Processing System**	Pressurised equipment (cylindrical/sphere) Atmospheric equipment Reactors and pressurised process equipment	o Treated material: LPG, gasoline, naphta, gasoil, kerosene, hydrogen, heavy oil, sulphur o Working pressure: atmospheric/pressure/vacuum o Size: small, medium, large
Road pavements (ground failure)	**Harbor - Roadway System**		o Number of traffic lanes
SCADA (Supervisory Control And Data Acquisition system)	**All**		o Anchored/unanchored components o Building type o Foundation type o With / without backup power
Sheet Pile Wharves	**Harbor – Waterfront components**	Sheet pile wharves with auxiliary structures for anchoring Sheet pile with platform (horizontal pile-supported slab)	o Sheet pile o Pile o Fill-soil foundation
Substations	**Dam – Hydropower System**		o Anchored/ Unanchored components o Open/ closed type o Voltage: Low, medium, high
Switchyard	**Dam – Hydropower System**		o Floodplain: in/out

COMPONENT	CRITICAL INFRASTRUCTURE / SYSTEM	GENERIC TYPOLOGY	CLASSIFICATION PARAMETERS
Telecommunication centre	**Dam - Communication System** **Harbor - Communication System**		o Anchored/ unanchored components o With or without backup power o Floodplain: in/out
Tracks	**Harbor - Railway System**		o Traction system: diesel, electric, other o Sleepers (ties): wooden, steel, concrete, twin block
Transmission lines	**Dam - Communication System** **Harbor - Communication System**		o Wired communication o Optic fiber o Floodplain: in/out
Treatment plant	**Oil Refinery - Waste-Water System**		o Small/medium/large o Anchored/Unanchored Sub-components
Water Pipelines / Conduits	**Dam – Hydropower System** **Harbor - Water System** **Harbor - Waste-water System** **Oil Refinery - Waste-Water System** **Oil Refinery - Fire-Fighting System**		o Location: buried/elevated /in the flood plain/along the valley downstream the dam o Type: continuous/segmented o Material (type, strength): ductile iron, steel, PVC (acrylonitrile-butadiene styrene/ABS), polyethylene/PE, reinforced plastic mortar/RPM, resin transfer molding/RTM- asbestos-cement pipes, cast iron, concrete, clay o Type of joints: rigid/flexible o Capacity: diameter / discharge o Geometry: wall thickness / section o Type of coating and lining o Depth o History of failure o Appurtenances and branches o Corrosiveness of soil conditions o Age o Pressure
Water Storage Tanks	**Harbor - Water System** **Hydrocarbon - Distribution System**	Closed Tanks Open Cut Reservoirs	o Material: wood, steel, concrete, masonry o Capacity: small, medium, large o Anchorage: yes/no o Position: at grade, elevated by columns or frames) o Type of roof: RC, steel, wood o Seismic design: yes/no o Construction type: elevated by columns, built “at- grade” to rest directly on the ground, build “at grade” to rest on a foundation, concrete pile foundation o Presence of side-located inlet-outlet pipes o Volume: height, diameter o Thicknesses o Operational function: full, nearly full, less than full

COMPONENT	CRITICAL INFRASTRUCTURE / SYSTEM	GENERIC TYPOLOGY	CLASSIFICATION PARAMETERS
Water Tunnels	**Dam – Hydropower System**		o Construction technique o Liner system o Geologic conditions o Inlet o Outlet o Diameter o Discharge o Pressure o History of failure o Geometry/section

3 Vulnerability Factsheets

This Chapter presents the vulnerability factsheets that have been compiled by the leaders of each case study. A table for each case study is provided in the following pages, based on the following filling instructions:

1 – Has to match the STREST taxonomy;

2 – Duplicate lines if the same component is vulnerable to more than one hazard;

3 – Most important parameter controlling structural response;

4 – Secondary, if any, parameter controlling structural response in the study;

5 – What defines failure and undesired performance conditions triggering loss? Does the structure deteriorate in multiple events (e.g., aftershocks)?

6 – Most important analysis input parameter characterizing the potential of the natural hazard;

7 – Secondary, if any, analysis input parameter characterizing the potential of the natural hazard;

8 – Are IMs required at a single location or at multiple locations?

9 – The vulnerability model for the component exists, or if not, how you will address it?

10 – What is the tool to address uncertainty in vulnerability of the component?

11 – What method is used to evaluate vulnerability (e.g., non-linear dynamic analysis, observational data in other events…)?

12 – Is the performance of the component affected or does it affect other components of the same CI or of other CIs?

13 – Any other which is not in the list or any comment.

* Optional.

3.1 VULNERABILITY FACTSHEET CI-A1

STREST – WP4 VULNERABILITY FACTSHEET CI-A1 (ver Oct. 2014)

Partner and investigated CI	**Component needing a vulnerability model[1] and its coordinates (lat. lon.)**	**Vulnerable to which hazard?[2]**	**Primary Engineering Demand parameter[3] (EDP1)**	**Secondary Engineering Demand parameter[4,*] (EDP2)**	**Limit States of interest / consequences of failure (do they accumulate?)[5]**	**Primary preferred hazard intensity measure (IM1)[6]**	**Secondary preferred hazard intensity measure (IM2)[7,*]**	**Site-specific or regional [8]**	**Vulnerability model for the component exist, will be developed in the project, other?[9] (include ref. if available)**	**Stochastic modeling / uncertainty treatment in the model[10]**	**Analysis method for the performance assessment of the component[11]**	**Interdependency[12]**	**Other[13]**
AMRA – Oil Refinery in Milazzo	Steel oil storage tank (entire plant area[g])	Seismic shaking	Stress in the shell	Displacement	Loss of containment – not accumulating	Peak Ground Acceleration	N/A	Site specific	Exists [a,b,c]	Seismic fragility	Observational data in other events/ non-linear dynamic analysis	Pipelines in the same CI	N/A
AMRA – Oil Refinery in Milazzo	Steel oil storage tank (entire plant area[g])	Tsunamis	Displacement	Uplifting	Loss of containment – not accumulating	Maximum inundation depth	Maximum water velocity	Site specific	To be developed	Tsunami fragility	Observational data in other events/ non-linear dynamic analysis	Pipelines in the same CI	N/A
AMRA – Oil Refinery in Milazzo	Pressurised equipment (38.2041, 15.2680)	Seismic shaking	Stress in the shell	Overturning moment	Loss of containment – not accumulating	Peak Ground Acceleration	N/A	Site specific	Exists, to be improved [d]	Seismic fragility	Observational data in other events/ non-linear dynamic analysis	Pipelines in the same CI	N/A
AMRA – Oil Refinery in Milazzo	Pressurised equipment (38.2041, 15.2680)	Tsunamis	Uplifting	Stress for the connection (detachment)	Loss of containment – not accumulating	Maximum inundation depth	Maximum water velocity	Site specific	To be developed	Tsunami fragility	Observational data in other events/ non-linear dynamic analysis	Pipelines in the same CI	N/A
AMRA – Oil Refinery in Milazzo	Pressurised horizontal tank (buried) (38.2037, 15.2593)	Seismic shaking	Stress in the shell	Stress for the connection (detachment)	Loss of containment – not accumulating	Peak Ground Velocity	Peak Ground Acceleration (proxy for permanent ground deformation)	Site specific	Exists, to be improved [d]	Seismic fragility	Observational data in other events/ non-linear dynamic analysis	Pipelines in the same CI	N/A

STREST – WP4 VULNERABILITY FACTSHEET CI-A1 (ver Oct. 2014)

Partner and investigated CI	Component needing a vulnerability model[1] and its coordinates (lat. lon.)	Vulnerable to which hazard?[2]	Primary Engineering Demand parameter[3] (EDP1)	Secondary Engineering Demand parameter[4,*] (EDP2)	Limit States of interest / consequences of failure (do they accumulate?)[5]	Primary preferred hazard intensity measure (IM1)[6]	Secondary preferred hazard intensity measure (IM2)[7,*]	Site-specific or regional[8]	Vulnerability model for the component exist, will be developed in the project, other?[9] (include ref. if available)	Stochastic modeling / uncertainty treatment in the model[10]	Analysis method for the performance assessment of the component[11]	Interdependency[12]	Other[13]
AMRA – Oil Refinery in Milazzo	Pressurised Sphere (38.2037, 15.2593)	Seismic shaking	Stress in the supporting beams	Stress for the connection (detachment)	Loss of containment – not accumulating	Peak Ground Acceleration	N/A	Site specific	Exists, to be improved [d]	Seismic fragility	Observational data in other events/ non-linear dynamic analysis	Pipelines in the same CI	N/A
AMRA – Oil Refinery in Milazzo	Pressurised Sphere (38.2037, 15.2593)	Tsunamis	Stress in the supporting beams	Stress for the connection (detachment)	Loss of containment – not accumulating	Maximum inundation depth	Maximum water velocity	Site specific	To be developed	Tsunami fragility	Observational data in other events/ non-linear dynamic analysis	Pipelines in the same CI	N/A
AMRA – Oil Refinery in Milazzo	Pumping system (38.2041, 15.2680)	Seismic shaking	Stress for the equipment (displacement)	Stress for the connection (detachment)	Loss of containment – not accumulating	Peak Ground Acceleration	N/A	Site specific	Exists, to be improved [d]	Seismic fragility	Observational data in other events/ non-linear dynamic analysis	Pipelines in the same CI	N/A
AMRA – Oil Refinery in Milazzo	Pumping system (38.2041, 15.2680)	Tsunamis	Stress for the equipment (displacement)	Stress for the connection (detachment)	Loss of containment – not accumulating	Maximum inundation depth	Maximum water velocity	Site specific	To be developed	Tsunami fragility	Observational data in other events/ non-linear dynamic analysis	Pipelines in the same CI	N/A
AMRA – Oil Refinery in Milazzo	Atmospheric elongated equipment (38.2041, 15.2680)	Seismic shaking	Stress in the shell	Overturning moment	Loss of containment – not accumulating	Peak Ground Acceleration	N/A	Site specific	Exists, to be improved [d]	Seismic fragility	Observational data in other events/ non-linear dynamic analysis	Pipelines in the same CI	N/A
AMRA – Oil Refinery in Milazzo	Atmospheric elongated equipment (38.2041, 15.2680)	Tsunamis	Stress in the shell	Overturning moment	Loss of containment – not accumulating	Maximum inundation depth	Maximum water velocity	Site specific	To be developed	Tsunami fragility	Observational data in other events/ non-linear dynamic analysis	Pipelines in the same CI	N/A

STREST – WP4 VULNERABILITY FACTSHEET CI-A1 (ver Oct. 2014)

Partner and investigated CI	Component needing a vulnerability model[1] and its coordinates (lat. lon.)	Vulnerable to which hazard?[2]	Primary Engineering Demand parameter[3] (EDP1)	Secondary Engineering Demand parameter[4,*] (EDP2)	Limit States of interest / consequences of failure (do they accumulate?)[5]	Primary preferred hazard intensity measure (IM1)[6]	Secondary preferred hazard intensity measure (IM2)[7,*]	Site-specific or regional [8]	Vulnerability model for the component exist, will be developed in the project, other?[9] (include ref. if available)	Stochastic modeling / uncertainty treatment in the model[10]	Analysis method for the performance assessment of the component[11]	Interdependency[12]	Other[13]
AMRA – Oil Refinery in Milazzo	Pipeline (buried) (entire plant area[g])	Seismic shaking	Stress in the shell/(solid deformation or displacement)	Stress for the connection (detachment)	Loss of containment – not accumulating	Peak Ground Velocity	Peak Ground Acceleration (proxy for permanent ground deformation)	Site specific	Exists [e,f]	Seismic fragility	Observational data in other events/ non-linear dynamic analysis	Storage Tanks in the same CI	N/A
AMRA – Oil Refinery in Milazzo	Pipeline (overground /rack) (entire plant area[g])	Seismic shaking	Stress in the shell or support	Stress for the connection (detachment)	Loss of containment – not accumulating	Peak Ground Acceleration	N/A	Site specific	Exists, to be improved [e,f]	Seismic fragility	Observational data in other events/ non-linear dynamic analysis	Storage Tanks in the same CI	N/A
AMRA – Oil Refinery in Milazzo	Pipeline (overground /rack) (entire plant area[g])	Tsunamis	Stress in the shell or support	Stress for the connection (detachment)	Loss of containment – not accumulating	Maximum inundation depth	Maximum water velocity	Site specific	To be developed	Tsunami fragility	Observational data in other events/ non-linear dynamic analysis	Storage Tanks in the same CI	N/A
AMRA – Oil Refinery in Milazzo	Reactors/Low content process equipment (38.2041, 15.2680)	Seismic shaking	Stress in the shell	Stress for the connection (detachment)	Loss of containment – not accumulating	Peak Ground Acceleration	N/A	Site specific	Exists, to be improved [d]	Seismic fragility	Observational data in other events/ non-linear dynamic analysis	Storage Tanks in the same CI	N/A
AMRA – Oil Refinery in Milazzo	Fire Fighting system (entire plant area[g])	Seismic shaking	Stress for the equipment (displacement	Stress for connection (detachment)	Loss of containment – not accumulating	Peak Ground Acceleration	N/A	Site specific	Exists, to be improved [e,f]	Seismic fragility	Observational data in other events/ non-linear dynamic analysis	Storage Tanks in the same CI	N/A

STREST – WP4 VULNERABILITY FACTSHEET CI-A1 (ver Oct. 2014)

Partner and investigated CI	Component needing a vulnerability model[1] and its coordinates (lat. lon.)	Vulnerable to which hazard?[2]	Primary Engineering Demand parameter[3] (EDP1)	Secondary Engineering Demand parameter[4,*] (EDP2)	Limit States of interest / consequences of failure (do they accumulate?)[5]	Primary preferred hazard intensity measure (IM1)[6]	Secondary preferred hazard intensity measure (IM2)[7,*]	Site-specific or regional[8]	Vulnerability model for the component exist, will be developed in the project, other?[9] (include ref. if available)	Stochastic modeling / uncertainty treatment in the model[10]	Analysis method for the performance assessment of the component[11]	Interdependency[12]	Other[13]
AMRA – Oil Refinery in Milazzo	Fire Fighting system (entire plant area[g]))	Tsunamis	Stress for the equipment (displacement	Stress for connection (detachment)	Loss of containment – not accumulating	Maximum inundation depth	Maximum water velocity	Site specific	To be developed	Tsunami fragility	Observational data in other events/ non-linear dynamic analysis	Storage Tanks in the same CI	N/A

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Coordinates of the vertices

g. **(**38.2037, 15.2593); **(**38.2076, 15.2611); **(**38.2071, 15.2730); **(**38.1981, 15.2715)

3.2 VULNERABILITY FACTS SHEET CI-A2

STREST – WP4 VULNERABILITY FACTS SHEET CI-A2 (ver Sept. 2014)

Partner and investigated CI	Component needing a vulnerability model[1] and its coordinates (lat. lon.)	Vulnerable to which hazard?[2]	Primary Engineering Demand parameter[3] (EDP1)	Secondary Engineering Demand parameter[4,*] (EDP2)	Limit States of interest / consequences of failure (do they accumulate?)[5]	Primary preferred hazard intensity measure (IM1)[6]	Secondary preferred hazard intensity measure (IM2)[7,*]	Site-specific or regional[8]	Vulnerability model for the component exist, will be developed in the project, other?[9] (include ref. if available)	Stochastic modeling / uncertainty treatment in the model[10]	Analysis method for the performance assessment of the component[11]	Interdependency[12]	Other[13]
EPFL - Large dams (Concrete dam, Les Toules) (CI-A2)	Dam and foundation (45.9813, 7.2004)	Seismic shaking	Stress in the shell	Stress in the abutment / foundation	Dam failure (not accumulating) Development of cracks / loss of sealing properties (accumulating)	Peak ground acceleration (horizontal and vertical)	Duration of ground motion / location of the faults	Site specific	To be confirmed (c,d,g,l)	Seismic fragility	Pseudo-static / non-linear dynamic	All appurtenant and downstream structures	More than one failure mode. Depends on reservoir water level
EPFL - Large dams (fill dam, Mattmark) (CI-A2)	Dam and foundation (46.0476, 7.9590)	Seismic shaking	Stress in the embankment / pore pressure	Displacement in relation to the foundation	Dam failure (liquefaction, slope instability, not accumulating) Lowering of the dam crest; displacement of embankment sections; crack formation (accumulating)	Peak ground acceleration (horizontal and vertical)	Duration of ground motion	Site specific	To be confirmed (c,d,l)	Seismic fragility	Pseudo-static / non-linear dynamic	All appurtenant and downstream structures	More than one failure mode. Depends on reservoir water level
EPFL - Large dams (fill dam, Mattmark) (CI-A2)	Dam (46.0476, 7.9590)	Flood (Overtopping due to floods)	Hydraulic shear stress		Dam failure (not accumulating)	Magnitude of the flood	Duration of the flood	Site specific	To be confirmed (b,d,e)	Flood fragility	Threshold sediment transport / dynamic fluid analysis	All appurtenant and downstream structures	Presents high risk for fill dams and/or downstream areas

STREST – WP4 VULNERABILITY FACTS SHEET CI-A2 (ver Sept. 2014)

Partner and investigated CI	Component needing a vulnerability model[1] and its coordinates (lat. lon.)	Vulnerable to which hazard?[2]	Primary Engineering Demand parameter[3] (EDP1)	Secondary Engineering Demand parameter[4,*] (EDP2)	Limit States of interest / consequences of failure (do they accumulate?)[5]	Primary preferred hazard intensity measure (IM1)[6]	Secondary preferred hazard intensity measure (IM2)[7,*]	Site-specific or regional[8]	Vulnerability model for the component exist, will be developed in the project, other?[9] (include ref. if available)	Stochastic modeling / uncertainty treatment in the model[10]	Analysis method for the performance assessment of the component[11]	Interdependency[12]	Other[13]
EPFL - Large dams (fill dam, Mattmark) (CI-A2)	Dam (46.0476, 7.9590)	Slope instability (Overtopping - due to large soil mass movements)	Hydraulic shear stress		Dam failure (not accumulating)	Volume of overtopping	Duration of the overtopping	Site specific	To be confirmed (b,d,i)	Slope stability analysis	Threshold sediment transport / dynamic fluid analysis	All appurtenant and downstream structures	Presents high risk for fill dams and/or downstream areas
EPFL - Large dams (fill dam, Mattmark) (CI-A2)	Dam (46.0476, 7.9590)	Internal erosion (likely not a natural hazard)	Seepage force	Dam displacement in relation to the foundation	Dam failure (through breach formation, not accumulating). Pipe formation / increased permeability (accumulating)	Seepage flow	Crack characteristics	Site specific	To be confirmed (a,c)	Geotechnical analysis	Observational data from other events	Historical crack formation and displacement. All appurtenant and downstream structures	
EPFL - Large dams (both) (CI-A2)	Spillway (45.9813, 7.2004) and (46.0476, 7.9590)	Seismic shaking	Stress in the interface	Stress in the structure	Structure inoperability (not accumulating)	Peak ground acceleration (horizontal and vertical)	Duration of ground motion	Site specific	To be confirmed (j)	Seismic fragility	Pseudo-static / non-linear dynamic	Dam (through outflow capacity)	Extreme events can either increase of decrease outflows
EPFL - Large dams (both) (CI-A2)	Bottom outlet (45.9813, 7.2004) and (46.0476, 7.9590)	Seismic shaking	Stress in the interface	Stress in the structure	Structure inoperability (not accumulating)	Peak ground acceleration (horizontal and vertical)	Duration of ground motion	Site specific	To be confirmed (j)	Seismic fragility	Pseudo-static / non-linear dynamic	Dam (through outflow capacity)	Must be operational if the reservoir needs to be emptied

STREST – WP4 VULNERABILITY FACTS SHEET CI-A2 (ver Sept. 2014)

Partner and investigated CI	Component needing a vulnerability model[1] and its coordinates (lat. lon.)	Vulnerable to which hazard?[2]	Primary Engineering Demand parameter[3] (EDP1)	Secondary Engineering Demand parameter[4,*] (EDP2)	Limit States of interest / consequences of failure (do they accumulate?)[5]	Primary preferred hazard intensity measure (IM1)[6]	Secondary preferred hazard intensity measure (IM2)[7,*]	Site-specific or regional[8]	Vulnerability model for the component exist, will be developed in the project, other?[9] (include ref. if available)	Stochastic modeling / uncertainty treatment in the model[10]	Analysis method for the performance assessment of the component[11]	Interdependency[12]	Other[13]
EPFL - Large dams (both) (CI-A2)	Hydropower and pressure systems (45.9813, 7.1893), (46.0828, 7.9577) and (46.2378, 7.8745)	Seismic shaking	Stress in the pressure system	Actions upon hydromechanical and electrical components	No power production; reduced outflow capacity (not accumulating)	Peak ground acceleration (horizontal and vertical)	Duration of ground motion	Site specific	To be confirmed [j]	Seismic fragility	Pseudo-static	Dam (through outflow capacity)	Taken as a whole, this includes Structural, hydraulic, mechanical and electrical components
EPFL - Large dams (both) (CI-A2)	Hydropower and pressure systems (45.9813, 7.1893), (46.0828, 7.9577) and (46.2378, 7.8745)	Flood	Water level	Actions upon hydromechanical and electrical components	No power production; reduced outflow capacity (not accumulating)	Magnitude of the flood		Site specific	To be confirmed	Flood fragility	Observational data from other events	Dam (through outflow capacity)	Taken as a whole, this includes Structural, hydraulic, mechanical and electrical components
EPFL - Large dams (both) (CI-A2)	Compensation basin (45.9813, 7.1893) and (46.0828, 7.9577)	Seismic shaking	Stress in the embankment / pore pressure	Displacement in relation to the foundation	Compensation basin failure (not accumulating)	Peak ground acceleration (horizontal and vertical)	Duration of ground motion	Site specific	To be confirmed [k]	Seismic fragility	Pseudo-static	None	Can constitute a risk to downstream areas
EPFL - Large dams (both) (CI-A2)	Compensation basin (45.9813, 7.1893) and (46.0828, 7.9577)	Flood	Water level	Hydraulic shear stress	Compensation basin failure (not accumulating)	Magnitude of the flood	Duration of the flood	Site specific	To be confirmed [k]	Flood vulnerability	Threshold sediment transport / dynamic fluid analysis	None	Can constitute a risk to downstream areas

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3.3 VULNERABILITY FACTS SHEET CI-B1

STREST – WP4 VULNERABILITY FACTS SHEET CI-B1 (ver Sept. 2014)

Partner and investigated CI	**Component needing a vulnerability model[1] and its coordinates (lat. lon.)**	**Vunerable to which hazard?[2]**	**Primary Engineering Demand parameter[3] (EDP1)**	**Secondary Engineering Demand parameter[4],* (EDP2)**	**Limit States of interest / consequences of failure (do they accumulate?)[5]**	**Primary preferred hazard intensity measure (IM1)[6]**	**Secondary preferred hazard intensity measure (IM2)[7],***	**Site-specific or regional[8]**	**Vulnerability model for the component exist, will be developed in the project, other?[9] (include ref. if available)**	**Stochastic modeling / uncertainty treatment in the model[10]**	**Analysis method for the performance assessment of the component[11]**	**Interdependency[12]**	**Other[13]**
BU-KOERI/ Hydrocarbon pipe	Steel pipeline (buried)[h]	Seismic shaking	Axial strain *Typically Low strains (less than 0.1-0.2%)*	-	Loss of containment / Local buckling Indirect limit state (See comments)	Peak Ground Velocity	Pulse period	Site specific	Simple analytical expressions to calculate equivalent ground strains from elastic velocity pulses (Ref.b). (to be adopted)	Seismic fragility/ A reasonable range of variation of the main attributes of the model will be used in the parametric analysis. The uncertainties will be assessed through statistical treatment of the capacity results.	Elastic wave propagation analysis	1) Natural Gas pipeline (different CI) is laid parallel to the existing BTC crude oil pipeline (up to 15 m. proximity) Ref.b 2)Storage Tanks in the same CI	Local buckling does not result in loss of containment. However in the long term, it can cause fatigue failure during operational vibrations (Ref d,e). Indirect limit state.
		Permanent Ground Deformation (PGD)	Axial compressive strain		Loss of containment / Local buckling	Magnitude (proxy for the fault displacement)	N/A		Parametric analysis using simplified non-linear methods (to be developed) (Ref.c).		Large displacement geometric and material non-linear static analysis		
			Axial tensile strain (due to pipe extension) *Typically high strains (up to 15-20 %)*		Loss of containment / Tension failure (Direct limit								Tension rupture, cold rolling (Ref.b) or brittle welding failure are the possible failure modes. Ends up with loss of containment. Direct limit state.

					state)								
		PGD	Hoop displacement ratio	Ovalization	Functionality problem (pls see the comment)								A functionality parameter does not result in loss of containment. Therefore will be ignored as per discussions made during the meeting.

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d. Vazouras P, Karamanos SA, Dakoulas PD (2010) Finite element analysis of buried steel pipelines under strike-slip fault displacements. Soil Dyn Earthq Eng 30: 1361-1376

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Coordinates of the fault locations

h. Erzurum East Fault Zone (41.410, 39.968)

Erzurum West (Middle) Fault Zone (41.371, 39.965)

North Anatolian Fault (39.142, 39.925)

Deliler Fault Zone (36.931, 39.360)

Cokak Fault Zone (36.340, 37.734)

Cokak Fault Zone (36.336, 37.734)

3.4 VULNERABILITY FACTS SHEET CI-B2

STREST – WP4 VULNERABILITY FACTS SHEET CI-B2 (Sept. 2014)

Partner and investigated CI	Component needing a vulnerability model[1]	Vunerable to which hazard?[2]	Primary Engineering Demand parameter[3] (EDP1)	Secondary Engineering Demand parameter[4,*] (EDP2)	Limit States of interest / consequences of failure (do they accumulate?)[5]	Primary preferred hazard intensity measure (IM1)[6]	Secondary preferred hazard intensity measure (IM2)[7,*]	Site-specific or regional[8]	Vulnerability model for the component exist, will be developed in the project, other?[9] (include ref. if available)	Stochastic modeling / uncertainty treatment in the model[10]	Analysis method for the performance assessment of the component[11]	Interdependency[12]	Other[13]
TNO_Groningen_GASUNIE	Pressurized pipeline (buried)	Seismic shaking	Stress in the shell	Stress for the connection (detachment)	Leakages/buckling/ bending failure	Peak Ground Velocity	Peak Ground Acceleration	Site specific for the single element but considering multiple event in the same gas-network	Exists[a,b], to be improved for the specific case (specific characteristic for the Groningen GasUnie of : - seismic wave [e] - static constraints of the pipes [c] – stations details [d])	Seismic fragility (seismic hazard curves provided by KNMI / damage scenarios are available within GasUnie)	Dynamic non linear analysis	Pipelines in the same CI/ adjacent soil dikes/canals/storages/tanks	N/A
TNO_Groningen_GASUNIE	pressurized pipeline (over ground)	Seismic shaking	Stress in the shell	Stress for the connection (detachment)	Leakages/buckling/bending failure	Peak Ground Acceleration	Duration of ground motion	Site specific for the pipeline over-ground in vicinity of stations, but also considering multiple event in the same gas-network for the branches above ground	Exists[a,b], to be improved for the specific case (specific characteristic for the Groningen GasUnie of : - seismic wave [e] - static constraints of the pipes [c] – stations details [d])	Seismic fragility (seismic hazard curves provided by KNMI / damage scenarios are available within GasUnie)	Dynamic non linear analysis	Pipelines in the same CI/ adjacent soil dikes	N/A

STREST – WP4 VULNERABILITY FACTS SHEET CI-B2 (Sept. 2014)

Partner and investigated CI	Component needing a vulnerability model[1]	Vunerable to which hazard?[2]	Primary Engineering Demand parameter[3] (EDP1)	Secondary Engineering Demand parameter[4,*] (EDP2)	Limit States of interest / consequences of failure (do they accumulate?)[5]	Primary preferred hazard intensity measure (IM1)[6]	Secondary preferred hazard intensity measure (IM2)[7,*]	Site-specific or regional[8]	Vulnerability model for the component exist, will be developed in the project, other?[9] (include ref. if available)	Stochastic modeling / uncertainty treatment in the model[10]	Analysis method for the performance assessment of the component[11]	Interdependency[12]	Other[13]
TNO_Groningen_ GASUNIE	Pressurized pipeline (buried and over ground)	Liquefaction	Stress in the shell	Stress for the connection (detachment) Displacements	Leakages/bending failure /rupture	Peak Ground Acceleration (proxy for permanent ground deformation)	Duration of ground motion	Site specific	Exists[a,b], to be improved for the specific case (specific characteristic for the Groningen GasUnie of : - seismic wave [e] - static constraints of the pipes [c] – stations details [d])	Seismic fragility (seismic hazard curves provided by KNMI / damage scenarios are available within GasUnie)	Dynamic non linear analysis	Pipelines in the same CI/ adjacent soil dikes/canals/ storages	N/A
TNO_Groningen_ GASUNIE	Pumping system	Seismic shaking	Stress for the equipment (displacement)	Stress for the connection (detachment)	Loss of containment /rupture	Peak Ground Acceleration	Duration of ground motion	Site specific	Exists[d] ,	Seismic fragility (seismic hazard curves provided by KNMI / damage scenarios are available within GasUnie)	Fault tree analysis [d]	Pipelines in the same CI	N/A
TNO_Groningen_ GASUNIE	Pumping system	Flood	Stress for the equipment (displacement)	Stress for the connection (detachment)	Loss of containment	Maximum inundation depth	Wind speed	Site specific	Tbd (input available from literature)	Fragility curves (input available from internal reports)	Observational data in other events/ Fault tree analysis / Expert judgment	Pipelines in the same CI/ Stations	N/A

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TNO

Partner and investigated CI	Component needing a vulnerability model[1]	Vunerable to which hazard?[2]	Primary Engineering Demand parameter[3] (EDP1)	Secondary Engineering Demand parameter[4,*] (EDP2)	Limit States of interest / consequences of failure (do they accumulate?)[5]	Primary preferred hazard intensity measure (IM1)[6]	Secondary preferred hazard intensity measure (IM2)[7,*]	Site-specific or regional[8]	Vulnerability model for the component exist, will be developed in the project, other?[9] (include ref. if available)	Stochastic modeling / uncertainty treatment in the model[10]	Analysis method for the performance assessment of the component[11]	Interdependency[12]	Other[13]
TNO_Groningen_ GASUNIE	Station Halls	Seismic shaking	Displacement	Stress in shell masonry	Collapse	Peak Ground Acceleration	Duration of ground motion	Site specific	Tbd (input available from literature)	Seismic fragility	Dynamic non linear analysis	Pipelines in the same CI	N/A
TNO_Groningen_ GASUNIE	Station Halls	Flood	Displacements	Pressure on wall	Collapse	Maximum inundation depth	Wind speed	Site specific	Tbd (input available from literature)	Fragility curves (input available from internal reports)	Observational data in other events/ Expert judgment	Pipelines in the same CI	N/A
TNO_Groningen_ GASUNIE	Flood barriers (i.e. soil dikes and steel locks)	Seismic shaking	Displacement	Tbd	Instability/piping	Peak Ground Acceleration	Duration of the ground motion	Site specific	Tbd (input available from literature)	Seismic fragility	Dynamic non linear analysis	Pipelines and stations in the same CI/Station halls	N/A
TNO_Groningen_ GASUNIE	Flood barriers	Flood	Displacement	Tbd	Instability/ collapse	Maximum inundation depth	Wind speed	Site specific	Tbd (input available from literature)	Fragility curves (input available from internal reports)	Observational data in other events	Pipelines in the same CI/Station halls	N/A

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c. Piping and pipeline Engineering: Design, Construction, Maintenance, Integrity and Repair. Antaki G., Dekker Inc. NY.2003.
d. Fragility Functions for gas and oil system networks. Pitilakis K., SYNER-G deliverable 3.4. 2009.
e. Probabilistic Seismic Hazard Analysis Induced Earthquakes Groningen. Eck, van T., Caccavale M., Dost B., Kraaijpoel D., KNMI Report. 2013.

Coordinates of area for CI-B2.

Corner Point	Coordinate System					
	Amersfoort / RD New		Nord Sahara 1959 / UTM zone 29N		WGS84 DD	
North West	219000	610000	1527002	6047282	6.35101	53.47234
North East	279000	610000	1574883	6047282	7.25422	53.46173
South East	279000	553000	1574883	5978451	7.23225	52.94977
South West	219000	553000	1527002	5978451	6.33966	52.96022

3.5 VULNERABILITY FACTS SHEET CI-B3

STREST – WP4 VULNERABILITY FACTS SHEET CI-B3 (ver Sept. 2014)

Partner and investigated CI	**Component needing a vulnerability model[1] and its coordinates (lat. lon.)**	**Vulnerable to which hazard?[2]**	**Primary Engineering Demand parameter[3] (EDP1)**	**Secondary Engineering Demand parameter[4,*] (EDP2)**	**Limit States of interest / consequences of failure (do they accumulate?)[5]**	**Primary preferred hazard intensity measure (IM1)[6]**	**Secondary preferred hazard intensity measure (IM2)[7,*]**	**Site-specific or regional[8]**	**Vulnerability model for the component exist, will be developed in the project, other?[9] (include ref. if available)**	**Stochastic modeling / uncertainty treatment in the model[10]**	**Analysis method for the performance assessment of the component[11]**	**Interdependency[12]**	**Other[13]**
AUTH - Thessaloniki port	Waterfront structures/ quay walls (Various types)[p]	Seismic shaking & Liquefaction	Residual (permanent) displacement	Rotation/tilt	Normalized seaward displacement, sliding, residual tilting – not accumulating	Peak ground acceleration (proxy for permanent ground deformation)		Site specific / both single multiple locations	Exists [a-h]	Seismic fragility for both shaking and liquefaction	Non-linear dynamic analysis/ observational data	Cranes and cargo handling equipment located on the waterfront structure or on the apron behind it	N/A
AUTH - Thessaloniki port	Waterfront structures/ quay walls (Various types)[p]	Tsunamis	Displacement	Stress / Overturning moment	Normalized seaward displacement, sliding, residual tilting – not accumulating	Maximum Inundation depth	Maximum Water velocity	Site specific / both single and multiple locations	Not existing/ to be developed	Tsunami fragility	Observational data / non-linear analysis	Cranes and cargo handling equipment located on the waterfront structure or on the apron behind it	N/A
AUTH - Thessaloniki port	Cranes and cargo handling equipment (Various types)[q]	Seismic shaking	Permanent displacements (vertical, horizontal)	Members' internal stresses and overturning moment	Derailment/ toppling, structural damage - not accumulating	Peak Ground Acceleration		Site specific single locations	Exists [a]	Seismic fragility	Expert judgment/ observational data	Electric power substations and lines in the same CI supplying electricity Road and railway system	N/A
AUTH - Thessaloniki port	Cranes and cargo handling equipment (Various types)[q]	Liquefaction	Permanent displacements (vertical, horizontal)	Members' internal stresses and overturning moment	Derailment/ toppling, structural damage - not accumulating	Peak ground acceleration (proxy for permanent ground deformation)		Site specific single locations	Exists [a]	Seismic fragility	Expert judgment/ observational data	Electric power substations and lines in the same CI supplying electricity Road and railway system	N/A

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Partner and investigated CI	Component needing a vulnerability model[1] and its coordinates (lat. lon.)	Vulnerable to which hazard?[2]	Primary Engineering Demand parameter[3] (EDP1)	Secondary Engineering Demand parameter[4,*] (EDP2)	Limit States of interest / consequences of failure (do they accumulate?)[5]	Primary preferred hazard intensity measure (IM1)[6]	Secondary preferred hazard intensity measure (IM2)[7,*]	Site-specific or regional[8]	Vulnerability model for the component exist, will be developed in the project, other?[9] (include ref. if available)	Stochastic modeling / uncertainty treatment in the model[10]	Analysis method for the performance assessment of the component[11]	Interdependency[12]	Other[13]
AUTH - Thessaloniki port	Cranes and cargo handling equipment (Various types)[q]	Tsunamis	Stress in the equipment Permanent ground displacement	Members' internal stresses for the connection (detachment) Overturning moment	Derailment/ toppling, structural damage – not accumulating	Maximum Inundation depth	Maximum Water velocity	Site specific single location	Not existing (to be confirmed if new curves will be developed)	Tsunami fragility	Observational data/ non-linear numerical analysis	Electric power substations and lines in the same CI supplying electricity Road and railway system	N/A
AUTH - Thessaloniki port	Electric power substation[r]	Seismic shaking	Stress for the equipment (micro-components)		Power availability – not accumulating	Peak Ground Acceleration	Peak ground Velocity	Site specific	Exists [a,i]	Seismic fragility	Expert judgment/ fault tree analysis	Cranes and cargo handling equipment, buildings, utilities and infrastructures in the same CI	N/A
AUTH - Thessaloniki port	Harbor Buildings- RC buildings of various typologies	Seismic shaking	Interstory drift		Collapse of the structure - not accumulating	Spectral Acceleration as a function of the period	Peak Ground Acceleratio n	Site specific	Exists [j]	Seismic fragility	Non linear dynamic/static analyses		N/A
AUTH - Thessaloniki port	Harbor Buildings- Masonry buildings of various typologies	Seismic shaking	Displacement	Shear stresses	Collapse of the structure - not accumulating	Peak Ground Acceleration		Site specific	Exists [j]	Seismic fragility	Non linear dynamic/static analyses		N/A
AUTH - Thessaloniki port	Harbor Buildings- Steel buildings of various typologies	Seismic shaking	Interstory drift		Collapse of the structure - not accumulating	Spectral displacement as a function of the period	Peak Ground Acceleratio n	Site specific	Exists [a]	Seismic fragility	Observational data and expert judgment		N/A
AUTH - Thessaloniki port	Harbor Buildings of various typologies	Liquefaction	Residual displacement		Collapse of the structure - not accumulating	Peak ground acceleration (proxy for permanent ground deformation)		Site specific	Exists [a]	Seismic fragility	Observational data and expert judgment		N/A

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Partner and investigated CI	Component needing a vulnerability model[1] and its coordinates (lat. lon.)	Vulnerable to which hazard?[2]	Primary Engineering Demand parameter[3] (EDP1)	Secondary Engineering Demand parameter[4,*] (EDP2)	Limit States of interest / consequences of failure (do they accumulate?)[5]	Primary preferred hazard intensity measure (IM1)[6]	Secondary preferred hazard intensity measure (IM2)[7,*]	Site-specific or regional[8]	Vulnerability model for the component exist, will be developed in the project, other?[9] (include ref. if available)	Stochastic modeling / uncertainty treatment in the model[10]	Analysis method for the performance assessment of the component[11]	Interdependency[12]	Other[13]
AUTH - Thessaloniki port	Harbor Buildings of various typologies	Tsunamis	Interstory drift	Displacement	Collapse of the structure - not accumulating	Maximum inundation depth	Maximum Water velocity	Site specific	Exists [k]	Tsunami fragility	Observational data and expert judgment		N/A
AUTH - Thessaloniki port	Fuel storage tanks*	Seismic shaking	Stress in the shell	Displacement	Collapse of the tank and loss of its contents - not accumulating	Peak ground acceleration		Site specific	Exists [a,i]	Seismic fragility	Expert judgment/ fault tree analysis	Pipelines in the same CI, fuel supply for ships	N/A
AUTH - Thessaloniki port	Water storage tanks*	Seismic shaking	Stress in the shell	Displacement	Collapse of the tank and loss of its contents - not accumulating	Peak ground acceleration		Site specific	Exists [a,l,m,n,o]	Seismic fragility	Expert judgment, Empirical/ Bayesian approach	Pipelines in the same CI, water supply for ships	N/A
AUTH - Thessaloniki port	Water storage tanks*	Liquefaction	Stress in the shell	Displacement	Collapse of the tank and loss of its contents - not accumulating	Peak ground acceleration (proxy for permanent ground deformation)		Site specific	Exists [a,l,m,n,o]	Seismic fragility	Expert judgment, Empirical/ Bayesian approach	Pipelines in the same CI, water supply for ships	N/A
AUTH - Thessaloniki port	Water/ waste-water pipelines*	Seismic shaking	Axial strain		Leakages/ breaks - not accumulating	Peak ground velocity		Site specific	Exists [j,m,n]	Seismic fragility in terms of repair rate	Empirical	Storage tanks in the same CI, supply for ships	N/A
AUTH - Thessaloniki port	Water/ waste-water pipelines*	Liquefaction	Axial strain		Leakages/ breaks - not accumulating	Peak ground acceleration (proxy for permanent ground deformation)		Site specific	Exists [j,m,n]	Seismic fragility in terms of repair rate	Empirical	Storage tanks in the same CI, supply for ships	N/A
AUTH - Thessaloniki port	Pumping (lift) station*	Seismic shaking	Roof drift		Collapse of the building/ not accumulating	Peak ground acceleration		Site specific	Exists [i,a]	Seismic fragility	Empirical/ fault tree analysis	Pipelines in the same CI	N/A
AUTH - Thessaloniki port	Natural gas pipelines*	Seismic shaking	Axial strain		Leakages/ breaks- not accumulating	Peak ground velocity		Site specific	Exists [j,m,n]	Seismic fragility in terms of repair rate	Empirical	Storage tanks in the same CI, supply for ships	N/A

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Partner and investigated CI	Component needing a vulnerability model[1] and its coordinates (lat. lon.)	Vulnerable to which hazard?[2]	Primary Engineering Demand parameter[3] (EDP1)	Secondary Engineering Demand parameter[4,*] (EDP2)	Limit States of interest / consequences of failure (do they accumulate?)[5]	Primary preferred hazard intensity measure (IM1)[6]	Secondary preferred hazard intensity measure (IM2)[7,*]	Site-specific or regional[8]	Vulnerability model for the component exist, will be developed in the project, other?[9] (include ref. if available)	Stochastic modeling / uncertainty treatment in the model[10]	Analysis method for the performance assessment of the component[11]	Interdependency[12]	Other[13]
AUTH - Thessaloniki port	Natural gas pipelines*	Liquefaction	Axial strain		Leakages/ breaks - not accumulating	Peak ground acceleration (proxy for permanent ground deformation)		Site specific	Exists [j,m,n]	Seismic fragility in terms of repair rate	Empirical	Storage tanks in the same CI, supply for ships	N/A
AUTH - Thessaloniki port	Road pavements Containers storage area	Liquefaction	Residual (permanent) displacement		Settlement/ not accumulating	Peak ground acceleration (proxy for permanent ground deformation)		Site specific	Exists [a]	Seismic fragility	Expert judgment/ observational data	Transportation of goods and supplies. Underneath utility networks (e.g. pipelines, cables etc)	N/A
AUTH - Thessaloniki port	Road pavements Containers storage area	Tsunamis	Displacement		Pavement deformation/ not accumulating	Maximum inundation depth		Site specific	Not existing (to be confirmed if new curves will be developed)	Tsunami fragility	Expert judgment/ observational data	Transportation of goods and supplies. Underneath utility networks (e.g. pipelines, cables etc)	N/A
AUTH - Thessaloniki port	Road bridge	Seismic shaking	Chord rotation at the ends of piers, shear force of piers	Deformation of bearings	Large deformation of bearing, rotation of piers/ not accumulating	Peak ground acceleration		Site specific	Exists [j]	Seismic fragility/ model uncertainties and dispersion of geometry and material properties	Linear elastic analysis ("equal displacement rule")	Transportation of goods and supplies.	N/A
AUTH - Thessaloniki port	Road bridge	Liquefaction	Displacement		Large deformation of bearing, rotation of piers/ not accumulating	Peak ground acceleration (proxy for permanent ground deformation)		Site specific	Exists [a]	Seismic fragility	Expert judgment	Transportation of goods and supplies.	N/A
AUTH - Thessaloniki port	Road bridge	Tsunamis	Displacement		Collapse of any column, rupture of bearings, deck rotation/ not accumulating	Maximum inundation depth	Maximum water velocity	Site specific	Exists [a]	Tsunami fragility	Expert judgment and empirical based	Transportation of goods and supplies.	N/A

STREST – WP4 VULNERABILITY FACTS SHEET CI-B3 (ver Sept. 2014)

Partner and investigated CI	Component needing a vulnerability model[1] and its coordinates (lat. lon.)	Vulnerable to which hazard?[2]	Primary Engineering Demand parameter[3] (EDP1)	Secondary Engineering Demand parameter[4,*] (EDP2)	Limit States of interest / consequences of failure (do they accumulate?)[5]	Primary preferred hazard intensity measure (IM1)[6]	Secondary preferred hazard intensity measure (IM2)[7,*]	Site-specific or regional[8]	Vulnerability model for the component exist, will be developed in the project, other?[9] (include ref. if available)	Stochastic modeling / uncertainty treatment in the model[10]	Analysis method for the performance assessment of the component[11]	Interdependency[12]	Other[13]
AUTH - Thessaloniki port	Railway tracks*	Liquefaction	Residual (permanent) displacement		Track deformation/ not accumulating	Peak ground acceleration (proxy for permanent ground deformation)		Site specific	Exists [j]	Seismic fragility	Expert judgment and empirical based	Transportation of goods and supplies	N/A

* to be confirmed if these components will be included in the systemic analysis

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Coordinates

Entire area: lat1=40.658, long1=22.839, lat 2=40.658, long 2=22.957, lat 3=40.629, long 3=22.957, lat 4=40.629, long 4=22.839

3.6 VULNERABILITY FACTS SHEET CI-C1

STREST – WP4 VULNERABILITY FACTS SHEET CI-C1 (ver Sept. 2014)

Partner and investigated CI	Component needing a vulnerability model[1] and its coordinates (lat. lon.)	Vulnerable to which hazard?[2]	Primary Engineering Demand parameter[3] (EDP1)	Secondary Engineering Demand parameter[4,*] (EDP2)	Limit States of interest / consequences of failure (do they accumulate?)[5]	Primary preferred hazard intensity measure (IM1)[6]	Secondary preferred hazard intensity measure (IM2)[7,*]	Site-specific or regional[8]	Vulnerability model for the component exist, will be developed in the project, other?[9] (include ref. if available)	Stochastic modeling / uncertainty treatment in the model[10]	Analysis method for the performance assessment of the component[11]	Interdependency[12]	Other[13]
EUCENTRE - industrial precast buildings	concrete, precast; DX: post and beams, nonductile, DY: no lateral load resisting system; one storey; pre 1996	Seismic shaking	Roof drift	Shear demand at connections	Column flexure yield and collapse and connection collapse - accumulating**	Spectral acceleration as a function of period	N/A	Regional	Existing (b)	Seismic fragility	Non-linear dynamic analysis	Industrial buildings in the same CI	no seismic design action, long span beams, short distance between frames, friction connections
EUCENTRE - industrial precast buildings	concrete, precast; DX: post and beams, nonductile, DY: no lateral load resisting system; one storey; 1996-2009	Seismic shaking	Roof drift	Shear demand at connections	Column flexure yield and collapse and connection collapse - accumulating**	Spectral acceleration as a function of period	N/A	Regional	To be developed	Seismic fragility	Non-linear dynamic analysis	Industrial buildings in the same CI	no seismic design action, long span beams, short distance between frames, dowel connections
EUCENTRE - industrial precast buildings	concrete, precast; DX: post and beams, nonductile, DY: no lateral load resisting system; one storey; 1996-2009	Seismic shaking	Roof drift	Shear demand at connections	Column flexure yield and collapse and connection collapse - accumulating**	Spectral acceleration as a function of period	N/A	Regional	Existing (b)	Seismic fragility	Non-linear dynamic analysis	Industrial buildings in the same CI	very low seismic action (4%W), long span beams, short distance between frames, dowel connections

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Partner and investigated CI	Component needing a vulnerability model[1] and its coordinates (lat. lon.)	Vulnerable to which hazard?[2]	Primary Engineering Demand parameter[3] (EDP1)	Secondary Engineering Demand parameter[4,*] (EDP2)	Limit States of interest / consequences of failure (do they accumulate?)[5]	Primary preferred hazard intensity measure (IM1)[6]	Secondary preferred hazard intensity measure (IM2)[7,*]	Site-specific or regional[8]	Vulnerability model for the component exist, will be developed in the project, other?[9] (include ref. if available)	Stochastic modeling / uncertainty treatment in the model[10]	Analysis method for the performance assessment of the component[11]	Interdependency[12]	Other[13]
EUCENTRE - industrial precast buildings	concrete, precast; DX: post and beams, nonductile, DY: no lateral load resisting system; one storey; 1996-2009	Seismic shaking	Roof drift	Shear demand at connections	Column flexure yield and collapse and connection collapse - accumulating**	Spectral acceleration as a function of period	N/A	Regional	Existing (b)	Seismic fragility	Non-linear dynamic analysis	Industrial buildings in the same CI	low seismic action (7%W), long span beams, short distance between frames, dowel connections
EUCENTRE - industrial precast buildings	concrete, precast; DX: post and beams, nonductile, DY: no lateral load resisting system; one storey; 1996-2009	Seismic shaking	Roof drift	Shear demand at connections	Column flexure yield and collapse and connection collapse - accumulating**	Spectral acceleration as a function of period	N/A	Regional	Existing (b)	Seismic fragility	Non-linear dynamic analysis	Industrial buildings in the same CI	medium seismic action (10%W), long span beams, short distance between frames, dowel connections
EUCENTRE - industrial precast buildings	concrete, precast; DY: post and beams, nonductile, DX: no lateral load resisting system; one storey; pre 1996	Seismic shaking	Roof drift	Shear demand at connections	Column flexure yield and collapse and connection collapse - accumulating**	Spectral acceleration as a function of period	N/A	Regional	Existing (b)	Seismic fragility	Non-linear dynamic analysis	Industrial buildings in the same CI	no seismic design action, short span beams, large distance between frames, friction connections

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Partner and investigated CI	Component needing a vulnerability model[1] and its coordinates (lat. lon.)	Vulnerable to which hazard?[2]	Primary Engineering Demand parameter[3] (EDP1)	Secondary Engineering Demand parameter[4],* (EDP2)	Limit States of interest / consequences of failure (do they accumulate?)[5]	Primary preferred hazard intensity measure (IM1)[6]	Secondary preferred hazard intensity measure (IM2)[7],*	Site-specific or regional[8]	Vulnerability model for the component exist, will be developed in the project, other?[9] (include ref. if available)	Stochastic modeling / uncertainty treatment in the model[10]	Analysis method for the performance assessment of the component[11]	Interdependency[12]	Other[13]
EUCENTRE - industrial precast buildings	concrete, precast; DY: post and beams, nonductile, DX: no lateral load resisting system; one storey; 1996-2009	Seismic shaking	Roof drift	Shear demand at connections	Column flexure yield and collapse and connection collapse - accumulating**	Spectral acceleration as a function of period	N/A	Regional	To be developed	Seismic fragility	Non-linear dynamic analysis	Industrial buildings in the same CI	no seismic design action, short span beams, large distance between frames, dowel connections
EUCENTRE - industrial precast buildings	concrete, precast; DY: post and beams, nonductile, DX: no lateral load resisting system; one storey; 1996-2009	Seismic shaking	Roof drift	Shear demand at connections	Column flexure yield and collapse and connection collapse - accumulating**	Spectral acceleration as a function of period	N/A	Regional	Existing (b)	Seismic fragility	Non-linear dynamic analysis	Industrial buildings in the same CI	very low seismic action (4%W), short span beams, large distance between frames, dowel connections
EUCENTRE - industrial precast buildings	concrete, precast; DY: post and beams, nonductile, DX: no lateral load resisting system; one storey; 1996-2009	Seismic shaking	Roof drift	Shear demand at connections	Column flexure yield and collapse and connection collapse - accumulating**	Spectral acceleration as a function of period	N/A	Regional	Existing (b)	Seismic fragility	Non-linear dynamic analysis	Industrial buildings in the same CI	low seismic action (7%W), short span beams, large distance between frames, dowel connections

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Partner and investigated CI	Component needing a vulnerability model[1] and its coordinates (lat. lon.)	Vulnerable to which hazard?[2]	Primary Engineering Demand parameter[3] (EDP1)	Secondary Engineering Demand parameter[4,*] (EDP2)	Limit States of interest / consequences of failure (do they accumulate?)[5]	Primary preferred hazard intensity measure (IM1)[6]	Secondary preferred hazard intensity measure (IM2)[7,*]	Site-specific or regional[8]	Vulnerability model for the component exist, will be developed in the project, other?[9] (include ref. if available)	Stochastic modeling / uncertainty treatment in the model[10]	Analysis method for the performance assessment of the component[11]	Interdependency[12]	Other[13]
EUCENTRE - industrial precast buildings	concrete, precast; DY: post and beams, nonductile, DX: no lateral load resisting system; one storey; 1996-2009	Seismic shaking	Roof drift	Shear demand at connections	Column flexure yield and collapse and connection collapse - accumulating**	Spectral acceleration as a function of period	N/A	Regional	Existing (b)	Seismic fragility	Non-linear dynamic analysis	Industrial buildings in the same CI	medium seismic action (10%W), short span beams, large distance between frames, dowel connections
EUCENTRE - industrial precast buildings	concrete, precast; post and beams, nonductile; multi-storey; 1996-2009	Seismic shaking	Roof drift	Shear demand at connections	Column flexure yield and collapse and connection collapse - accumulating*	Spectral acceleration as a function of period	N/A	Regional	To be developed	Seismic fragility	Non-linear dynamic analysis	Industrial buildings in the same CI	no seismic action
EUCENTRE - industrial precast buildings	concrete, precast; post and beams, nonductile; multi-storey; 1996-2009	Seismic shaking	Roof drift	Shear demand at connections	Column flexure yield and collapse and connection collapse - accumulating*	Spectral acceleration as a function of period	N/A	Regional	To be developed	Seismic fragility	Non-linear dynamic analysis	Industrial buildings in the same CI	very low seismic action (4%W)
EUCENTRE - industrial precast buildings	concrete, precast; post and beams, nonductile; multi-storey; 1996-2009	Seismic shaking	Roof drift	Shear demand at connections	Column flexure yield and collapse and connection collapse - accumulating**	Spectral acceleration as a function of period	N/A	Regional	To be developed	Seismic fragility	Non-linear dynamic analysis	Industrial buildings in the same CI	low seismic action (7%W)

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Partner and investigated CI	Component needing a vulnerability model[1] and its coordinates (lat. lon.)	Vulnerable to which hazard?[2]	Primary Engineering Demand parameter[3] (EDP1)	Secondary Engineering Demand parameter[4,*] (EDP2)	Limit States of interest / consequences of failure (do they accumulate?)[5]	Primary preferred hazard intensity measure (IM1)[6]	Secondary preferred hazard intensity measure (IM2)[7,*]	Site-specific or regional[8]	Vulnerability model for the component exist, will be developed in the project, other?[9] (include ref. if available)	Stochastic modeling / uncertainty treatment in the model[10]	Analysis method for the performance assessment of the component[11]	Interdependency[12]	Other[13]
EUCENTRE - industrial precast buildings	concrete, precast; post and beams, nonductile; multi-storey; 1996-2009	Seismic shaking	Roof drift	Shear demand at connections	Column flexure yield and collapse and connection collapse - accumulating**	Spectral acceleration as a function of period	N/A	Regional	To be developed	Seismic fragility	Non-linear dynamic analysis	Industrial buildings in the same CI	medium seismic action (10%W)
EUCENTRE - industrial precast buildings	concrete, precast; post and beams, ductile; one-storey; post 2009	Seismic shaking	Roof drift	Shear demand at connections	Column flexure yield and collapse and connection collapse - accumulating**	Spectral acceleration as a function of period	N/A	Regional	To be developed	Seismic fragility	Non-linear dynamic analysis	Industrial buildings in the same CI	high seismic action and design (also of connections)
EUCENTRE - industrial precast buildings	concrete, precast; post and beams, ductile; multi-storey; post 2009	Seismic shaking	Roof drift	Shear demand at connections	Column flexure yield and collapse and connection collapse - accumulating**	Spectral acceleration as a function of period	N/A	Regional	To be developed	Seismic fragility	Non-linear dynamic analysis	Industrial buildings in the same CI	high seismic design (also of connections)
EUCENTRE - industrial precast buildings	All above typologies	Seismic shaking	Peak floor acceleration	N/A	Loss of contents due to significant damage to storage racks or significant shedding of merchandise from shelves	Peak ground acceleration	N/A	Regional	Existing (c)	Seismic fragility	Experimental data	Industrial buildings in the same CI	Steel storage racks assumed to be on the ground

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Partner and investigated CI	Component needing a vulnerability model[1] and its coordinates (lat. lon.)	Vulnerable to which hazard?[2]	Primary Engineering Demand parameter[3] (EDP1)	Secondary Engineering Demand parameter[4,*] (EDP2)	Limit States of interest / consequences of failure (do they accumulate?)[5]	Primary preferred hazard intensity measure (IM1)[6]	Secondary preferred hazard intensity measure (IM2)[7,*]	Site-specific or regional[8]	Vulnerability model for the component exist, will be developed in the project, other?[9] (include ref. if available)	Stochastic modeling / uncertainty treatment in the model[10]	Analysis method for the performance assessment of the component[11]	Interdependency[12]	Other[13]
UL - industrial precast buildings	concrete, precast; DX: post and beams, nonductile, DY: no lateral load resisting system; one storey; pre 1996	Seismic shaking	Displacement of panels relatively to the bearing structure	Roof acceleration	Failure of cladding - accumulating**	Spectral acceleration as a function of period	N/A	Regional	To be developed	Seismic fragility	Non-linear dynamic analysis	Industrial buildings in the same CI	no seismic design action, long span beams, short distance between frames, friction connections, horizontal cladding
UL - industrial precast buildings	concrete, precast; DX: post and beams, nonductile, DY: no lateral load resisting system; one storey; pre 1996	Seismic shaking	Displacement of panels relatively to the bearing structure	Roof acceleration	Failure of cladding - accumulating**	Spectral acceleration as a function of period	N/A	Regional	To be developed	Seismic fragility	Non-linear dynamic analysis	Industrial buildings in the same CI	no seismic design action, long span beams, short distance between frames, friction connections, vertical cladding
UL - industrial precast buildings	concrete, precast; DX: post and beams, nonductile, DY: no lateral load resisting system; one storey; pre 1996	Seismic shaking	Displacement of panels relatively to the bearing structure	Roof acceleration	Failure of cladding - accumulating**	Spectral acceleration as a function of period	N/A	Regional	To be developed	Seismic fragility	Non-linear dynamic analysis	Industrial buildings in the same CI	no seismic design action, long span beams, short distance between frames, friction connections, masonry infill panels

STREST – WP4 VULNERABILITY FACTS SHEET CI-C1 (ver Sept. 2014)

Partner and investigated CI	Component needing a vulnerability model[1] and its coordinates (lat. lon.)	Vulnerable to which hazard?[2]	Primary Engineering Demand parameter[3] (EDP1)	Secondary Engineering Demand parameter[4,*] (EDP2)	Limit States of interest / consequences of failure (do they accumulate?)[5]	Primary preferred hazard intensity measure (IM1)[6]	Secondary preferred hazard intensity measure (IM2)[7,*]	Site-specific or regional[8]	Vulnerability model for the component exist, will be developed in the project, other?[9] (include ref. if available)	Stochastic modeling / uncertainty treatment in the model[10]	Analysis method for the performance assessment of the component[11]	Interdependency[12]	Other[13]
UL-industrial precast buildings	concrete, precast; DY: post and beams, nonductile, DX: no lateral load resisting system; one storey; pre 1996	Seismic shaking	Displacement of panels relatively to the bearing structure	Roof acceleration	Failure of cladding - accumulating**	Spectral acceleration as a function of period	N/A	Regional	To be developed	Seismic fragility	Non-linear dynamic analysis	Industrial buildings in the same CI	no seismic design action, short span beams, large distance between frames, friction connections, vertical cladding
UL - industrial precast buildings	concrete, precast; DY: post and beams, nonductile, DX: no lateral load resisting system; one storey; pre 1996	Seismic shaking	Displacement of panels relatively to the bearing structure	Roof acceleration	Failure of cladding - accumulating**	Spectral acceleration as a function of period	N/A	Regional	To be developed	Seismic fragility	Non-linear dynamic analysis	Industrial buildings in the same CI	no seismic design action, short span beams, large distance between frames, friction connections, masonry infill panels
UL - industrial precast buildings	concrete, precast; DY: post and beams, nonductile, DX: no lateral load resisting system; one storey; 1996-2009	Seismic shaking	Displacement of panels relatively to the bearing structure	Roof acceleration	Failure of cladding - accumulating**	Spectral acceleration as a function of period	N/A	Regional	To be developed	Seismic fragility	Non-linear dynamic analysis	Industrial buildings in the same CI	low seismic action (7%W), short span beams, large distance between frames, dowel connections, vertical cladding

STREST – WP4 VULNERABILITY FACTS SHEET CI-C1 (ver Sept. 2014)

Partner and investigated CI	Component needing a vulnerability model[1] and its coordinates (lat. lon.)	Vulnerable to which hazard?[2]	Primary Engineering Demand parameter[3] (EDP1)	Secondary Engineering Demand parameter[4,*] (EDP2)	Limit States of interest / consequences of failure (do they accumulate?)[5]	Primary preferred hazard intensity measure (IM1)[6]	Secondary preferred hazard intensity measure (IM2)[7,*]	Site-specific or regional[8]	Vulnerability model for the component exist, will be developed in the project, other?[9] (include ref. if available)	Stochastic modeling / uncertainty treatment in the model[10]	Analysis method for the performance assessment of the component[11]	Interdependency[12]	Other[13]
UL - industrial precast buildings	concrete, precast; DY: post and beams, nonductile, DX: no lateral load resisting system; one storey; 1996-2009	Seismic shaking	Displacement of panels relatively to the bearing structure	Roof acceleration	Failure of cladding - accumulating**	Spectral acceleration as a function of period	N/A	Regional	To be developed	Seismic fragility	Non-linear dynamic analysis	Industrial buildings in the same CI	low seismic action (7%W), short span beams, large distance between frames, dowel connections, masonry infill panels

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a. Vamvatsikos, D., Cornell, A. [2005] "Developing efficient scalar and vector intensity measures for IDA capacity estimation by incorporating elastic spectral shape information," Earthquake Engineering and Structural Dynamics. Vol. 34, No. 13, pp. 1573–1600.

b. Casotto, C., Silva, V., Crowley, H., Nascimbene, R., Pinho, R. (2014) "Seismic fragility of Italian pre-cast industrial structures," *Submitted to Engineering Structures*

c. FEMA-58 (2011) "Fragility curves for storage racks," Background document for FEMA-58 prepared by Andre Filiatrault and Robert Bachman

Coordinates of rectangle: (9.6, 44.5); (12.5, 44.5); (12.5, 42.3); (9.6, 42.3)

** We will not consider accumulation of damage in our models, but it can occur and could be considered in future work

4 Dependencies Factsheet

The purpose of this chapter is to carry out a survey of multiple dependencies of CIs accounting for the consequences of cascading failures and loss and availability assessment for supply-chains-like system. Multi-infrastructure stress tests at a regional scale will be performed on the basis of loss propagation and reciprocal impacts caused by failures. Dependencies eventually to be accounted for by the STREST approach and in the applications of WP6 should be identified herein. A preliminary definition has been included in the vulnerability factsheets (presented in Chapter 3 herein), which also provides the description of components for each CI. For a more systemic description, the following factsheets have been filled in for each CI. In particular, Table 2 classifies the existing intra-dependencies (between the components of each CI) and inter-dependencies (between the infrastructures of the CI and other networks) based on the SYNER-G project approach. The taxonomy of each CI (see Chapter 2) is used as a basis for the compilation of the table. Three different priority levels (i.e. crucial, important and secondary) and two types of interactions (i.e. direct and indirect) are considered (see filling notes below). Crucial and important dependencies have been defined taking into consideration the methodology that will be implemented for their simulation. As a general remark, direct dependencies should be in most cases classified at least as crucial and/or important. It is noted that only interactions between components of different infrastructures and subsystems have been considered, and so the diagonal terms of the table have not been filled in. Table 3 describes the dependencies in each CI, giving examples of the dependencies in each type of interaction. Table 4 attempts a preliminary definition of the dependencies to be accounted in STREST application for each CI, specifying the components that need to be included in the model.

The following filling notes/instructions were provided for the compilation of the factsheets:

Table 2

CI components are used in columns and rows. Here, the impact of the components in rows have on the components in columns is described. In other words, the components in columns are affected by those in the rows. Different columns/rows will be used for each CI based on their taxonomy.

Priorities definitions:

1 - Crucial dependencies (that MUST be both well described and implemented).

2 - Important dependencies [that NEED to be well described and that SHOULD be implemented (if possible, using simplifications if necessary)].

3 - Optional/secondary dependencies (that should be mentioned, but whose implementation is not necessary).

Types of interactions:

Direct:

- PHY: Physical, functional interdependency - functional damage propagation.

Indirect:

- INF: Cyber, informational interdependency.
- GEO: Collocation, geographic, space interdependency - physical damage propagation.

- RES: Restoration - recovery interdependency.
- SUB: Substitute interdependency.
- SEQ: Sequential interdependency - scaling effects.
- LOG: Logical interdependency, financial markets - policy/procedural interdependency.
- GEN: General interaction.
- SOC: Societal interdependency.

Table 3

Describe the dependencies in system level.

Table 4

Describe the dependencies in component level to be studied in STREST applications (preliminary definition).

4.1 CLASSIFICATION OF DEPENDENCIES FACTS SHEET

Table 2 Classification of dependencies per CI

Oil refinery and petrochemical plants										
Impacts →		**REF01**	**REF02**	**REF03**	**REF04**	**REF05**	**REF06**	**REF07**	**REF08**	**REF09**
Steel oil storage tank	**REF01**		3-SEQ		1-PHY					
Pressurised equipment	**REF02**						3-SEQ			
Pressurised horizontal tank (buried)	**REF03**		3-SEQ		3-SUB					
Pressurised Sphere	**REF04**	1-PHY 1-GEO	1-PHY 1-GEO 3-SEQ	3-SUB			3-PHY		3-PHY	
Pumping system	**REF05**	2-SEQ	2-SEQ	2-SEQ	2-SEQ		2-SEQ	2-SEQ	2-SEQ	
Atmospheric elongated equipment	**REF06**		3-SEQ							
Pipeline (buried)	**REF07**								3-SUB	3-SEQ
Pipeline (overground/rack)	**REF08**							3-SUB		3-SEQ
Fire-fighting system	**REF09**	1-PHY 1-SEQ	1-PHY 1-SEQ				1-PHY 1-SEQ			

Large dams

Impacts →		DAM01	DAM02	DAM03	DAM04	DAM05	DAM06	DAM07	DAM08	DAM09	DAM10	DAM11	DAM12	DAM13	DAM14
Concrete dam (Les Toules)	**DAM01**			2-PHY		2-GEN		1-GEN	2-GEN						
Fill dam (Mattmark)	**DAM02**			1-PHY		2-GEN		1-GEN	2-GEN						
Foundation	**DAM03**	1-PHY	1-PHY		2- PHY	2-GEN 2-PHY		2-GEN	2-GEN 2-PHY						
Spillway	**DAM04**					2-GEN		1-GEN							
Bottom outlet	**DAM05**							1-GEN							
Compensation basin	**DAM06**								1-GEN	2-GEO	3-GEO	3-GEO	3-GEO	3-GEO	
Reservoir level (absolute and changes)	**DAM07**	1-PHY 2-RES	1-PHY 2-RES	2-PHY 2-RES			2- GEO		1-GEN 2-GEO	2-GEO	2-GEO	2-GEO	3-GEO	3-GEO	
Hydropower and pressure systems	**DAM08**						2-GEN	3-GEN							
Accesses	**DAM09**	3-RES	3-RES	3-RES	3-RES	3-RES	3-RES		3-RES		3-RES	3-RES	3-RES	3-RES	3-RES
Electrical system	**DAM10**					2-PHY			2-PHY				3-GEN	3-GEN	3-GEN
Main power line	**DAM11**								2-PHY						
Monitoring system	**DAM12**	2-RES	2-RES	2-RES											
Communication system	**DAM13**					2-PHY			2-PHY						
Warning system	**DAM14**														

Hydrocarbon pipelines

KOERI

Impacts →		HDRC01	HDRC02	HDRC03	HDRC04	HDRC05	HDRC06	HDRC07	HDRC08	HDRC09	HDRC_10	HDRC11	HDRC12	HDRC13	HDRC14	HDRC15	HDRC16	HDRC17	HDRC18	HDRC19	HDRC20
Pipeline (Buried)	**HDRC01**		3-SUB 1-PHY	3-GEO	3-GEO	2-PHY	3-PHY	3-PHY	3-PHY	2-PHY	2-GEO		3-INF	3-SEQ	2-SEQ 2-RES					1-GEO 1-RES 1-PHY	
Pipes (Above ground/ rack)	**HDRC02**	3-SUB 1-PHY		1-PHY	1-PHY	2-PHY					2-GEO		3-INF	3-SEQ						2-GEO	
Tanks Steel oil storage (Atmosph)	**HDRC03**	3-GEO	1-PHY		3-SEQ																
HPV (Pressure relief tanks)	**HDRC04**	3-GEO	1-PHY																	2-GEO	
Pump station	**HDRC05**	2-SEQ 2-PHY	2-SEQ 2-PHY	2-SEQ	2-SEQ						3-GEO				3-SEQ					1-PHY 1-GEO 1-RES	
Pressure Reduction syst.	**HDRC06**		3-GEO																		
Pig stations (Maint. Sys)	**HDRC07**	3-PHY													3-PHY						
Cathotic protection Long term safety	**HDRC08**	3-PHY													3-PHY						
BVD: Block valves (buried)	**HDRC09**	1-PHY																	3-INF		
Station bldgs.	**HDRC10**	2-GEO 2-PHY	2-GEO 2-PHY			2-GEO 2-PHY								3-GEO	3-GEO	3-GEO	3-GEO		3-GEO		
Control bldgs.	**HDRC11**																		1-PHY		
LDSLeakDetecSy	**HDRC12**	3-INF																	1-INF		
Fire-fighting sys	**HDRC13**	1-PHY 1-SEQ	1-PHY 1-SEQ								3-PHY	3-PHY				3-SUB					
Electric system	**HDRC14**										2-PHY	2-PHY		2-PHY		2-PHY 3-INF	2-PHY 3-INF	2-PHY 3-INF	2-PHY 3-INF		

Water system	**HDRC15**										3-PHY	3-PHY		3-PHY 3-RES	3-PHY 3-GEO 3-RES		3-PHY 3-GEO		3-PHY	1-PHY	
Waste water system	**HDRC16**										3-PHY	3-PHY		3-PHY	3-PHY	3-GEO 3-RES					
Sewage treatment	**HDRC17**																2-GEO 2-PHY				
Communication SCADA,Fiber Optic (FOC), Satellite	**HDRC18**	1-INF									3-PHY	3-PHY		3-INF	3-INF	3-INF	3-INF				
BTE: Parallel Gas pipeline	**HDRC19**					3-GEO															
Waterfront Marine terminal: Berthing loading facility	**HDRC20**														1-PHY						

Gas storage and distribution network

Impacts →		GPN01	GPN02	GPN03	GPN04	FLB01	INFRA01	INFRA02	INFRA03	INFRA04
Pressurized pipeline (buried)	**GPN01**		1-PHY	2-PHY	2-GEO	2-GEO	3-SEQ 3-GEN	3-SEQ 3-GEN	3-SEQ 3-GEN	3-SEQ 3-GEN
Pressurized pipeline (above ground)	**GPN02**	1-PHY		2-PHY	2-GEO	2-GEO	3-SEQ 3-GEN	3-SEQ 3-GEN	3-SEQ 3-GEN	3-SEQ 3-GEN
Pumping system	**GPN03**	2-PHY	2-PHY		3-GEO	3-GEO	3-GEO	3-GEO	3-GEO	3-GEO
Station halls (buildings)	**GPN04**	1-GEO 2-PHY	1-GEO 2-PHY	2-GEO 2-PHY		3-GEO	3-GEO	3-GEO	3-GEO	3-GEO
Flood barriers (soil dikes, steel locks)	**FLB01**	3-GEO 3-RES	3-GEO 3-RES	3-GEO 3-RES 3-PHY	2-GEO 3-RES		3-GEO	3-GEO	3-GEO	3-GEO
Railways/bridges	**INFRA01**	3-GEO	3-GEO	3-GEO	3-GEO	3-GEO		3-GEO	3-GEO	3-GEO
Roadways/bridges	**INFRA02**	3-GEO	3-GEO	3-GEO	3-GEO	3-GEO	3-GEO		3-GEO	3-GEO
High Voltage Transmission towers	**INFRA03**	3-GEO	3-GEO	3-GEO	3-GEO	3-GEO	3-GEO	3-GEO		3-GEO
Windmills (wind turbines)	**INFRA04**	3-GEO	3-GEO	3-GEO	3-GEO	3-GEO	3-GEO	3-GEO	3-GEO	

Port infrastructures

Impacts →		HBR01	HBR02	HBR03	HBR04	HBR_A	HBR_B	HBR_C	HBR_D	HBR_E	HBR_F	HBR_G	HBR_H	HBR_I
Waterfront	**HBR01**		1-GEO	1-GEO									3-GEO	3-GEO
Earthen embankments	**HBR02**	1-GEO		1-GEO										
Cargo handling and Storage	**HBR03**													
Buildings	**HBR04**					3-GEO	3-GEO	3-GEO	3-GEO	3-GEO	3-GEO	3-GEO	1-GEO	3-GEO
Electric system	**HBR_A**			1-PHY	2-PHY		2-PHY 3-INF	2-PHY 3-INF	2-PHY 3-INF	2-PHY 3-INF	2-PHY 3-INF	2-PHY	2-PHY	2-PHY
Water system	**HBR_B**				3-PHY	3-PHY 3-GEO 3-RES		3-PHY 3-GEO	3-GEO		3-PHY	3-PHY 3-RES	3-GEO	3-GEO
Waste-water system	**HBR_C**				3-PHY	3-PHY	3-GEO 3-RES		3-GEO			3-PHY	3-GEO	3-GEO
Gas system	**HBR_D**				3-PHY	3-PHY								
Oil system	**HBR_E**				3-PHY	3-PHY								
Communication system	**HBR_F**				3-PHY	3-INF	3-INF		3-INF	3-INF		3-INF	3-INF	3-INF
Fire-fighting system	**HBR_G**				3-PHY		3-SUB		3-SEQ	3-SEQ				
Roadway	**HBR_H**		3-PHY	3-PHY	3-RES	3-RES	3-GEO 3-RES	3-GEO 3-RES	3-GEO 3-RES	3-GEO 3-RES	3-GEO 3-RES	3-PHY 3-RES 3-GEO		3-SUB
Railway	**HBR_I**		3-PHY	3-PHY	3-RES	3-RES	3-GEO 3-RES	3-GEO 3-RES	3-GEO 3-RES	3-GEO 3-RES	3-GEO 3-RES	3-PHY 3-RES 3-GEO	3-SUB	

Industrial district				
Impacts		**ID01**	**ID02**	**ID03**
Building (structural system)	**ID01**		1-GEO 3-PHY	1-GEO 3-PHY
Non-structural panels	**ID02**	2-GEO 3-PHY		2-GEO
Contents	**ID03**	-	-	

4.2 DESCRIPTION OF DEPENDENCIES IN SYSTEM LEVEL FACTS SHEET

Table 3 Description of dependencies in system level per CI

CI/ Interaction type	**CI-A1** **ENI/Kuwait oil refinery and petrochemical plant, Milazzo, Italy**	**CI-A2** **Large dams in the Valais region of Switzerland**	**CI-B1** **Major hydrocarbon pipelines, Turkey**	**CI-B2** **Gasunie national gas storage and distribution network, Holland**	**CI-B3** **Port infrastructures of Thessaloniki, Greece**	**CI-C1** **Industrial district, Italy**
PHY	- Oil storage tank can severely impact pressurised sphere in the case of fire (tank fire, pool fire) due to physical (heat radiation) interaction - Pressurised sphere can explode or fire with physical damage to aboveground equipment and pipeline due to fragment projection and shock wave propagation	- The stability of both types of dam relies on the conditions of their foundations and abutments. - The body of the dam, if damaged, or being under unusual demands, can also induce undesired stress load on the foundation. - Through stresses and displacements of the foundation and abutments, spillway, bottom outlet and pressure systems can be affected. - Specific reservoir levels and their variations can lead to particular stress states on the dam's body. In the case of fill dams, too high reservoir levels may conduce to the dam's overtopping and consequent collapse. - Faulty electrical or communication systems may lead to the inoperability of the bottom outlet and the hydropower and pressure systems. - Damages in the main power line lead to the halt of the hydropower and pressure systems.	- Supply of gas (from BTE) to pump stations - Water to fire fighting system - Supply of electric power to Pump station	-Supply of gas inside the pipeline network / continuity of gas flow -Supply gas to pumping stations/ malfunction of pumping stations (gas driven pumps)	- Supply of electric power to cranes, traffic control infrastructures, building facilities, utility systems' and transportation infrastructures' components - Use of water to cooling equipment of buildings and utility systems and infrastructure components	- Supply material/stock stored within industrial buildings to other local industries
INF	-	-	- SCADA system and Above Ground Installations (AGI's) - Use of communications system in case of emergency	-	- Use of communications system in case of emergency	-
GEO	- Pressurised sphere can cause damage to aboveground equipment and pipeline due to	- The fast release of large water volumes from the reservoir might endanger components	- Damage to piping and connections in case of tank damage	- Damage to roads and railways due to misalignment of buried pipes	- Damage to cranes and cargo handling equipment in case of waterfront/ embankments	- Damage to non-structural panels due to structural (building) collapse

	fragment projection, particularly storage tanks and process equipment (pressurised and atmospheric)	downstream. These may be the compensation basin, accesses, electrical, monitoring and communication systems, main power line or warning system. - A failure of the compensation basin might, along the same lines, endanger components downstream.	- Damage to AGI's due to building collapse - Compressor stations in BTE (gas) and Pump stations in BTC (oil) are interconnected Closely spaced (15m) - Gas and Oil pipes are closely spaced - Damage to transmission systems components due to geographic proximity of other damaged components - Water pollution due to sewage system damage	- Damage to earthen embankments/ dikes due to damage of crossing pipelines - Damage to buildings and station halls (pressure of gas release, misalignments) - Collapse of station halls on installations (pipes, RM valves, security valves etc) due to gas release	damage - Road closures in case of building collapses - Damage to utility systems and/or infrastructure components due to building damage - Damage of utility systems components in case of waterfront damage or infrastructure components (e.g. bridge) damage - Damage to infrastructure components (e.g. railways) due to waterfront/ embankments damage - Damage to utility systems components due to geographic proximity of other damaged components - Water pollution due to sewage system damage	- Damage to contents due to structural (building) collapse - Damage to structural system due to response of non-structural panels - Damage to contents due to non-structural panel collapse
RES	-	- In some cases the reservoir level should be brought down prior to restoration/rehabilitation efforts of the dam and its foundation. - Accesses are important to conduct restoration/rehabilitation works in all components of the system. - A functional monitoring system should trigger rehabilitation works on the dam or foundations if the need arises.	- Restoration of adjacent AGI's in BTE and BTC lines - Transfer of restoration material through roadway/railway system	- Transfer of material for repair - Conduct an inspection (both flood related)	- Transfer of restoration material through roadway/ railway system - Hampering of restoration activities to adjacent utility and/or infrastructure components	-
SUB	- Use of alternative gas and liquid containment by unaffected buried tanks - Buried pipeline and aboveground can be used alternatively in case of disruption	-	- Use of adjacent AGI's of BTE gas pipe in case of emergency - Use of power supply infrastructures for fire suppression	-	- Use of adjacent waterfront structure in case of damage - Use of power supply infrastructures for fire suppression - Use of railway infrastructure for movement of cargo/passenger in case of roadway damage and vice versa	-
SEQ	- Pressurised equipment may be affected by oil plant (tank, pipeline, pumping system) malfunctioning or disruption - Pumping system malfunctioning affects the entire production	-	- Failure of pump stations in case of damage in the neighbouring Natural gas line - Cascading effects, fire ignition due to gas system failure in the neighbouring natural gas	-	- Cascading effects (e.g. short circuit propagation) in case of electric power network damage - Fire ignition due to gas system failures	-

	process - Fire fighting system failure affects the integrity of equipment in case of fire		transmission line - Hazardous material release in case of tank damage or sloshing			
LOG	-	-	-	-	-	-
GEN	-	- Failure of the dam body will cause a fast release of the reservoir. - Damages to the foundation can also lead to substantial releases of water from the reservoir. - The operational state of spillway and bottom outlet alike affect the level of the reservoir upstream, in particular the ability to drawdown in the face of an impending event. - The state of the reservoir and the compensation basin may affect the operation of the hydropower and pressure systems. - Damages in the dam or foundations can prompt the drawdown of the reservoir through the bottom outlet. Likewise, they can lead to the halt of the hydropower and pressure system's functioning. - The hydropower and pressure systems affect water levels in the main reservoir and compensation basin. - The electrical system is connected to, communication, monitoring, and warning systems.	- Environmental pollution due to oil and gas release from pipes or storage units	- Air pollution due to gas release	-	-
SOC	-	-	-	- Crisis management and communication to local communities	- Crisis management	-

4.3 DESCRIPTION OF DEPENDENCIES SHEET IN COMPONENT LEVEL

Table 4 Description of dependencies in component level per CI, to be studied in STREST applications (preliminary definition)

C.I/ Interdependency	CI-A1 ENI/Kuwait oil refinery and petrochemical plant, Milazzo, Italy	CI-A2 Large dams in the Valais region of Switzerland	CI-B1 Major hydrocarbon pipelines, Turkey	CI-B2 Gasunie national gas storage and distribution network, Holland	CI-B3 Port infrastructures of Thessaloniki, Greece	CI-C1 Industrial district, Italy
PHY	Storage tank Pressurised sphere Fire fighting system	Dam body, foundation, and reservoir. On a secondary level, electrical and communication systems and main power line.	Tanks, Vessel / AGI Pipes connections Pumps/BTE Nat Gas system Buried Block valve rooms (BVS)/ Buried pipes Failure of SCADA system in case of control building collapse Fire fighting system	Pipeline, gas driven pumping system, station equipment	Electric power substations/ Cranes	-
INF	-	-	Fiber Optic Cable (FOC), Backup satellite communication, Leak Detection System (LDS), Block Valve System (BVS), SCADA Electric system	-	-	-
GEO	Process equipment (non-tank pressurised system and atmospheric elongate)	Reservoir level (absolute and changes), compensation basin, and components of the system downstream.	Building, HPV tanks, piping Berthing and loading equipment/ waterfront structures/Electric sys. roads/buildings	Station halls, flood barriers, infrastructural system (railways, roadways, electricity transmission towers)	Cranes and cargo handling equipment/ Waterfront structures Roads/buildings	Non-structural panels/structure Contents/structure
RES		Reservoir level and dam body or foundation; monitoring system and dam body or foundation; accesses and all of the systems components except for the reservoir.	BTC pumps / BTE Gas supply	Pipeline, gas driven pumping system, station equipment, station halls		
SUB	Pipelines, buried and aboveground	-	Pipelines, buried and aboveground	-	-	-
SEQ	Pipeline (buried and aboveground) Fire fighting system Pumping system	-	Malfunctioning of SCADA system due to control building damage Malfunctioning of AGI's due to SCADA system collapse	-	-	-
LOG	-	-	-	-	-	-

GEN	-	Spillway, bottom outlet, compensation basin, dam body, reservoir level, and hydropower and pressure systems.	Collapse of AGI's on to other AGIS's such as pipings, pipe racks, storage units and pumps	-	-	-
SOC	-	-	-	-	-	-

4.4 CONCLUSIVE REMARKS

Inter- and intra-dependencies are highly affecting the performance of all kinds of complex facilities. This is recognized by all partners, as described in Tables 2-4.

In general, geographic (GEO) and physical (PHY) dependencies are the most common ones in all the CIs (see Figure 6 and 7). In the other hand, societal (SOC) and logical (LOG) interdependencies are not defined in any CI (at least in this phase). Restoration interactions (RES) are not present in REF and IDA, while Sequential (Seq) dependencies are not present in DAM and IDA. Information (Inf) dependencies are identified only in HBR and HDRC, while general (Gen) ones are defined only in DAM and GPN.

The most dependencies are described in the hydrocarbon pipeline system in Turkey (HDRC), the harbour of Thessaloniki (HBR) and the Gasunie national gas storage and distribution network in Holland (GPN), where 110, 102 and 88 dependencies have been recognized respectively (Figure 8). For the large dams in Switzerland (DAM) and the oil refinery and petrochemical plant in Milazzo (REF), 64 and 31 dependencies have been provided, while the least dependencies are defined in the industrial district in Italy (IDA).

This observation is related to the number of interacting assets that have been considered in each case, as in general, the ranking of dependencies per CI follows the amount of interacting components (Figure 9). However, the “dependency index” which here is defined as the ratio between the number of assets and the total number of dependencies in each CI (Figure 10), shows that the most dependent assets are in the industrial district (IDA), which is then followed by REF, DAM, HDRC, HBR and GPN. This is related to the way that each CI is working, the kind and number of different operations performed, as well as the number of components available to perform one task, e.g. the existence of redundant components minimizes the “dependency index”.

Concerning the importance of priorities (in the framework of stress test), it is observed that HDRC has the most crucial dependencies (22), while HBR, GPN and IDA have less such dependencies, 6, 4 and 2 respectively (Figure 11). The most dependencies of second priority are defined in DAM and HDRC (31 and 30 respectively). On the other hand, HBR, GPN and HDRC have the most dependencies of third priority, 87, 71 and 58 respectively. This is related also in a way to the chosen approach of analysis for each CI, and the system operations that are of major importance to the whole system functionality and are going to be included in the methodology analysis framework.

Finally, in total, the most crucial dependencies are the physical (PHY) and geographic (GEO) ones, while numerous geographic, physical and restoration dependencies are considered as third priority dependencies (Figure 12). The “priority index”, which here is defined as the ratio between the number of 1st, 2nd and 3rd priorities to the total number of dependencies for each type of interaction (Figure 13), shows that most of the dependencies are of 3rd priority. In particular, all the substitute (SUB) dependencies and most of the INF, Geo and Res dependencies are of 3rd priority. Such kind of interactions may in some cases have extremely adverse effects to the CI performance, and consequently to the served area, but since the subject of dependencies between CIs is rather a new research field, there are no available methods for their simulation and quantification.

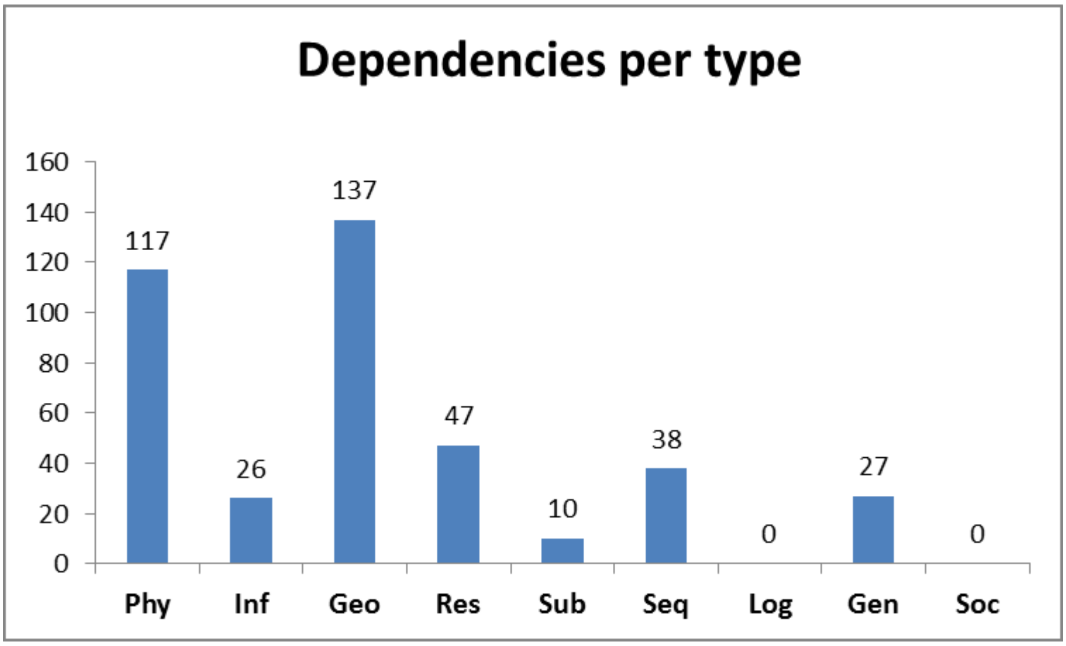

Figure 6 Dependencies per type for the six CIs.

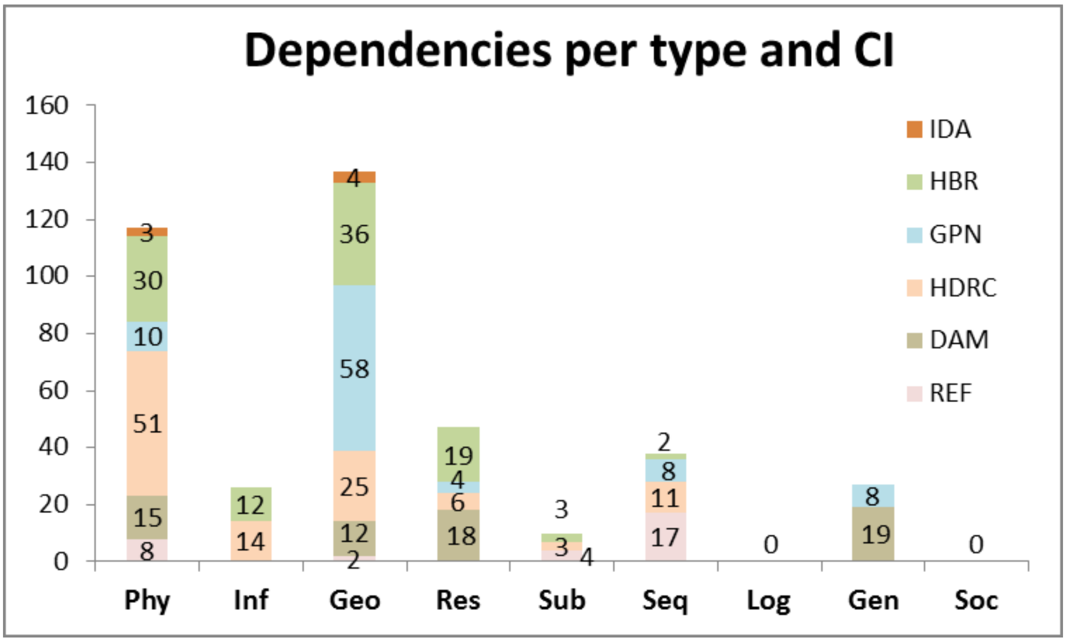

Figure 7 Dependencies per type and CI.

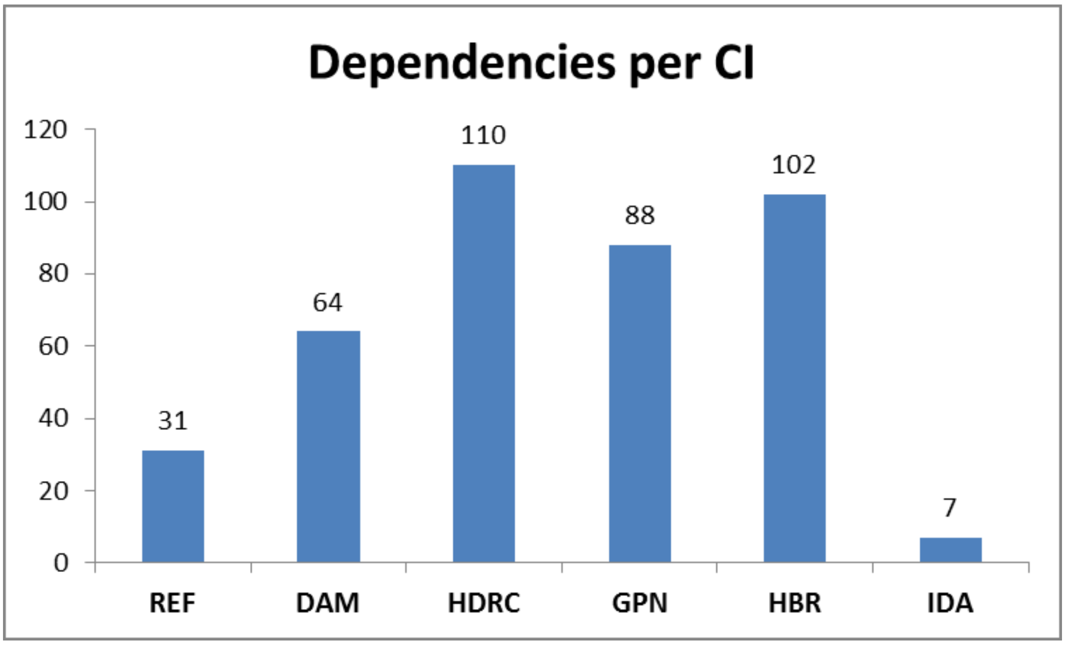

Figure 8 Dependencies per CI.

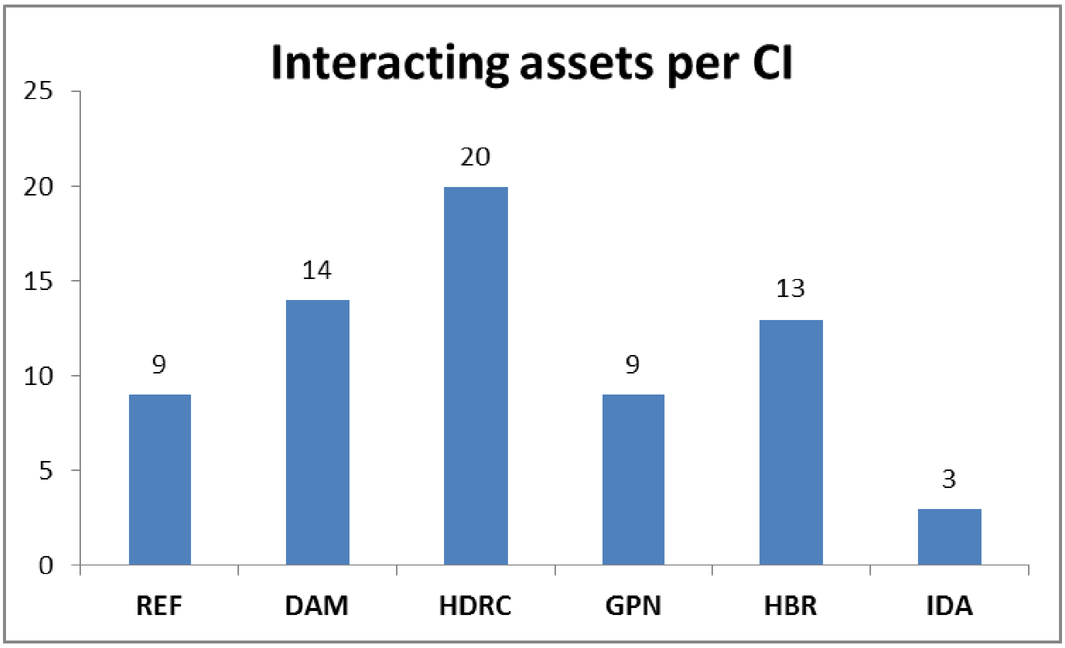

Figure 9 Interacting assets per CI.

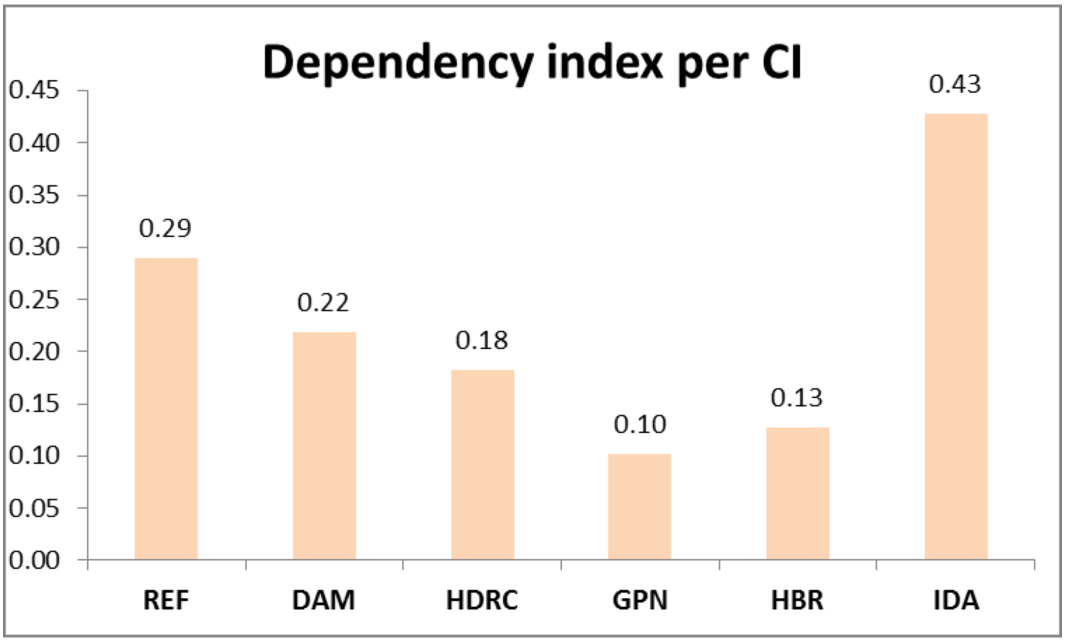

Figure 10 Dependency index per CI.

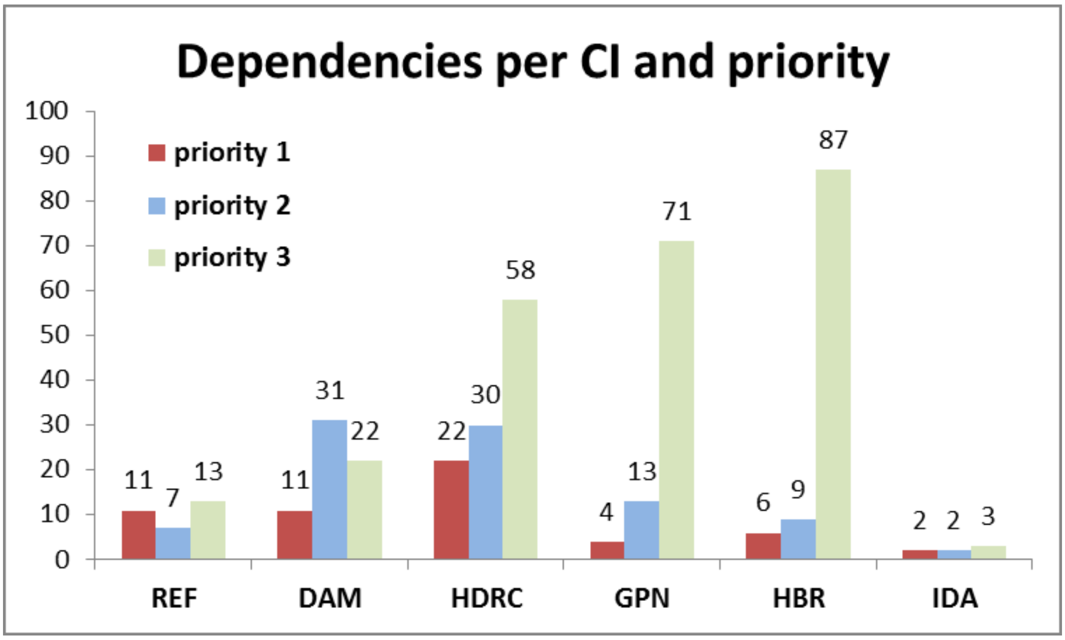

Figure 11 Dependencies per CI and priority.

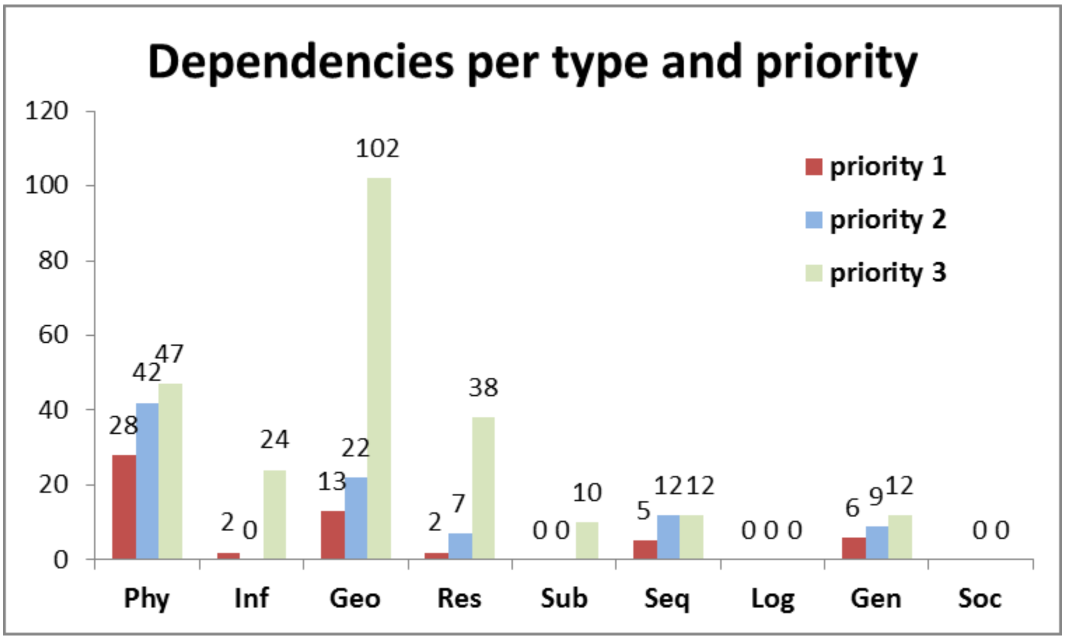

Figure 12 Dependencies per type and priority.

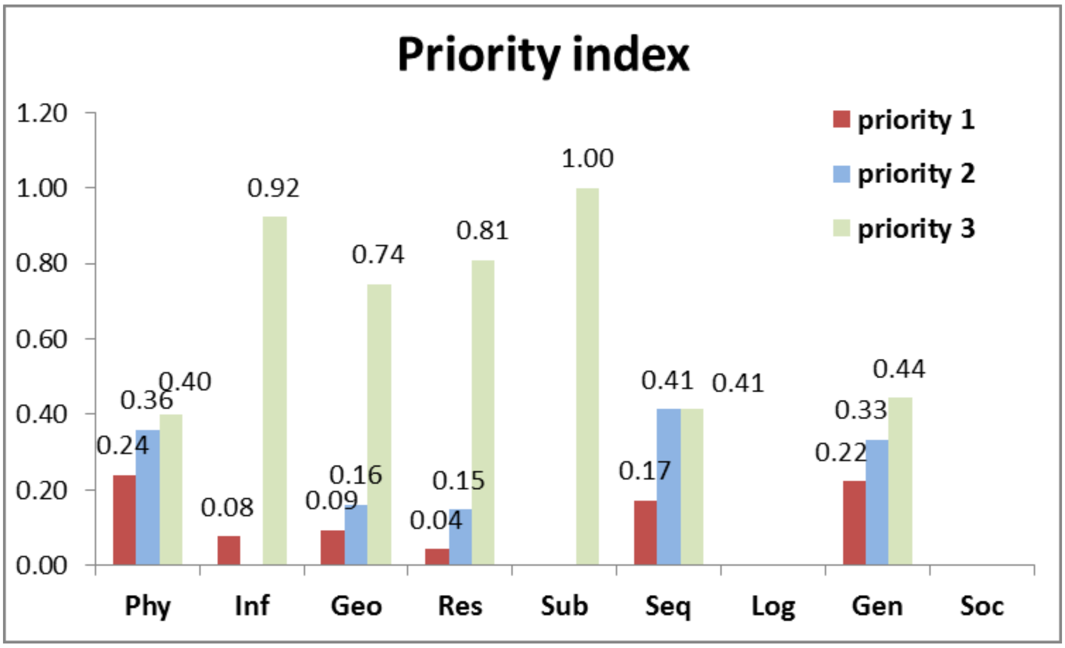

Figure 13 Priority index per type of dependency.

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Appendix A: Taxonomy of Buildings

Table G1 GEM Building Taxonomy v2.0: Attributes

TaxT Attribute Group	#	Attribute	Reference	Attribute levels	Type	Example
Structural System	1	Direction	Table A.1	Direction of the building		
	2	Material of the Lateral Load-Resisting System	Table A.2	Material type (Level 1)	Text	Steel
				Material technology (Level 2)		
				Material properties (Level 3)		
	3	Lateral Load-Resisting System	Table A.3	Type of lateral load-resisting system (Level 1)	Text	Braced frame
				System ductility (Level 2)		
Building Information	4	Height	Table A.4	Height	Integer	4
	5	Date of Construction or Retrofit	Table A.5	Construction completed (year)	Integer	1925

	6	Occupancy	Table A.6	Building occupancy class - general (Level 1) Building occupancy class - detail (Level 2)	Text	Residential
Exterior Attributes	7	Building Position within a Block	Table A.7		Text	
	8	Shape of the Building Plan	Table A.8	Plan shape (footprint)	Text	
	9	Structural Irregularity	Table A.9	Regular or irregular (Level 1) Plan irregularity or vertical irregularity Type of irregularity (Level 3)	Text	Re-entrant corner
	10	Exterior Walls	Table A.10	Exterior walls	Text	Wood
Roof/Floor/ Foundation	11	Roof	Table A.12	Roof shape (Level 1) Roof covering (Level 2) Roof system material (Level 3) Roof system type (Level 4)	Text	Tile (clay, concrete)

				Roof connections (Level 5)		
	12	Floor	Table A.11	Floor system material (Level 1)	Text	Concrete
				Floor system type (Level 2)		
				Floor connections (Level 3)		
	13	Foundation System	Table A.13	Foundation system	Text	Shallow foundation, with lateral capacity

Table A.1: Direction

ID	Level 1 (L1)	ID	Level 2 (L2)
	Direction of building under consideration		**Description of the direction**
DX	Direction X		
		D99	Unspecified direction
		PF	Parallel to street
DY	Direction Y		
		D99	Unspecified direction
		OF	Perpendicular to street

Table A.2: Material of the Lateral Load-Resisting System

ID	Level 1 (L1)	ID	Level 2 (L2)	ID	Level 3 (L3)
	Material type		**Material technology**		**Material properties**
MAT99	Unknown material				
C99	Concrete, unknown reinforcement	CT99	Unknown concrete technology		
CU	Concrete, unreinforced	CIP	Cast-in-place concrete		
CR	Concrete, reinforced	PC	Precast concrete		
SRC	Concrete, composite with steel section	CIPPS	Cast-in-place prestressed concrete		
		PCPS	Precast prestressed concrete		
S	Steel				
		S99	Steel, unknown	SC99	Steel connections, unknown
		SL	Cold-formed steel members	WEL	Welded connections
		SR	Hot-rolled steel members	RIV	Riveted connections
		SO	Steel, other	BOL	Bolted connections
ME	Metal (except steel)				
		ME99	Metal, unknown		

		MEIR	Iron		
		MEO	Metal, other		
M99	Masonry, unknown reinforcement	MUN99	Masonry unit, unknown	MO99	Mortar type unknown
MUR	Masonry, unreinforced	ADO	Adobe blocks	MON	No mortar
MCF	Masonry, confined	ST99	Stone, unknown technology	MOM	Mud mortar

ID	Level 1 (L1)	ID	Level 2 (L2)	ID	Level 3 (L3)
	Material type		**Material technology**		**Material properties**
MR	Masonry, reinforced	STRUB	Rubble (field stone) or semi-dressed stone	MOL	Lime mortar
		STDRE	Dressed stone	MOC	Cement mortar
		CL99	Fired clay unit, unknown type	MOCL	Cement:lime mortar
		CLBRS	Fired clay solid bricks	SP99	Stone, unknown type
		CLBRH	Fired clay hollow bricks	SPLI	Limestone
		CLBLH	Fired clay hollow blocks or tiles	SPSA	Sandstone
		CB99	Concrete blocks, unknown type	SPTU	Tuff
		CBS	Concrete blocks, solid	SPSL	Slate
		CBH	Concrete blocks, hollow	SPGR	Granite
		MO	Masonry unit, other	SPBA	Basalt
				SPO	Stone, other type
		MR99	Masonry reinforcement, unknown		
		RS	Steel-reinforced		
		RW	Wood-reinforced		

		RB	Bamboo-, cane- or rope-reinforced		
		RCM	Fibre reinforcing mesh		
		RCB	Reinforced concrete bands		

ID	Level 1 (L1)	ID	Level 2 (L2)	ID	Level 3 (L3)
	Material type		**Material technology**		**Material properties**
E99	Earth, unknown reinforcement	ET99	Unknown earth technology		
EU	Earth, unreinforced	ETR	Rammed earth		
ER	Earth, reinforced	ETC	Cob or wet construction		
		ETO	Earth technology, other		
W	Wood				
		W99	Wood, unknown		
		WHE	Heavy wood		
		WLI	Light wood members		
		WS	Solid wood		
		WW D	Wattle and daub		
		WBB	Bamboo		
		WO	Wood, other		
MATO	Other material				

Table A.3: Lateral Load-Resisting System

ID	Level 1 (L2)	ID	Level 2 (L2)
	Type of lateral load-resisting system		**System ductility**
L99	Unknown lateral load-resisting system	DU99	Ductility unknown
LN	No lateral load-resisting system	DUC	Ductile
LFM	Moment frame	DNO	Non-ductile
LFINF	Infilled frame	DBD	Equipped with base isolation and/or energy dissipation devices
LFBR	Braced frame		
LPB	Post and beam		
LWAL	Wall		
LDUAL	Dual frame-wall system		
LFLS	Flat slab/plate or waffle slab		
LFLSINF	Infilled flat slab/plate or infilled waffle slab		
LH	Hybrid lateral load-resisting system		
LO	Other lateral load-resisting system		

Table A.4: Height

ID	Level 1 (L1)	ID		Definition	Examples
	Height				
H99	Number of storeys unknown				
H	Number of storeys above ground				
		HBET	Range of number of storeys above ground	HBET:a,b = range of number of storeys (a=upper bound and b= lower bound)	Range HBET:3,1 (height range from 1 to 3 storeys)
		HEX	Exact number of storeys above ground	HEX:n = maximum number of storeys above ground level	Fixed number (integer) HEX:2 (two storeys)
		HAPP	Approximate number of storeys above ground	HAPP:n = approximate number of storeys above ground level	Fixed number (integer) HAPP:2 (two storeys)

ID	Level 1 (L1)	ID		Definition	Examples
	Height				
HB	Number of storeys below ground				
		HB99	Number of storeys below ground unknown		
		HBBET	Range of number of storeys below ground		Range (meters) HBBET: 3,1 (between 1 and 3 levels of basement)
		HBEX	Exact number of storeys below ground		Fixed number (integer) e.g. HBEX:2 (two levels of basement)
		HBAPP	Approximate number of storeys below ground		
HF	Height of ground floor level above grade				
		HF99	Height of ground floor level above grade unknown		

		HFBET	Range of height of ground floor level above grade	HFBET:a,b (a= upper bound and b=lower bound)	Range (meters) HFBET: 1.0,0.5 (between 0.5 m and 1.0 m)
		HFEX	Exact height of ground floor level above grade		HFEX:0.75 (exactly 0.75 m)
		HFAPP	Approximate height of ground floor level above grade		HFAPP:0.5 (approximately 0.5 m)
	Slope of the ground				
		HD99	Slope of the ground unknown		
		HD	Slope of the ground	HD:a	Integer (degrees) e.g. HD :10 (10 degrees)

Table A.5: Date of Construction or Retrofit

ID	Level 1 (L1)	Definition	Examples
	Date of construction or retrofit		
Y99	Year unknown		
YEX	Exact date of construction or retrofit	Year during which the construction was completed or retrofitted.	YEX:1936
YBET	Upper and lower bound for the date of construction or retrofit	The construction likely took place between 1930 and 1940.	YBET:1940,1930
YPRE	Latest possible date of construction or retrofit	The construction was completed before the World War II, thus the year entered is 1939.	YPRE:1939
YAPP	Approximate date of construction or retrofit	The construction was completed approximately in 1935	YAPP:1935

Note: There is a possibility of entering information related either to the date of original construction or the retrofit - whichever occurs later. For example, if a building was constructed in 1936 and it was retrofitted in 1991, the user should enter 1991.

Table A.6: Occupancy

ID	Level 1 (L1)		ID	Level 2 (L2)
	Building occupancy class - general	**Definition**		**Building occupancy class - detail**
OC99	Unknown occupancy type			
RES	Residential			
			RES99	Residential, unknown type
			RES1	Single dwelling
			RES2	Multi-unit, unknown type
			RES2A	2 Units (duplex)
			RES2B	3-4 Units
			RES2C	5-9 Units
			RES2D	10-19 Units
			RES2E	20-49 Units
			RES2F	50+ Units
			RES3	Temporary lodging

ID	Level 1 (L1)		ID	Level 2 (L2)
	Building occupancy class - general	**Definition**		**Building occupancy class - detail**
			RES4	Institutional housing
			RES5	Mobile home
			RES6	Informal housing
COM	Commercial and public			
			COM99	Commercial and public, unknown type
			COM1	Retail trade
			COM2	Wholesale trade and storage (warehouse)
			COM3	Offices, professional/technical services
			COM4	Hospital/medical clinic
			COM5	Entertainment
			COM6	Public building
			COM7	Covered parking garage

ID	Level 1 (L1)		ID	Level 2 (L2)
	Building occupancy class - general	**Definition**		**Building occupancy class - detail**
			COM8	Bus station
			COM9	Railway station
			COM10	Airport
			COM11	Recreation and leisure
MIX	Mixed use			
			MIX99	Mixed, unknown type
			MIX1	Mostly residential and commercial
			MIX2	Mostly commercial and residential
			MIX3	Mostly commercial and industrial
			MIX4	Mostly residential and industrial
			MIX5	Mostly industrial and commercial
			MIX6	Mostly industrial and residential

ID	Level 1 (L1)		ID	Level 2 (L2)
	Building occupancy class - general	**Definition**		**Building occupancy class - detail**
IND	Industrial			
			IND99	Industrial, unknown type
			IND1	Heavy industrial
			IND2	Light industrial
AGR	Agriculture			
			AGR99	Agriculture, unknown type
			AGR1	Produce storage
			AGR2	Animal shelter
			AGR3	Agricultural processing
ASS	Assembly			
			ASS99	Assembly, unknown type
			ASS1	Religious gathering
			ASS2	Arena
			ASS3	Cinema or concert hall

ID	Level 1 (L1)		ID	Level 2 (L2)
	Building occupancy class - general	**Definition**		**Building occupancy class - detail**
			ASS4	Other gatherings
GOV	Government			
			GOV99	Government, unknown type
			GOV1	Government, general services
			GOV2	Government, emergency response
EDU	Education			
			EDU99	Education, unknown type
			EDU1	Pre-school facility
			EDU2	School
			EDU3	College/university, offices and/or classrooms
			EDU4	College/university, research facilities and/or labs
OCO	Other occupancy type			

Table A.7: Building Position within a Block

ID	Level 1 (L1)
	Building Position within a Block
BP99	Unknown building position
BPD	Detached building
BP1	Adjoining building(s) on one side
BP2	Adjoining buildings on two sides
BP3	Adjoining buildings on three sides

Table A.8: Shape of the Building Plan

ID	Level 1 (L1)
	Shape of the Building Plan
PLF99	Unknownplan shape
PLFSQ	Square, solid
PLFSQO	Square, with an opening in plan
PLFR	Rectangular, solid
PLFRO	Rectangular, with an opening in plan
PLFL	L-shape
PLFC	Curved, solid (e.g. circular, elliptical, ovoid)
PLFCO	Curved, with an opening in plan
PLFD	Triangular, solid
PLFDO	Triangular, with an opening in plan
PLFP	Polygonal, solid (e.g. trapezoid, pentagon, hexagon)
PLFPO	Polygonal, with an opening in plan
PLFE	E-shape
PLFH	H-shape
PLFS	S-shape
PLFT	T-shape
PLFU	U- or C-shape
PLFX	X-shape

ID	Level 1 (L1)
	Shape of the Building Plan
PLFY	Y-shape
PLFI	Irregular plan shape

Table A.9: Structural Irregularity

ID	Level 1 (L1)	ID	Level 2 (L2)	ID	Level 3 (L3)
	Regular or irregular		**Plan irregularity or vertical irregularity**		**Type of irregularity**
IR99	Unknown structural irregularity				
IRRE	Regular structure				
IRIR	Irregular structure				
		IRPP	Plan irregularity-primary	IRN	No irregularity
				TOR	Torsion eccentricity
				REC	Re-entrant corner
				IRHO	Other plan irregularity
		IRPS	Plan irregularity-secondary	IRN	No irregularity
				TOR	Torsion eccentricity
				REC	Re-entrant corner
				IRHO	Other plan irregularity

ID	Level 1 (L1)	ID	Level 2 (L2)	ID	Level 3 (L3)
	Regular or irregular		**Plan irregularity or vertical irregularity**		**Type of irregularity**
		IRVP	Vertical structural irregularity - primary	IRN	No irregularity
				SOS	Soft storey
				CRW	Cripple wall
				SHC	Short column
				POP	Pounding potential
				SET	Setback
				CHV	Change in vertical structure (includes large overhangs)
				IRVO	Other vertical irregularity
		IRVS	Vertical structural irregularity - secondary	IRN	No irregularity
				SOS	Soft storey
				CRW	Cripple wall
				SHC	Short column
				POP	Pounding potential

				SET	Setback
				CHV	Change in vertical structure (includes large overhangs)
				IRVO	Other vertical irregularity

Table A.10: Exterior Walls

ID	Level 1 (L1)
	Exterior Walls
EW99	Unknown material of exterior walls
EWC	Concrete exterior walls
EWG	Glass exterior walls
EWE	Earthen exterior walls
EWMA	Masonry exterior walls
EWME	Metal exterior walls
EWV	Vegetative exterior walls
EWW	Wooden exterior walls
EWSL	Stucco finish on light framing for exterior walls
EWPL	Plastic/vinyl exterior walls, various
EWCB	Cement-based boards for exterior walls
EWO	Material of exterior walls, other

Table A.11: Roof

ID	Level 1	ID	Level 2	ID	Level 3 (L3)	ID	Level 4 (L4)	ID	Level 5 (L5)
	Roof shape		**Roof covering**		**Roof system material**		**Roof system type**		**Roof connections**[1]
RSH99	Unknown roof shape	RMT99	Unknown roof covering	R99	Roof material, unknown			RWC99	Roof-wall diaphragm connection unknown
RSH1	Flat	RMN	Concrete roof withoutadditional covering					RWCN	Roof-wall diaphragm connection not provided
RSH2	Pitched with gable ends	RMT1	Clay or concrete tile roof covering	RM	Masonry roof			RWCP	Roof-wall diaphragm connection present
RSH3	Pitched and hipped	RMT2	Fibre cement or metal tile roof covering			RM99	Masonry roof, unknown	RTD99	Roof tie-down unknown
RSH4	Pitched with dormers					RM1	Vaulted masonry roof	RTDN	Roof tie-down not provided
RSH5	Monopitch	RMT3	Membrane roof covering			RM2	Shallow-arched masonry roof	RTDP	Roof tie-down present
RSH6	Sawtooth	RMT4	Slate roof covering			RM3	Composite masonry and concrete roof system		
RSH7	Curved	RMT5	Stone slab roof	RE	Earthen roof				

ID	Level 1	ID	Level 2	ID	Level 3 (L3)	ID	Level 4 (L4)	ID	Level 5 (L5)
	Roof shape		**Roof covering**		**Roof system material**		**Roof system type**		**Roof connections**[1]
			covering						
RSH8	Complex regular	RMT6	Metal or asbestos sheet roof covering			RE99	Earthen roof, unknown		
RSH9	Complex irregular	RMT7	Wooden or asphalt shingle roof covering			RE1	Vaulted earthen roof		
RSHO	Roof shape, other	RMT8	Vegetative roof covering	RC	Concrete roof				
		RMT9	Earthen roof covering			RC99	Concrete roof, unknown		
		RMT1 0	Solar panelled roofs			RC1	Cast-in-place beamless reinforced concrete roof		
		RMT1 1	Tensile membrane or fabric roof			RC2	Cast-in-place beam-supported reinforced concrete roof		
		RMTO	Roof covering, other			RC3	Precast concrete roof with reinforced concrete topping		
						RC4	Precast concrete roof without reinforced concrete topping		

ID	Level 1	ID	Level 2	ID	Level 3 (L3)	ID	Level 4 (L4)	ID	Level 5 (L5)
	Roof shape		**Roof covering**		**Roof system material**		**Roof system type**		**Roof connections**[1]
				RME	Metal roof				
						RME99	Metal roof, unknown		
						RME1	Metal beams or trusses supporting light roofing		
						RME2	Metal roof beams supporting precast concrete slabs		
						RME3	Composite steel roof deck and concrete slab		
				RWO	Wooden roof				
						RWO99	Wooden roof, unknown		
						RWO1	Wooden structurewith light roof covering		
						RWO2	Wooden beams or trusses with heavy roof covering		
						RWO3	Wood-based sheets on rafters or purlins		

ID	Level 1	ID	Level 2	ID	Level 3 (L3)	ID	Level 4 (L4)	ID	Level 5 (L5)
	Roof shape		**Roof covering**		**Roof system material**		**Roof system type**		**Roof connections**[1]
						RWO4	Plywood panels or other light-weight panels for roof		
						RWO5	Bamboo, straw or thatch roof		
				RFA	Fabric roof				
						RFA1	Inflatable or tensile membrane roof		
						RFAO	Fabric roof, other		
				RO	Roof material, other				

Table A.12: Floor

ID	Level 1 (L1)	ID	Level 2 (L2)	ID	Level 3 (L3)
	Floor system material		**Floor system type**		**Floor connections**
FN	No elevated or suspended floor material (single-storey building)				
F99	Floor material, unknown			FWC 99	Floor-wall diaphragm connection unknown
FM	Masonry floor			FWC N	Floor-wall diaphragm connection not provided
		FM99	Masonry floor, unknown	FWC P	Floor-wall diaphragm connection present
		FM1	Vaulted masonry floor		
		FM2	Shallow-arched masonry floor		
		FM3	Composite cast-in-place reinforced concrete and masonry floor system		
FE	Earthen floor				
		FE99	Earthen floor, unknown		
FC	Concrete floor				

ID	Level 1 (L1)	ID	Level 2 (L2)	ID	Level 3 (L3)
	Floor system material		**Floor system type**		**Floor connections**
		FC99	Concrete floor, unknown		
		FC1	Cast-in-place beamless reinforced concrete floor		
		FC2	Cast-in-place beam-supported reinforced concrete floor		
		FC3	Precast concrete floor with reinforced concrete topping		
		FC4	Precast concrete floor without reinforced concrete topping		
FME	Metal floor				
		FME99	Metal floor, unknown		
		FME1	Metal beams, trusses, or joists supporting light flooring		
		FME2	Metal floor beams supporting precast concrete slabs		
		FME3	Composite steel deck and concrete slab		
FW	Wooden floor				

ID	Level 1 (L1)	ID	Level 2 (L2)	ID	Level 3 (L3)
	Floor system material		**Floor system type**		**Floor connections**
		FW99	Wooden floor, unknown		
		FW1	Wooden beams or trusses and joists supporting light flooring		
		FW2	Wooden beams or trusses and joists supporting heavy flooring		
		FW3	Wood-based sheets on joists or beams		
		FW4	Plywood panels or other light-weight panels for floor		
FO	Floor material, other				

Table A.13: Foundation System

ID	Level 1 (L1)
	Foundation System
FOS99	Unknown foundation system
FOSSL	Shallow foundation, with lateral capacity
FOSN	Shallow foundation, no lateral capacity
FOSDL	Deep foundation, with lateral capacity
FOSDN	Deep foundation, no lateral capacity
FOSO	Foundation, other