FP7 2013 Cooperation Work Programme
Theme 6: Environment (Including Climate Change)

Novel indicators for identifying critical *INFRA*structure at *RISK* from Natural Hazards

Deliverable D7.5

IDST Validation and User Manual

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Executive Summary

This report describes the functionality of the INFRARISK Decision Support Tool (IDST) portal developed in work package 7 of the INFRARISK project. The IDST is enabled with a set of software workflow processes that allow multiple and cascading natural hazards to be defined for a selected geospatial region and to evaluate the impact on critical road and rail infrastructure. The IDST enables stress tests to be performed and automated reports to be generated. An example stress test is performed using the IDST for one of the selected European case studies in the INFRARISK project is also presented in this report, providing details of each step of the process using the IDST.

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1 INTRODUCTION

The INFRARISK[1] (Novel indicators for identifying critical INFRAstructure at RISK from natural hazards) project has developed a methodology that enables stress testing for critical infrastructure networks. This methodology has been implemented by the INFRARISK Decision Support Tool (IDST) that allows the risks and robustness of infrastructure impacted by natural disasters such as earthquakes, landslides and flooding to be calculated.

In this document we describe the functionality of IDST portal and for illustration we provide a case study that describes stress test for a road network in Northern Italy. This case study provides a step-by-step account of the INFRARISK stress testing workflow. The IDST also provides partial support for a rail network in Croatia.

The presented deliverable consists of the following main sections:

a) Home page of IDST Portal
b) Login Options
c) IDST Dashboard
d) IDST Workflow
e) Summary
f) Appendix Case Study: Italian Road Network

[1] http://www.infrarisk-fp7.eu

2 HOME PAGE OF IDST PORTAL

The IDST[2] can be accessed via web browsers running on mobile and desktop operating systems. The IDST has been tested on these platforms:

- Linux: Firefox, Chromium
- Apple: Firefox, Safari
- Windows: Firefox, Chrome, IE9+
- Android tablets: Chrome
- iPad: Safari

The home page in Figure 1 provides a brief introduction to the IDST portal. In the top right corner of the page there two buttons: “Help” and “Login".

Figure 1: IDST home page

Under the “Help” link there is a dropdown menu with two options, these are “IDST Help” and “About INFRARISK”. The “IDST Help” provides the IDST User Manual. The “About INFRARISK” describes the objectives of the project and provides a URL where further information can be found.

2.1 Login Options

By clicking on the login link in the top right corner of the home page the user is presented with several authentication services (Figure 2), these are:

a) Mozilla Persona

[2] https://infrarisk.it-innovation.soton.ac.uk

b) Google

c) Yahoo

d) Linkedin

Once the authentication mechanism has been selected the user will be redirected to the respective site for the login. After a successful login the user is asked to allow the IDST portal to access the user's profile. This information is required for authentication. If permission is given then IDST portal will associate the user's profile with the provided account details. In case a different account is used this will be treated by the IDST portal as a different user.

Figure 2: IDST login

2.1.1 Mozilla Persona Login

If users do not want to use for authentication their social media account, Mozilla Persona provides an alternative authentication mechanism. Creating a Mozilla Persona account is simple and requires a valid email address only.

For creating a Mozilla Persona login (Figure 3) we need to follow these registration steps:

1. Click on the "sign in" button
2. Enter a valid email address by which the account can be identified
3. Provide a password for the Mozilla Persona account
4. The user is then sent an email for validation purposes

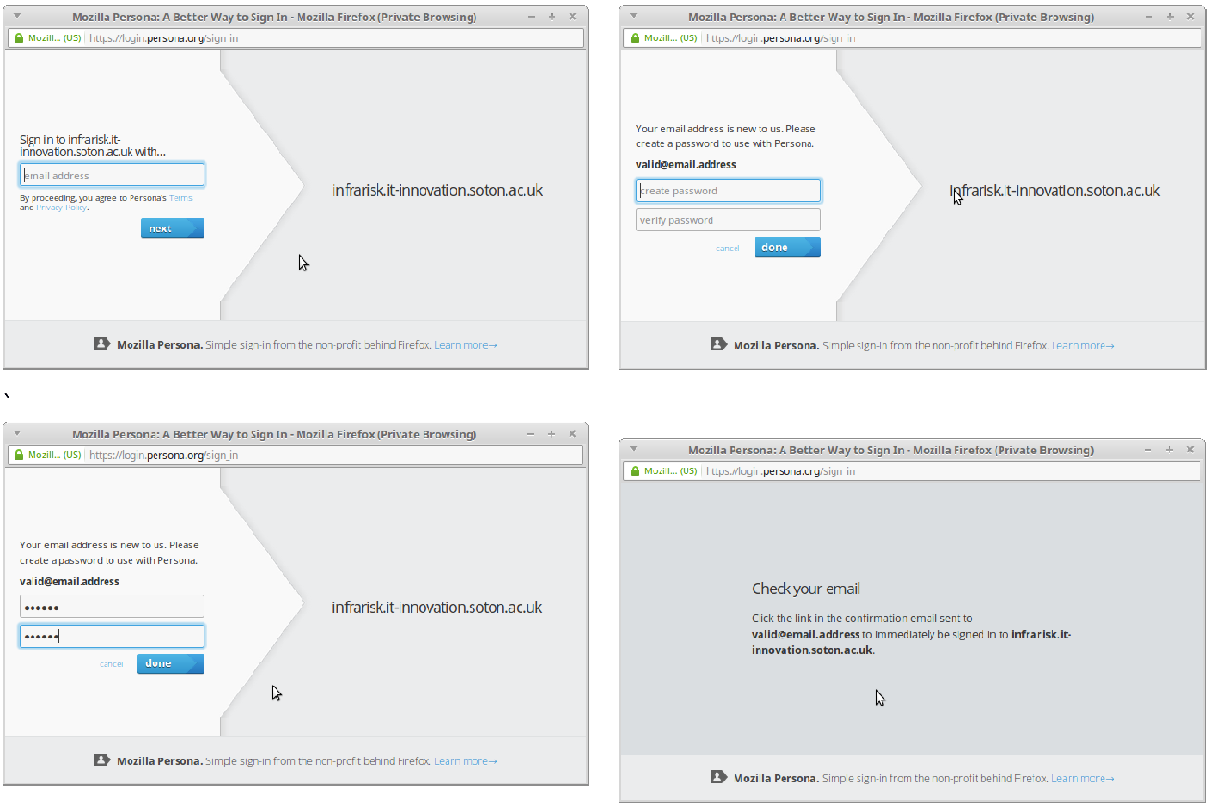


Figure 3: Login via Mozilla Persona

Once the account is created the sign-in into the IDST portal is simple. The user clicks on the login link, provides the registered email address and the Mozilla Persona password.

2.1.2 Google Login

By clicking on the “Google” option enables to use Google credentials for the IDST login (Figure 4).

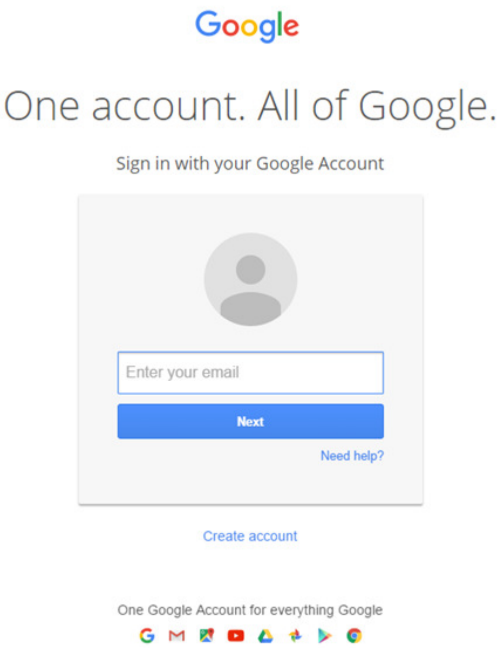


Figure 4: Standard Google login

2.1.3 Yahoo Login

By clicking on the "Yahoo" option enables to use the Yahoo credentials for the IDST login (Figure 5).

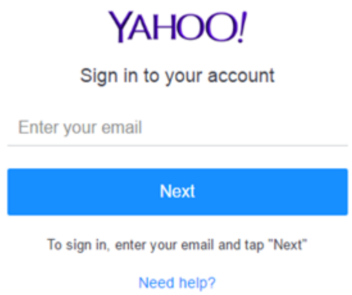


Figure 5: Yahoo login to IDST

2.1.4 LinkedIn login

By clicking on the "LinkedIn" option enables to use the LinkedIn credentials for the IDST login (Figure 6).

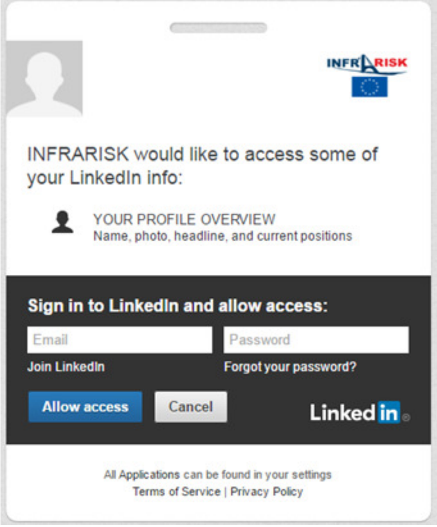


Figure 6: LinkedIn login to IDST

3 IDST DASHBOARD

After a successful login the user is presented the IDST Dashboard page (Figure 7). This dashboard represents a step-by-step process that allows multiple cascading hazards, geospatial boundaries, infrastructure elements and natural hazards to be defined. The user can access datasets, profile, usage statistics tools and information associated with case studies.

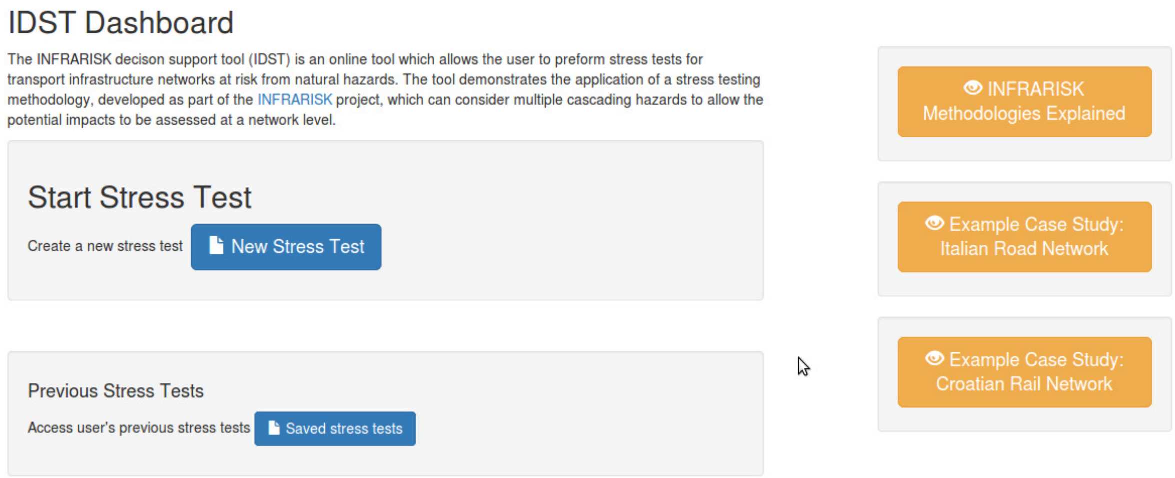


Figure 7: IDST dashboard

The IDST dashboard provides the following links:

a) In the top right corner: Help, IDST, Tools¸ Logout
b) The buttons on the right side are: INFRARISK Methodologies Explained, Example Case Study: Northern Italy Road Network and Example Case Study: Croatia Rail Network.
c) The central part of the dashboard represents the starting point of the workflow. By clicking on “New Stress Test” the user can start a new evaluation study. The “IDST Stress Test Summary List” provides access to previously defined cases studies. The user can re-visit these case studies, modify parameters and re-run the simulations.

In the following sections we provide a detailed description of each of these functions.

3.1 IDST User Profile

The IDST link provides information about the User Profile, Activity statistics and User defined datasets (Figure 8). The User Profile includes fields for: Status, User Email, User ID, Roles, Date joined and Last login. The Activity statistics keeps track of the reports generated by the user. The User defined datasets contain data about Bridges, Tunnels, Road Sections and hazard Scenarios.

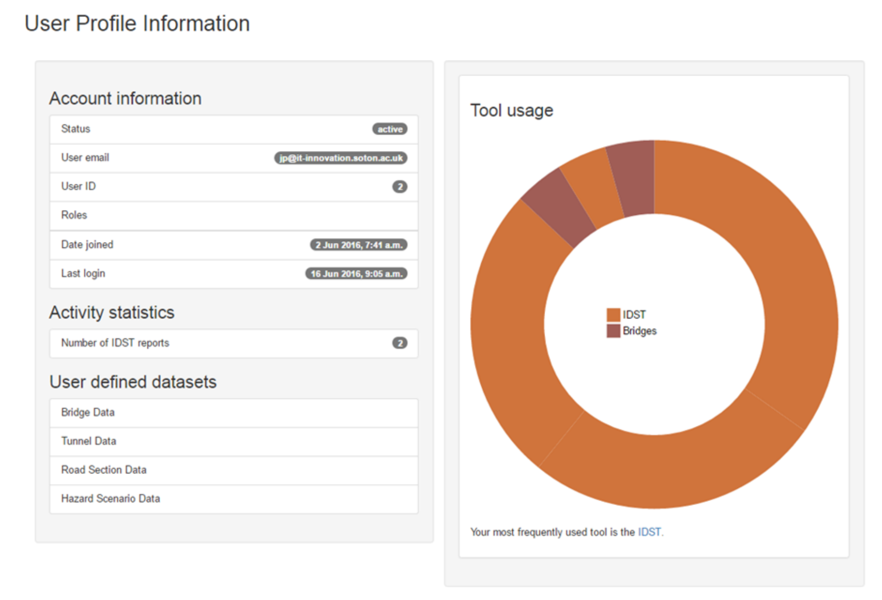


Figure 8: IDST User related information

3.2 Other Tools

The Tools menu contains a link to the Knowledge Base, and a link for the ORT application. Both tools are hosted externally. The Knowledge Base (https://infrarisk.datagraft.net/) provides information about road infrastructure elements of a geographical area (Figure 9).

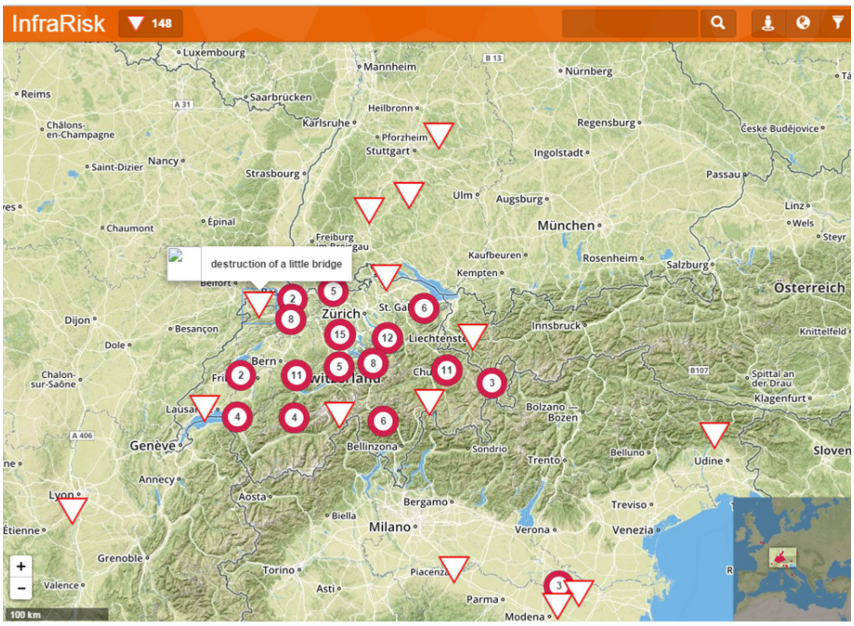


Figure 9: INFRARISK Knowledge Base

The ORT-application[3] will give insight in the three projects which are developed for the INFRARISK-project. The Croatian Case Study Rail focusing on the TEN-T corridor and the expected exposure for

[3] https://www.veilig.in

flooding, landslides and scour. The aim of this ORT application is to make an analysis on the exposure to the identified hazards for a whole line or network. This can be done scoring the railway sections to the most important criteria.

Based on the outcome an infrastructure manager can prioritize his further approach. In this approach the infrastructure manager can use the products and methodologies that are developed within the INFRARISK project and are available within the INFRARISK website, the IDST-application and the training videos.

3.3 The Overarching Risk Management Framework Workflow in General

In this section we describe the key elements of the Overarching Workflow (Hackl et al., 2016). The main steps that are required for running the workflow are the following (Figure 10):

a) Define Stress Test
b) Define System Representation
c) Define Spatial Boundaries
d) Define Network Elements
e) Define Hazard Scenario
f) Estimate Risk
g) Evaluate Risk

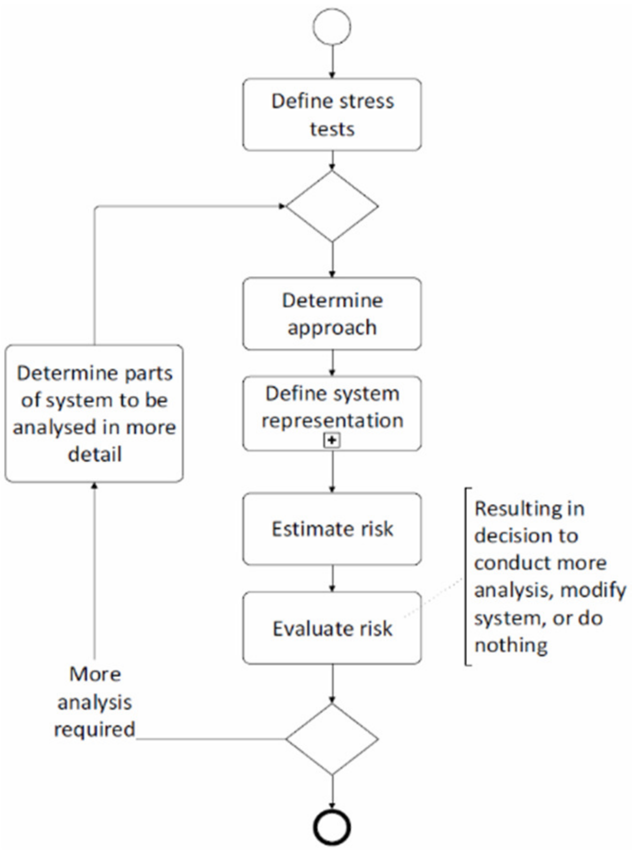


Figure 10: Overarching risk management framework workflow diagram

Problem Identification - provides generic information about the given case study, describes the reason and questions that the given case study addresses.

Define Stress Test - includes the events, elements, consequences, assumptions, agreements and boundary conditions that are necessary for the risk assessment.

Define System Representation – involves defining the Spatial and Temporal boundaries of the system. Multiple boundaries can be defined for the system, each is identified by a name for example "hazard return period", "ground motion area" etc.

Define Spatial Boundaries – the boundaries are defined by a polygon, it can be defined manually or a pre-defined boundary can be used. In this step we also define temporal boundaries that represent the type of hazard (for example flooding, earthquake etc.) and the hazard occurrence period.

Define Hazard Scenario – is described by the hazard source and a list of primary and secondary hazard events.

Define Network Scenario – represents the definition of network infrastructure, this includes the list of infrastructure elements with their associate hazard events (e.g. bridges, tunnels, etc.), contained within spatial boundaries.

Estimate Risk – involves the calculation of damage state statistics that provides information about the network elements and the histogram of damage.

Evaluate Risk – stage is represented by the Case Study report that contains summary information about: Problem Identification, System Stress Tests, System Boundaries, Hazard Scenario, Hazard Model Setup, Network Elements and Risk Estimation.

3.4 IDST Case Studies Stress Tests

The IDST provides examples of predefined stress tests for both two European case studies conducted in the project (Clarke et al., 2016). The Italian case study examines the impact of low probability, high consequence seismic hazard scenarios for a road network in Northern Italy (Figure 11).

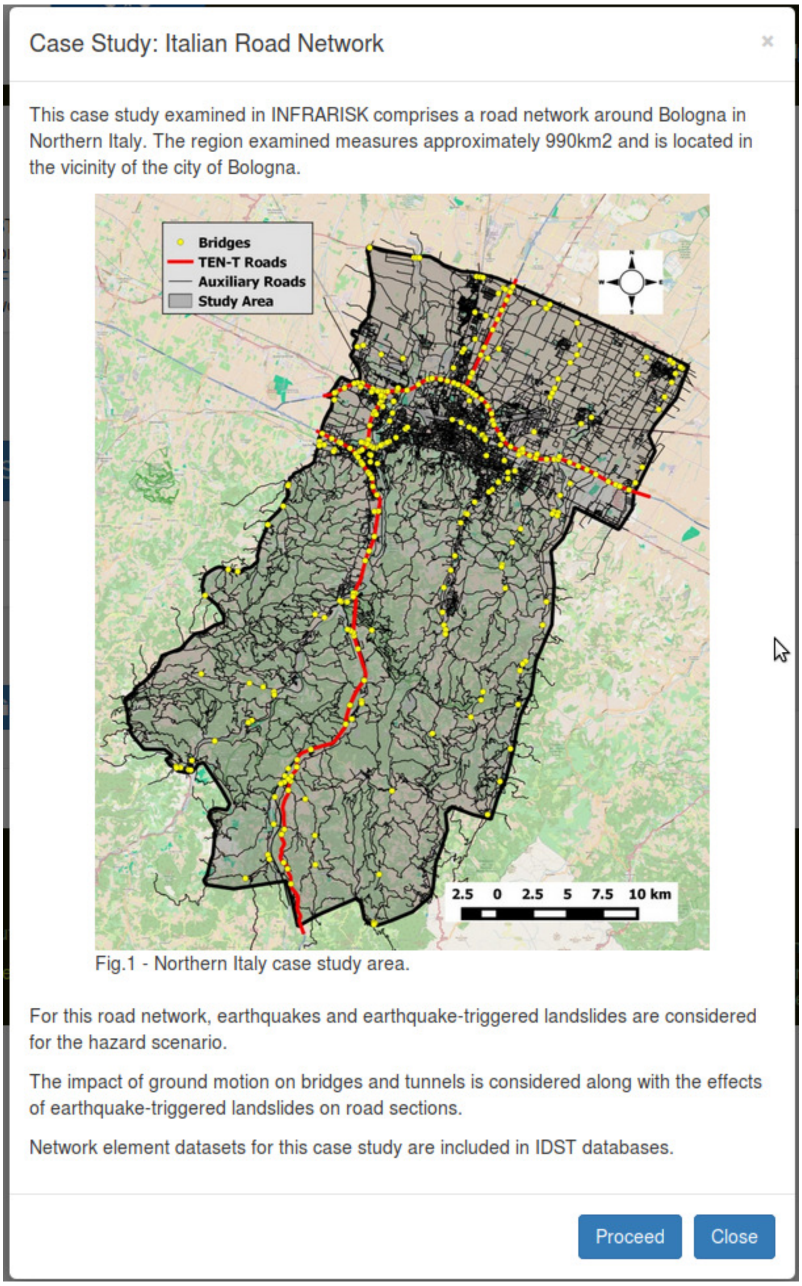


Figure 11 Italian road network case study

Figure 12 shows the Croatia rail network case study. The main source hazard in this scenario is flooding with rainfall triggered landslides that affects a railway network. Stress tests based on this case study are currently on the IDST with limited functionality.

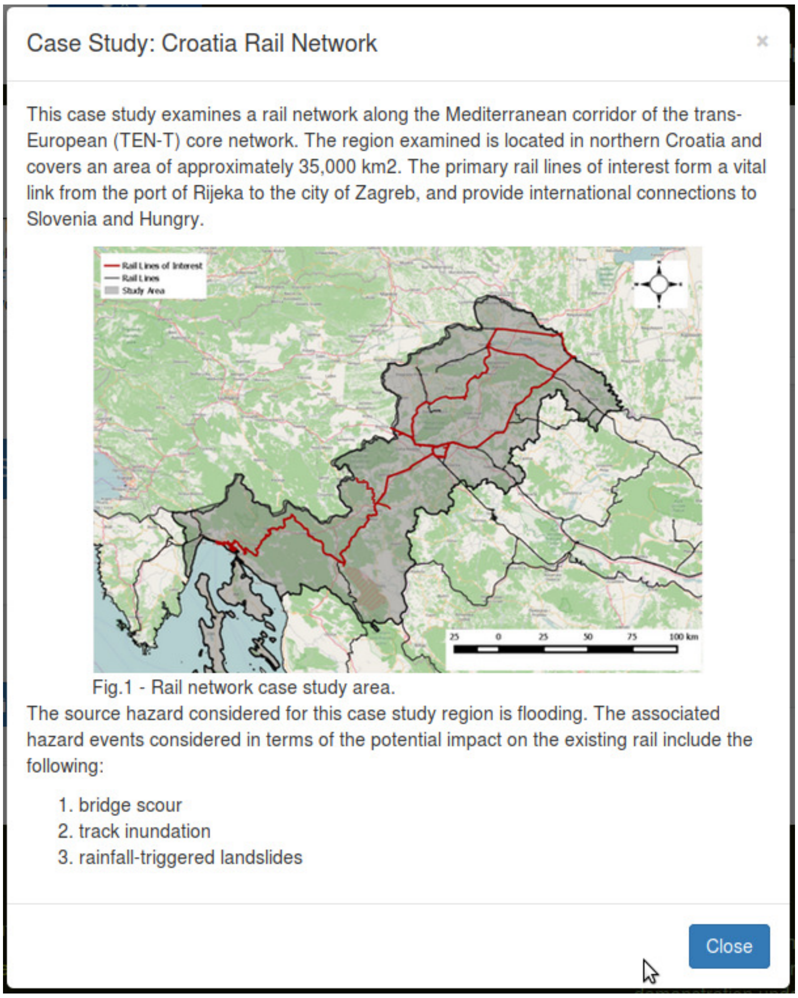


Figure 12 Croatian rail network case study

4 IDST WORKFLOW IN DETAIL

In this section we provide a detailed description of individual steps of the IDST implementation of the Overarching Workflow. Example models and figures in this section are mainly derived from the Italian road network case study (Clarke et al., 2016).

4.1 Define Stress Tests

Generic information about the stress test (van Gelder and van Erp, 2016) (Hackl et al., 2016) describes the reason and the relevant questions. By clicking on the "New Stress Test" button on the IDST Dashboard the user can define a new case study (Figure 13).

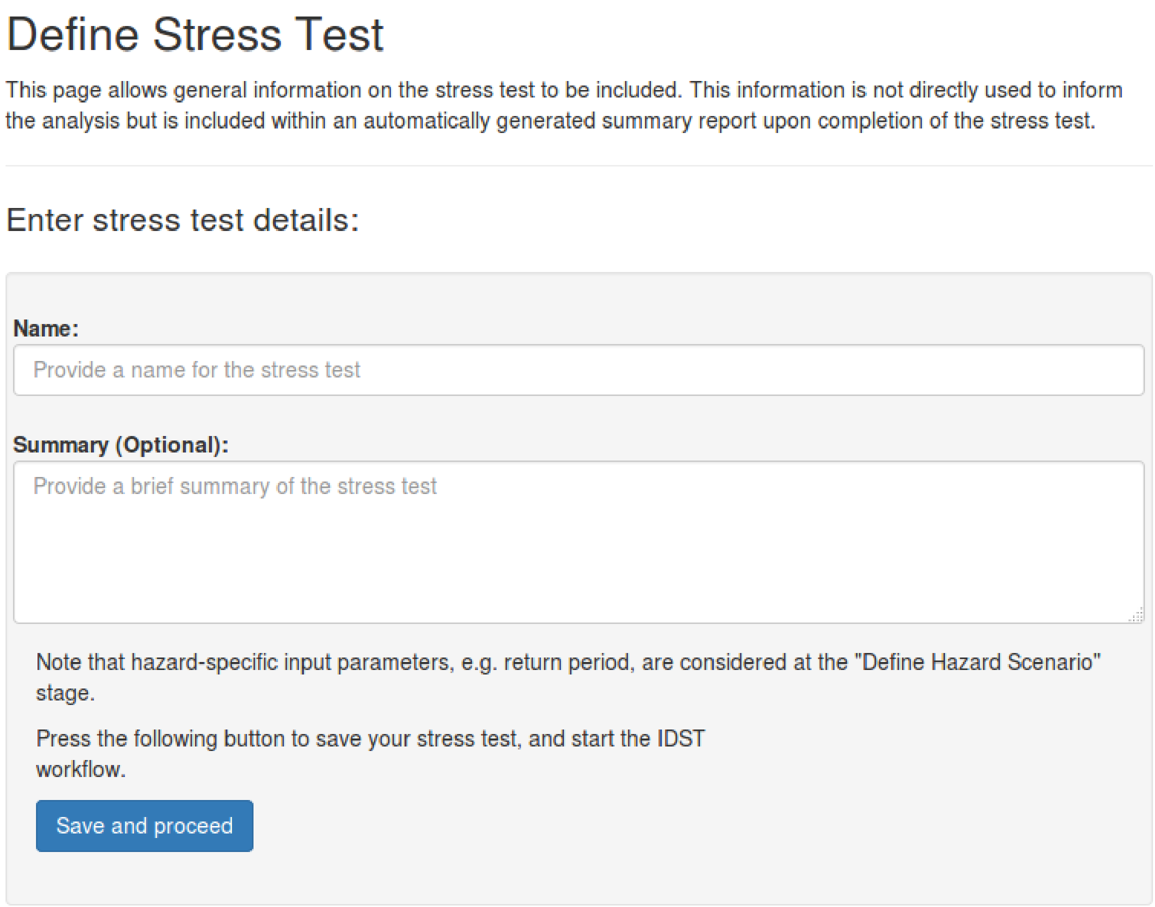


Figure 13: Problem identification

When all information is provided the user saves the information by clicking on the "Store case study" button.

A stress test can be for example represented by an earthquake event that can also trigger a landslide. The risk to the network is considered in terms of probable restoration costs. After providing the required information the user clicks on "Store Stress Tests Scenario" for storing the details in the database. This action transfers the user to the next page that allows the system with boundary conditions, network elements and hazard scenarios.

4.2 Define System Representation

Defining the system on which the calculations are performed is a four stage process that includes the definition of: boundaries, network elements, hazard scenarios, network events and network element models.

4.2.1 System Boundaries

The definition of system boundaries allows the geographical area for which the risk assessment will be performed to be specified (Figure 14).

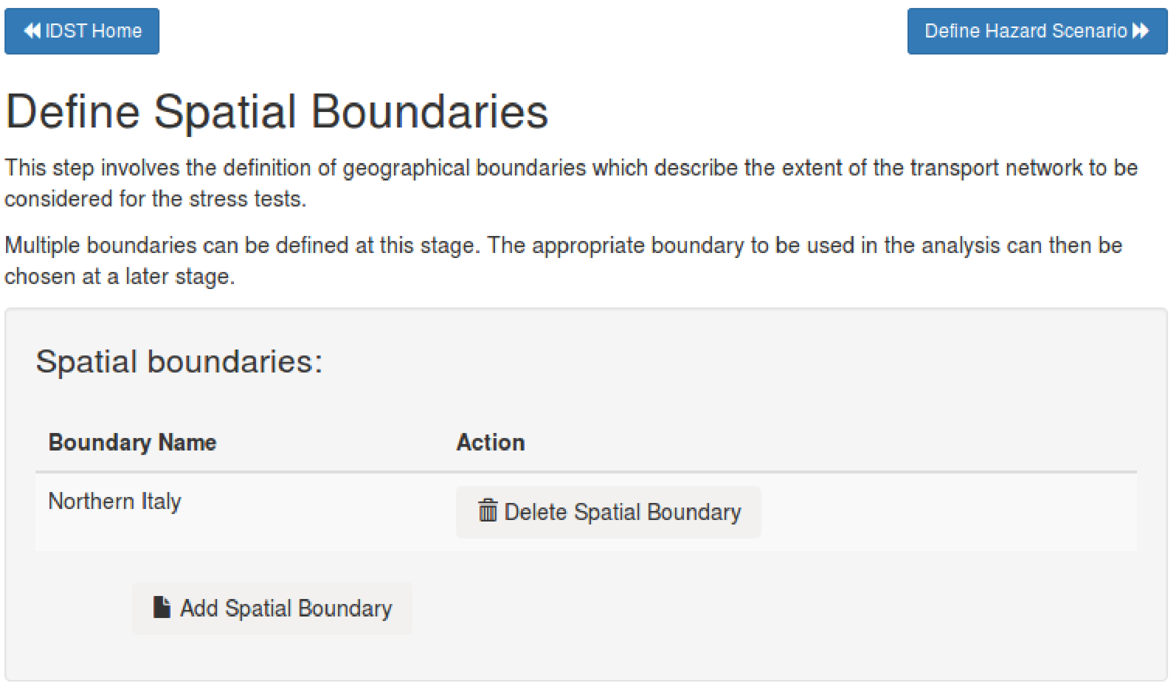


Figure 14: Definition of system boundaries

By clicking on the "Add Spatial Boundary" the user can highlight the area of interest. There are several options for defining boundaries (Figure 15), these are:

a) User defined boundaries
   - Manually defined spatial borders
   - User can also upload spatial borders defined in a separate file

b) Pre-defined boundaries
   - Northern Italy, case study borders
   - Croatia railway, case study borders (currently disabled)

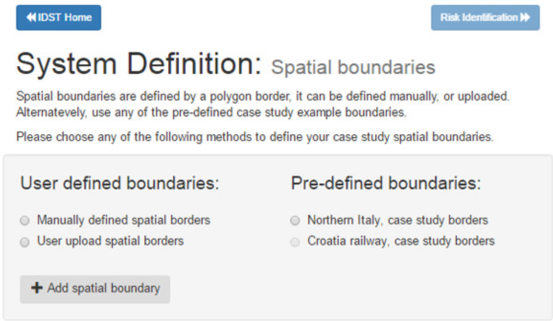


Figure 15: Defining spatial boundaries

By selecting the radio box "Manually defined spatial borders" and clicking on "Add Spatial Boundary" the user is presented with a map on which the particular area can be marked (Figure 16). On the left side of the map there are various controls that allow to zoom in (+), zoom out (-), type of polygon (pentagon or square), modifying the boundary or deleting the changes. Before completing this step the user needs to "Name" the selected area and click on the "Store Boundaries" button. This takes the user back to the "Define System Boundaries" page where the "Temporal boundaries" can be defined.

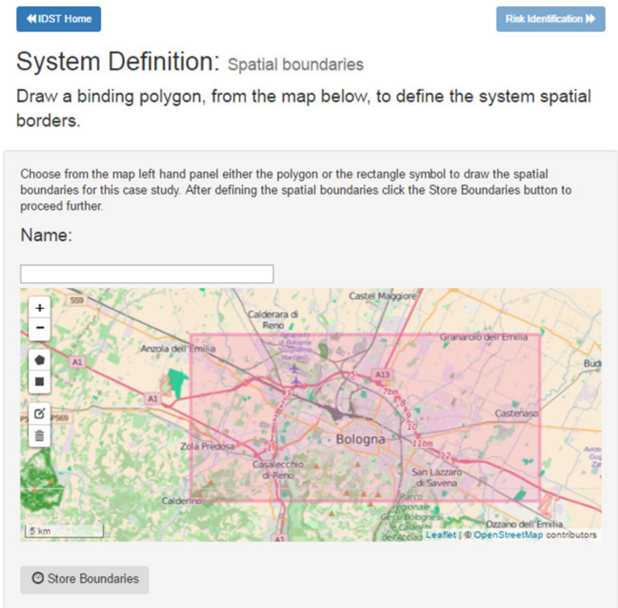
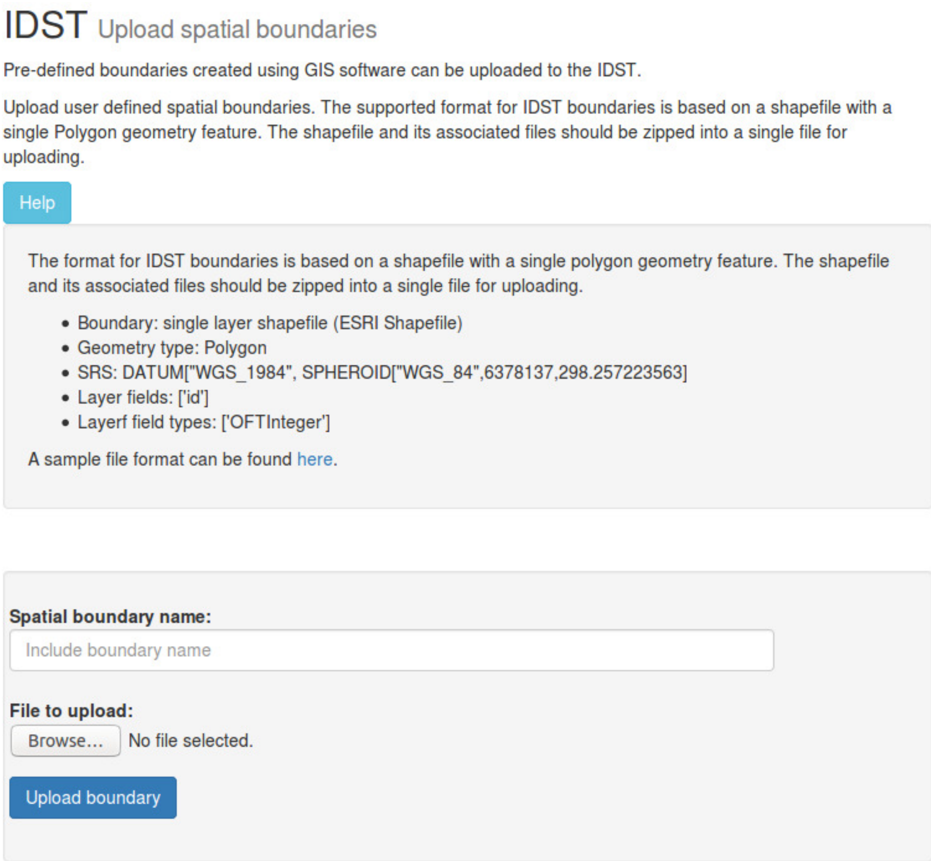


Figure 16: Selecting the area of interest

The user can define multiple spatial boundaries, for example might investigate the impact of a hazard event that happened in Northern Italy on the traffic in the neighbouring areas or for the entire country.



IDST Upload spatial boundaries

Pre-defined boundaries created using GIS software can be uploaded to the IDST.

Upload user defined spatial boundaries. The supported format for IDST boundaries is based on a shapefile with a single Polygon geometry feature. The shapefile and its associated files should be zipped into a single file for uploading.

Help

The format for IDST boundaries is based on a shapefile with a single polygon geometry feature. The shapefile and its associated files should be zipped into a single file for uploading.

- Boundary: single layer shapefile (ESRI Shapefile)
- Geometry type: Polygon
- SRS: DATUM["WGS_1984", SPHEROID["WGS_84",6378137,298.257223563]
- Layer fields: ['id']
- Layerf field types: ['OFTInteger']

A sample file format can be found here.

Spatial boundary name:
Include boundary name

File to upload:
Browse... No file selected.

Upload boundary

Figure 17: Spatial boundary shapefile format

The IDST supports user uploaded shapefile boundaries, as Figure 17 shows, in the following format:

Boundary: single layer shapefile (ESRI Shapefile)

Geometry type: Polygon

SRS: DATUM["WGS_1984", SPHEROID["WGS_84",6378137,298.257223563]

Layer fields: ['id']

Layerf field types: ['OFTInteger']

All associated shapefiles should be archived in a simple zip file for uploading e.g.

Archive: aoi.zip

```
  Length      Date    Time    Name
---------  ---------- -----   ----
       76  2016-05-18 16:48   AreaOfInterest_Polygon.dbf
      388  2016-05-18 16:48   AreaOfInterest_Polygon.prj
      597  2016-05-18 16:48   AreaOfInterest_Polygon.qpj
     3836  2016-05-18 16:48   AreaOfInterest_Polygon.shp
      108  2016-05-18 16:48   AreaOfInterest_Polygon.shx
---------                     -------
     5005                     5 files
```

4.2.2 Define Hazard Scenario

After defining the spatial and temporal boundaries the “Define Hazard Scenario” button gets enabled. The Definition of Hazard Scenario involves:

a) the hazard source
b) list of associated, primary or secondary, hazard events
c) list of hazard models associated with hazard events

It is important to mention that all hazard events must be assigned to hazard models. A hazard model is a detailed IDST module that describes in detail an actual hazard, e.g. earthquake. The currently implemented hazard sources are precipitation and earthquake (Figure 18). The selection of the hazard source is saved by clicking on the “Store Scenario Hazard Source” button.

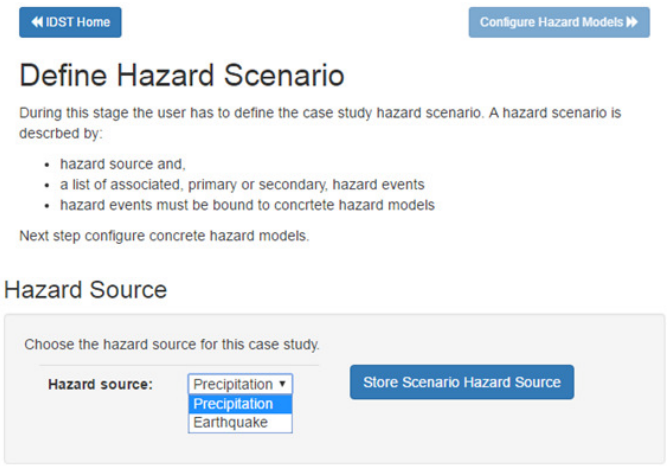


Figure 18: Defining hazard source

After defining the hazard source hazard events can be created and added by clicking on the "Add Hazard Event" button (Figure 19). The selected configuration is saved by clicking on the "Stored Hazard Event" button.

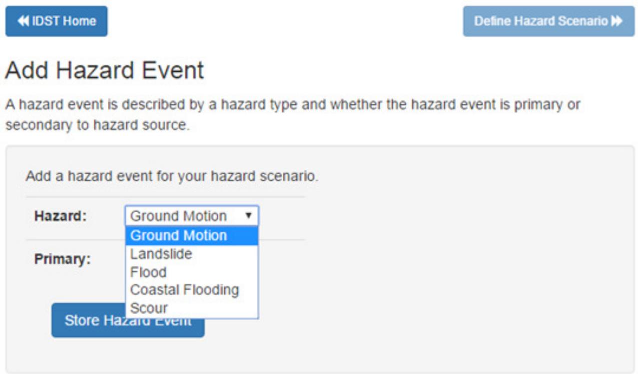


Figure 19: Defining a hazard event

Both the hazard source and the event must be bounded to a hazard model (Figure 20). By clicking on the "Assign to Model" allows to select from several hazard models that are applicable for the given hazard event. Binding a hazard event to a real a hazard model generates PGA data for a particular location on the map.

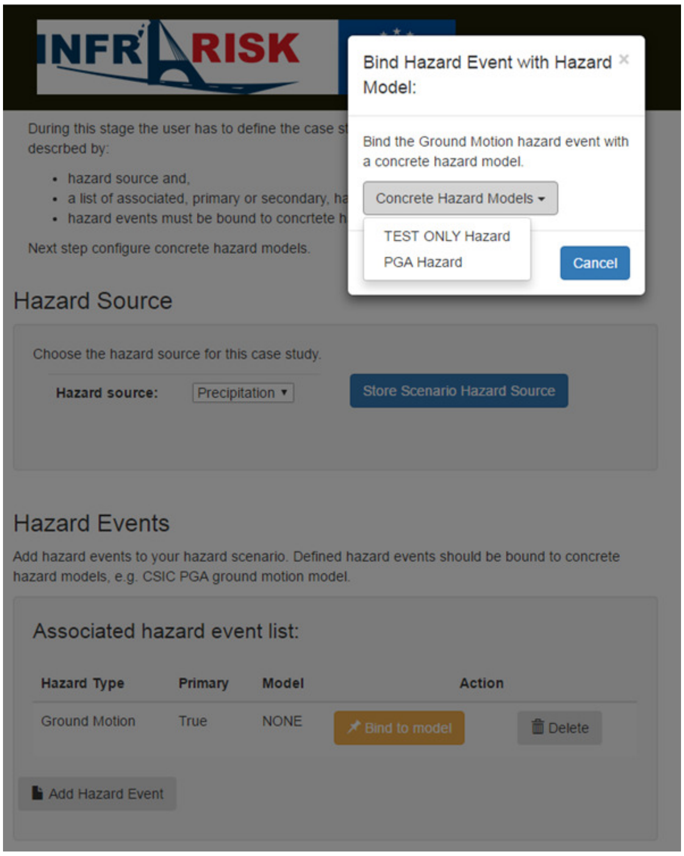


Figure 20: Assigning hazard models to hazard events

Once the hazard source and the hazard events are defined the following step is the configuration of the associated hazard models. This step is activated by clicking on the "Configure Hazard Models" button.

4.2.2.1 Configuring the hazard model

The reason for configuring the hazard model is that each model can take different parameters and values, these models can represent layers over a certain area. We can have one hazard source and several events, for example an earthquake that triggers a landslide. The IDST Portal will allow to plug-in different models in future releases. Currently, for demo purposes we use a seismic hazard model developed in the project (Jiménez and García-Fernández, 2016). The configuration of the model is activated by clicking on the "Setup PGA" button (Figure 21).

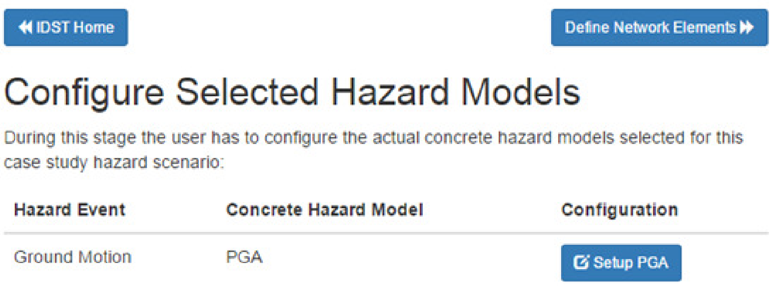


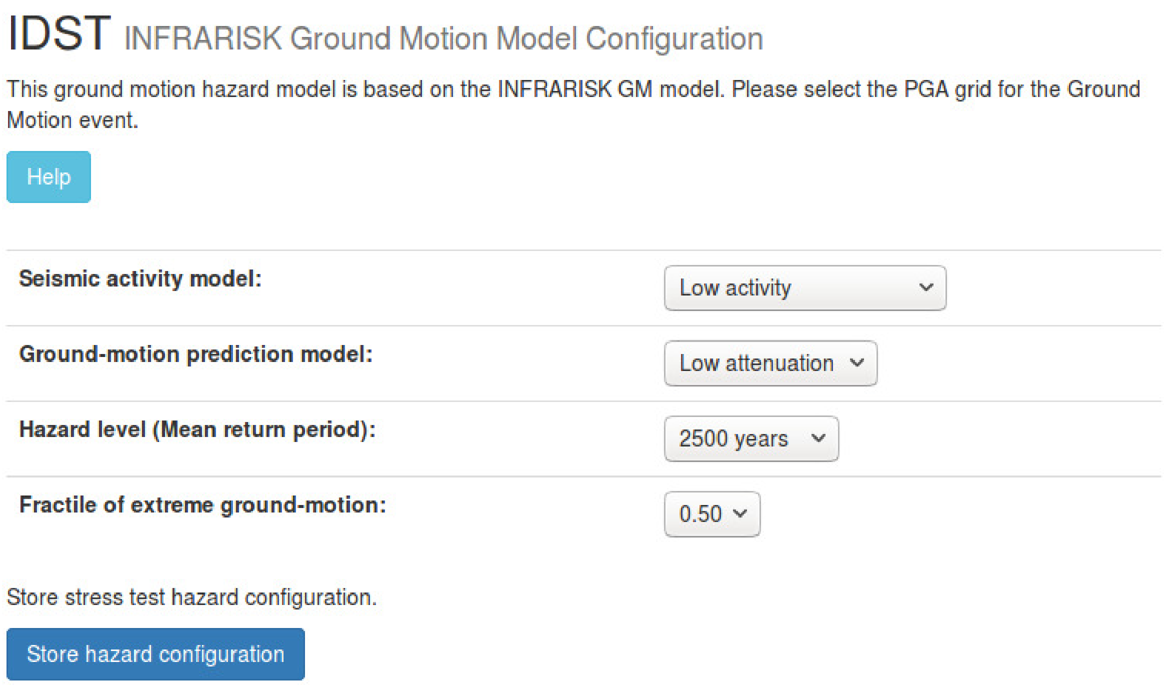
Figure 21: Configuring the PGA model

The methodology developed in INFRARISK introduces seismic hazard models for describing low probability seismic ground motions.

The configuration of the seismic hazard model (Jiménez and García-Fernández, 2016) (Figure 22) involves the specification of fields:

a) ***Seismic activity model***: Level of seismicity in the region of interest (i.e. high, moderate, moderate-to-low, low).
b) ***Ground-motion prediction model***: Attenuation of seismic energy with distance in the region of interest (i.e. generic low, generic high; European-based).
c) ***Hazard level (annual probability of ground motion exceedance)***: Mean return period (years) = 1/P; where P = probability of exceeding ground motion values at the reference central site per year.
d) ***Fractile of extreme ground-motion***: Fractile/Percentile of extreme ground-motion values at the reference central site (e.g. if fractile is 0.90, only 10% of extremes will be larger).

Each GM-field corresponds to a grid of Peak Ground Acceleration (PGA) value for the hazard region that is referenced to a specific extreme ground-motion value which is located at the centre of the ‘hazard region’. Furthermore, 18 random factors are used for describing the spatial variability associated with the PGA values. The cascading hazards effects were also considered in terms of earthquake-triggered landslides that heavily affect roads built on slopes. This method involves estimating the yield acceleration (k_y) values for the selected area.



The configuration of the PGA model is stored by clicking on the “Stored hazard configuration” button. This action takes us to the next stage of the workflow for *Defining the Network Scenario and Network Elements*.

Figure 22: Setting seismic hazard model parameters

Note: the seismic hazard model configuration should be finalised at a later stage when the specified PGA grid is anchored to an actual network element objects, e.g. bridge or tunnel.

4.2.2.2 Define Network Scenario

The hazard scenario at this stage of the IDST workflow is specified only in generic terms, it is not yet mapped to a particular area. The configuration of the network scenario and elements (Figure 23) is a three step process consisting of:

a) Network infrastructure
b) List of network infrastructure elements, or network event types (road network, bridges, tunnels etc.)
c) Spatial boundaries

Table 1 summarises the type of structural elements of the network and the associated hazards.

Network Element	Hazard Event
Bridges	Ground Motion
Tunnels	Ground Motion
Road sections	Ground Motion-triggered landslides

Table 1: Network elements and hazards considered

The damage for bridges, tunnels and road section was classified according to five states: no damage, slight/minor damage, moderate damage, extensive/major damage, and complete damage. Additional parameters such as the indicative restoration times and repair costs for the individual network elements were also obtained. For roads the length of sections is 10m, the values for bridges and tunnels are given per individual structure.

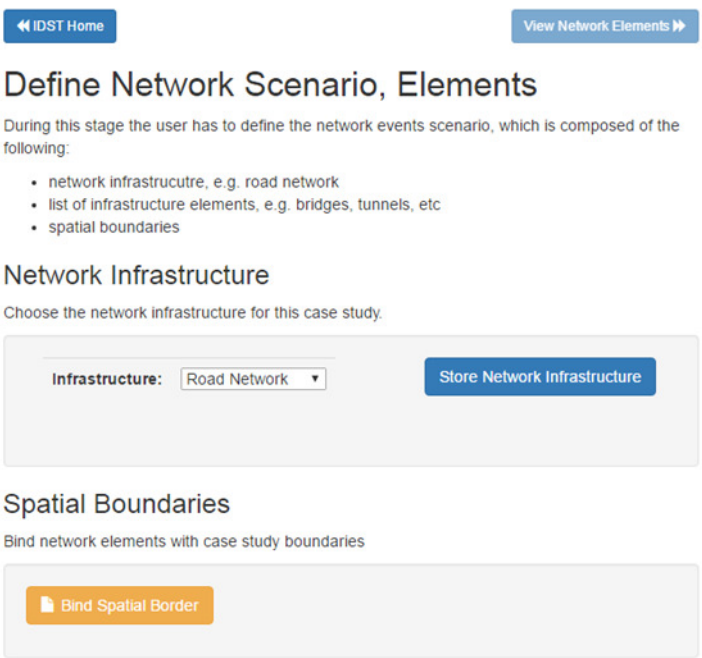


Figure 23: Define network scenario and elements

4.2.2.3 Define Network Event Type

After clicking on the "Store Network Infrastructure" the user can add more infrastructure elements to the scenario (Figure 24). Each network element type should be assigned to network and also to a hazard event that affects the specified network element type.

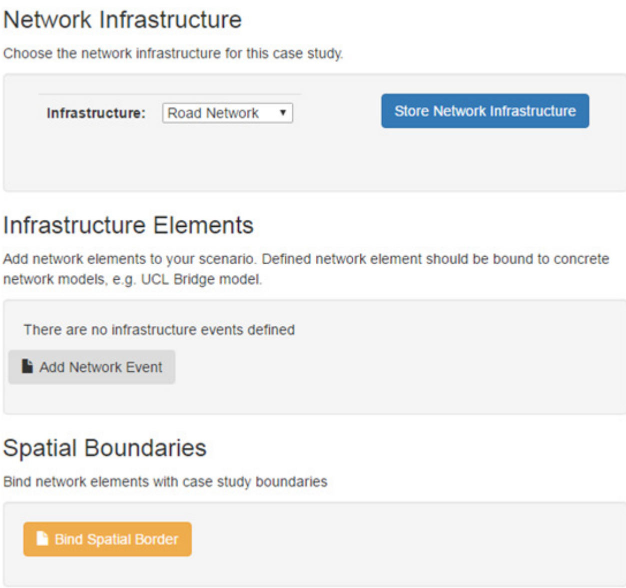


Figure 24: Defining infrastructure characteristics

By clicking on the "Add Network Event" we can associate the given network element with a specific hazard event defined earlier (Figure 25).

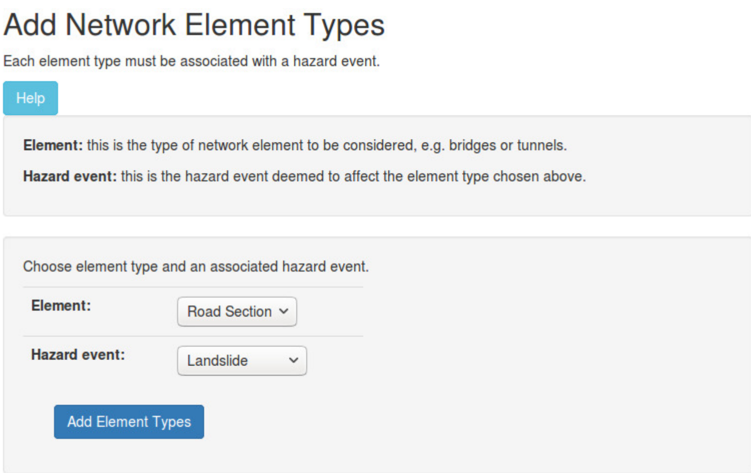


Figure 25: Linking network element types with events

4.2.2.4 Assign network event to the damage model fragility functions

Once the network event is selected by clicking on the "Choose Model" button the user can assign this event to a network model (Figure 26).

For the network bridges and tunnels, the IDST has adopted the median fragility functions with lower and upper confidence bounds. Information about the application of the SYNER-G database to the network bridges and tunnels can be founded in INFRARISK Deliverable D3.2 (D'Ayala and Gehl, 2015).

Information about assigning fragility functions to road sections built on slopes can also be found in Deliverable D3.2.

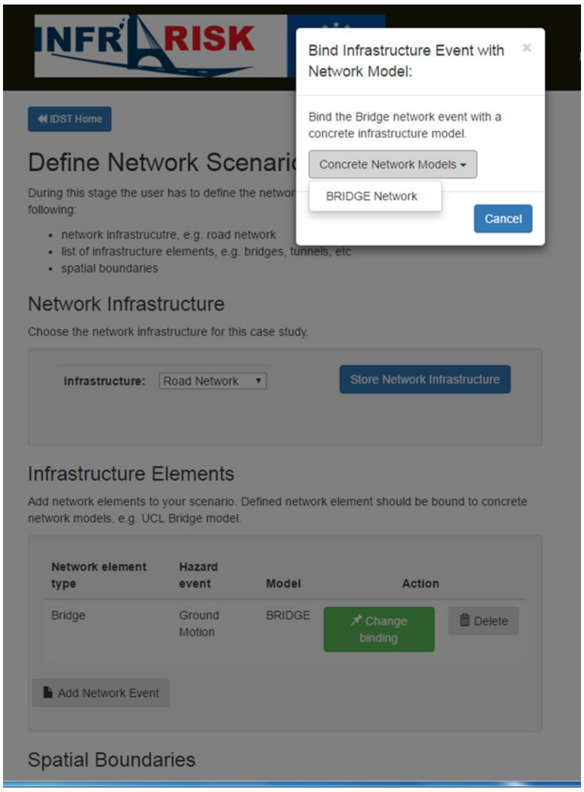


Figure 26: Assigning infrastructure event to a network model

The input parameters of models are values for the mean and sigma that are used for the generation of fragility curves, and the PGA value at that point. The output of the model is a numerical value representing the damage state ranging from 0 to 5.

For the network of bridges and tunnels, the physical damage due to the earthquake hazard is defined in terms of five damage states:

- no damage (Damage State 0), slight/minor damage (Damage State 1),
- moderate damage (Damage State 2),
- extensive/major damage (Damage State 3),
- complete damage (Damage State 4).

For the road sections the physical damage due to the earthquake-triggered landslide hazards is defined in terms of four damage states:

- no damage (Damage State 0),
- slight/minor damage (Damage State 1),
- moderate damage (Damage State 2),
- extensive/major damage (Damage State 3).

After selecting the Network Model the next step is defining the spatial boundaries applicable to network elements.

4.2.2.5 Assigning to a spatial border (example map of Italy)

By clicking on the “Choose Spatial Border” button the user can define the boundaries for the infrastructure event scenario (Figure 27). The user can add more boundaries in order to investigate the impact of a hazard event for various geographical regions.

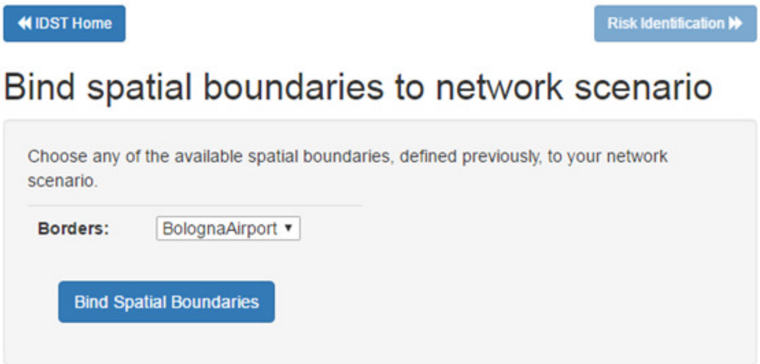


Figure 27: Assigning spatial boundaries for the network scenario

4.2.3 Adding network dataset elements (datasets)

At this step of the workflow the user defines the actual network element datasets (bridges, tunnels, road sections) for each network event type defined earlier. Multiple datasets of network elements can be associated with a network event by clicking on the “Add Network Dataset” (Figure 28).

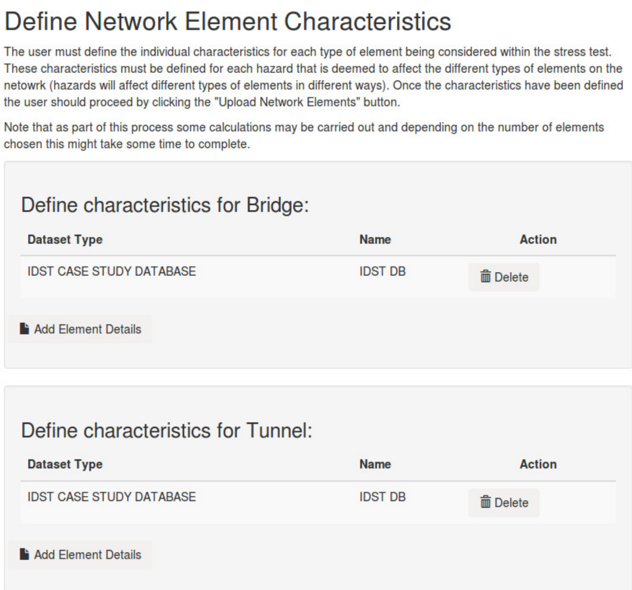


Figure 28: Network element datasets

Currently there are three different dataset formats of network elements supported by IDST (Figure 29):

a) Network element datasets already preloaded in IDST databases.
b) User defined network element datasets in a shape-file format.
c) User defined network element datasets in a CSV format.

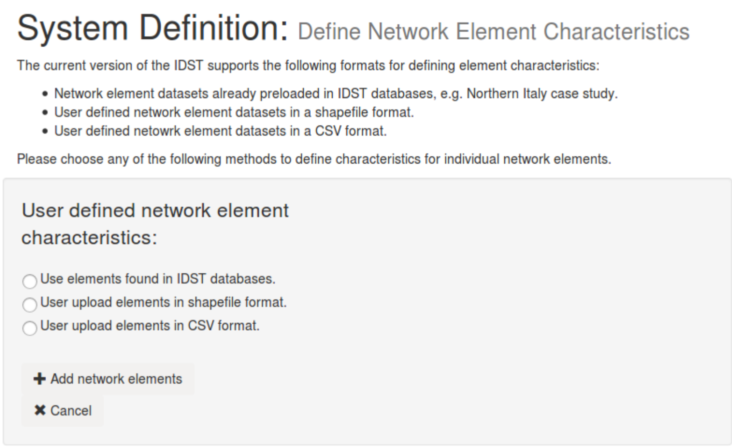


Figure 29: Selecting network elements

Currently the supporting Shapefile format for bridge and tunnel elements, as Figure 30 shows, is the following:

```
Bridges: single layer shapefile (ESRI Shapefile)

Geometry type: Point

SRS: DATUM["WGS_1984", SPHEROID["WGS_84",6378137,298.257223563]

Layer fields: ['bridge_id', 'y_coord', 'x_coord', 'material1', 'material2', 'bridge_wid', 'bridge_len', 'deck_struc', 'pier-to-de', 'type_of_pi', 'type_of_co', 'type_of__1', 'spans', 'span_lengt', 'connection', 'bridge_con', 'level_of_s', 'number_of_']

Layerf field types: ['OFTInteger', 'OFTReal', 'OFTReal', 'OFTString', 'OFTString', 'OFTString', 'OFTString', 'OFTString', 'OFTString', 'OFTString', 'OFTString', 'OFTString', 'OFTString', 'OFTString', 'OFTString', 'OFTString', 'OFTString', 'OFTInteger']
```

All associated shapefiles should be archived in a simple zip file for uploading e.g.

Archive: brg_whxu9wf_.zip

```
  Length      Date    Time    Name
---------  ---------- -----   ----
  1233109  2016-05-18 16:48   Bridges_UCL.dbf
      143  2016-05-18 16:48   Bridges_UCL.prj
      257  2016-05-18 16:48   Bridges_UCL.qpj
     9620  2016-05-18 16:48   Bridges_UCL.shp
```

```
     2820  2016-05-18 16:48   Bridges_UCL.shx
---------                     -------
  1245949                     5 files
```

Similarly, the tunnel's single layer shapefile (ESRI Shapefile) is defined as:

```
Geometry type: Point

SRS: DATUM["WGS_1984", SPHEROID["WGS_84",6378137,298.257223563]

Layer fields: ['tunnel_id', 'y_coord', 'x_coord', 'constructi',
'shape', 'depth', 'geological', 'supporting', 'no_of_lane']

Layerf field types: ['OFTInteger', 'OFTReal', 'OFTReal',
'OFTString', 'OFTString', 'OFTString', 'OFTString', 'OFTString',
'OFTInteger']
```

Archive: brg_pef0r4t_.zip

```
 Length      Date    Time    Name
---------  ---------- -----   ----
    40491  2016-05-24 21:22   Tunnels_UCL.dbf
      143  2016-05-24 21:22   Tunnels_UCL.prj
      257  2016-05-24 21:22   Tunnels_UCL.qpj
      940  2016-05-24 21:22   Tunnels_UCL.shp
      340  2016-05-24 21:22   Tunnels_UCL.shx
---------                     -------
    42171                     5 files
```

Currently the supporting Shapefile format for bridge and tunnel elements is the following:

Bridge element shapefile format:

- Bridges: single layer shapefile (ESRI Shapefile)
- Geometry type: Point
- SRS: DATUM["WGS_1984", SPHEROID["WGS_84",6378137,298.257223563]
- Layer fields: ['bridge_id', 'y_coord', 'x_coord', 'material1', 'material2', 'bridge_wid', 'bridge_len', 'deck_struc', 'pier-to-de', 'type_of_pi', 'type_of_co', 'type_of__1', 'spans', 'span_lengt', 'connection', 'bridge_con', 'level_of_s', 'number_of_']
- Layerf field types: ['OFTInteger', 'OFTReal', 'OFTReal', 'OFTString', 'OFTString', 'OFTString', 'OFTString', 'OFTString', 'OFTString', 'OFTString', 'OFTString', 'OFTString', 'OFTString', 'OFTString', 'OFTString', 'OFTString', 'OFTString', 'OFTInteger']

A sample shapefile for bridges can be found here.

Tunnel element shapefile format:

- Tunnels: single layer shapefile (ESRI Shapefile)
- Geometry type: Point
- SRS: DATUM["WGS_1984", SPHEROID["WGS_84",6378137,298.257223563]
- Layer fields: ['tunnel_id', 'y_coord', 'x_coord', 'constructi', 'shape', 'depth', 'geological', 'supporting', 'no_of_lane']
- Layerf field types: ['OFTInteger', 'OFTReal', 'OFTReal', 'OFTString', 'OFTString', 'OFTString', 'OFTString', 'OFTString', 'OFTInteger']

A sample shapefile for tunnels can be found here.

CSV file format:

The CSV format for bridges elements is the following:

x coordinate, y coordinate, number of lines, medean

X coord	Y coord	Number of lines	Median DS1	Sigma DS1	Median DS2	Sigma DS2	Median DS3	Sigma DS3	Median DS4	Sigma DS4
21.5	44.1	4	0.2	0.34	0.34	0.45	0.48	0.56	0.65	0.73
...										

Figure 30: Shapefile and CSV format for network element datasets

After selecting the relevant datasets for the Bridge and Tunnels the "Analyse Network Element" can be activated (Figure 31).

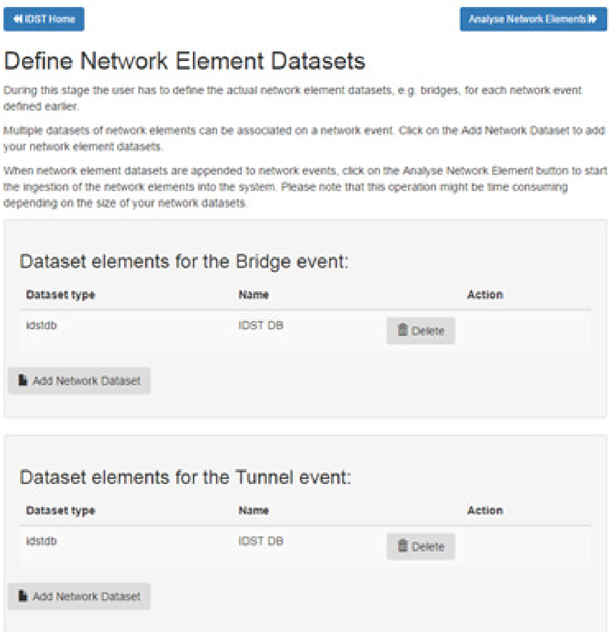


Figure 31: Defining network element datasets

The main functions of "Analyse Network Element" are data ingest and filtering the elements inside the area boundary (Figure 32). This operation can be time consuming depending on the size of datasets as Figure 32 shows.

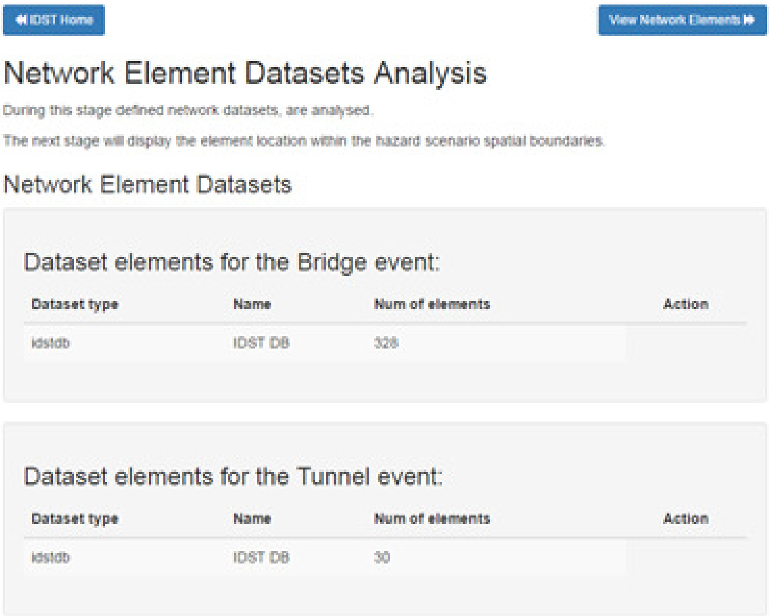


Figure 32: Analysing network elements

4.2.3.1 View network elements

Once all components of the network scenario are specified the user can click on "View Network Elements" button for checking the parameters of elements (Figure 33). For the full specification of Network scenario the user provides information for three categories:

a) Network Infrastructure
b) Infrastructure Element Types
c) Spatial Boundaries

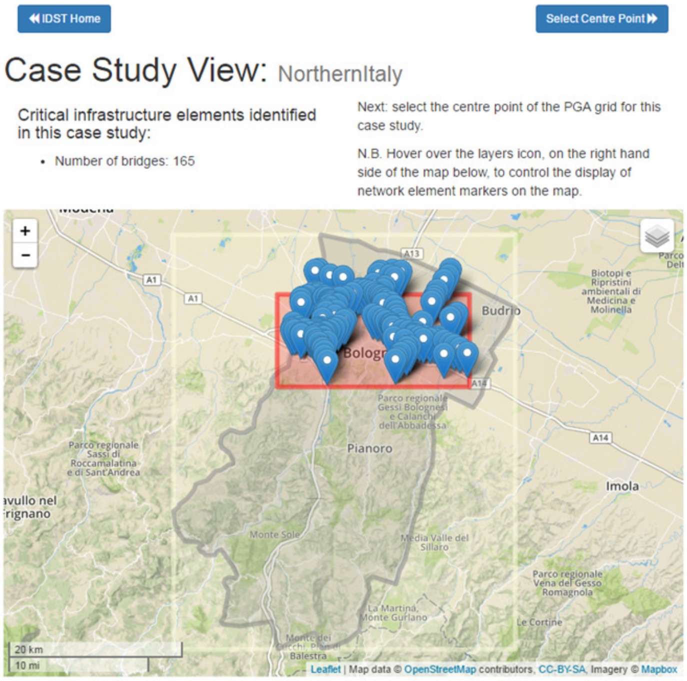


Figure 33: Viewing network elements

4.2.3.2 Inspecting individual network elements

By clicking in individual network elements the user can obtain additional information about the location, construction material, architecture details, fragility curves etc. (Figure 34Figure 34). To each of the network element (e.g. bridges, tunnels and roads) a fragility curve is assigned. These fragility curves provide the probability of exceeding a defined damage state for a given level of loading. The data used for this step is obtained from Open Street Map.

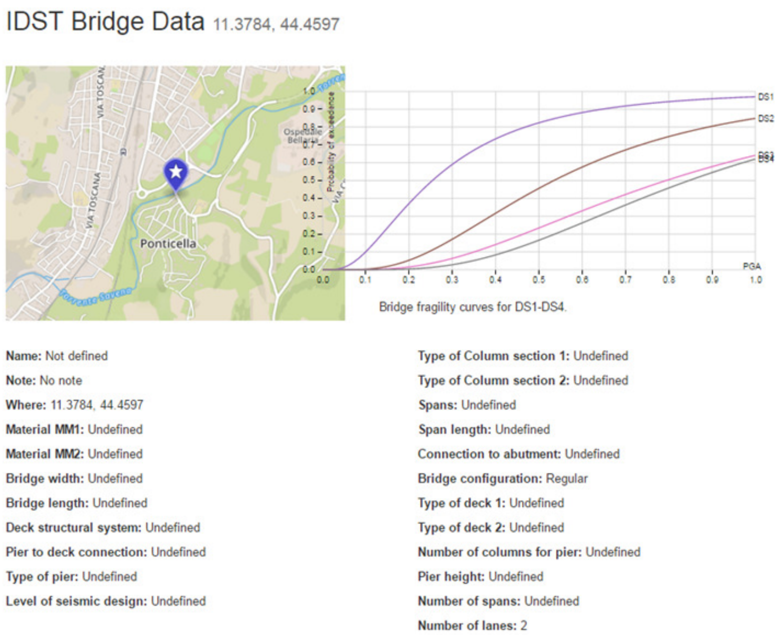


Figure 34: Inspecting individual network elements

The parameters describing for example the bridge characteristics are provided in Table 2.

Parameter	Options
Material	Concrete, masonry, steel, wood, iron, mixed
Secondary material	RC, pre-stressed RC, low/average/high strength concrete, unreinforced/reinforced masonry, lime/cement/mud mortar
Type of superstructure	Girder bridge, arch bridge, suspension bridge, slab bridge
Type of deck	Solid slab, slab with voids, box girder, modern/ancient arch bridge
Deck characteristics	Length
Deck structural system	Simply supported, continuous
Pier-to-deck connection	Monolithic, through bearings
Type of pier to superstructure connection	Single/multi column piers
Number of columns per pier	N/A
Type of pier section	Rectangular, cylindrical, oblong, wall-type, solid/hollow
Height of pier	N/A
Spans	Single, multi
Span characteristics	number, length
Type of connection to the abutments	Free, monolithic, through bearings

Table 2: Parameters of bridge characteristics

For describing tunnels with fragility curves we need to provide information as described in Table 3.

Parameter	Options
Construction Method	Bored or mined, cut-and-cover, immersed
Section Shape	Circular, rectangular, horseshoe
Depth	Surface, shallow, deep
Supporting System	Concrete, masonry, steel
Geological Conditions	Rock/alluvial
Length	-

Table 3: Tunnel parameters

The fragility curves for bridges and tunnels are available from the literature. For each individual bridge/tunnel, the median fragility curve is estimated based on different fragility models. This curve is then used for calculating the expected damage.

4.2.3.3 Finalising Hazard Model Configurations

This is an optional step that might be required to finalise the configuration of previously selected hazard models with extra parameters that were not available during the initial configuration of that hazard model. Such parameters are usually spatial boundaries or actual network objects.

The seismic hazard model (Jiménez and García-Fernández, 2016) is an example of such a hazard model as it requires the selection of a network object to be defined as the anchored point of its PGA grid. The flowing sections describe in detail how the user can identify a network object and anchor the PGA grid around that point.

4.2.3.4 Selecting a Centre Point for the Ground Motion Hazard

The final step of network scenario definition is entered by clicking on the "Select Centre Point" button (Figure 33). The purpose of this step is to overlay (anchor) the Ground Motion PGA grid on a certain geographical area. First the user picks one of the network elements on the map, then by clicking on "Make Central Point" button. As a result the Central point is anchored on the map of the specified region (Figure 35).

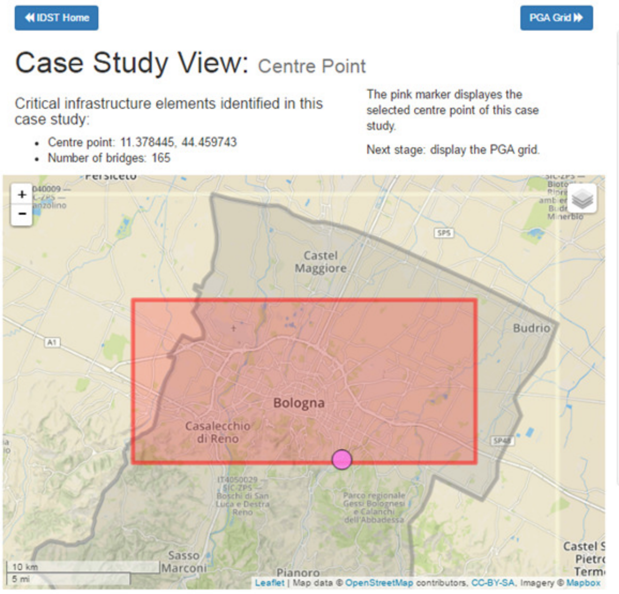


Figure 35: Selecting a Centre Point

4.2.3.5 Displaying the anchored PGA grid

After selecting the Central Point, the PGA grid can be overlaid on the map. By clicking on the PGA Grid button, a colored map (heatmap) of the region, where the colours represent the distribution of PGA data in relation to the Central point (Figure 36). In this case the brighter areas represent higher values. By clicking on the "Download PGA Grid" the user can obtain the PGA values in CSV format.

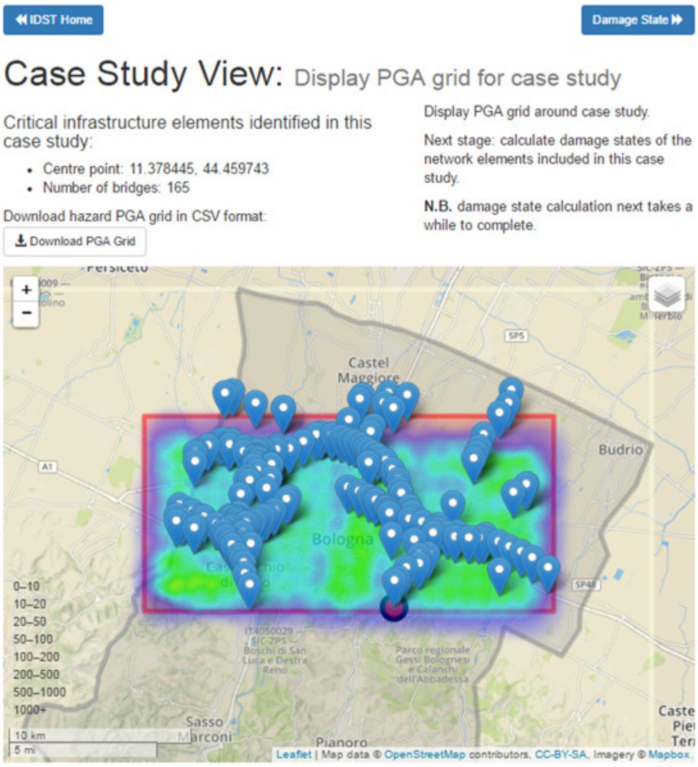


Figure 36: Displaying PGA grid

4.2.4 Calculating damage state

By clicking on the "Damage State" button on Figure 36 we calculate the predicted damage for the dataset elements (see also Figure 37). The panel provides information about the type of dataset, source, and the number of element objects identified.

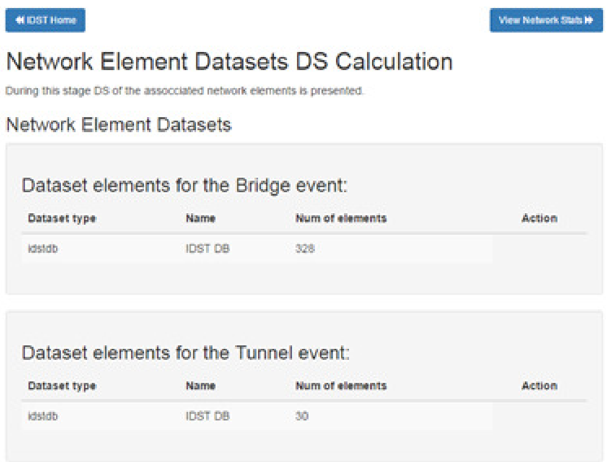


Figure 37: Damage state calculations

4.2.5 Calculating direct consequences

After the damage state calculations, the IDST can determine the direct consequences, for example repair costs associated with the network elements e.g. bridges, tunnels, road sections. Direct consequences, including repair cost and duration of repair works, are calculated based on the following table (Table 4).

Damage State Description	Repair Cost (Euro)	Restoration Duration (Days)
Bridges (per individual structure)		
No Damage	0	0
Slight/Minor	100,000	120
Moderate	750,000	120
Extensive/Major/Severe	1,000,000	150
Complete/Collapse/Failure	1,000,000	150
Tunnels (per individual structure)		
No Damage	0	0
Slight/Minor	150,000	120
Moderate	1,000,000	120
Extensive/Major/Severe	3,000,000	120
Complete/Collapse/Failure	10,000,000	365
Road Sections (per 10m road section)		
No Damage	0	0
Slight/Minor	500	0.1
Moderate	1,000	0.2
Extensive/Complete	3,500	0.3

Table 4: Direct costs

Information about the correspondence between physical damage states and repair cost/duration can be found in (D'Ayala and Gehl, 2015).

4.3 Risk Estimation

The risk for the road network caused by earthquakes and earthquake-triggered landslides is calculated, while the network repair cost, repair duration and indirect consequences can potentially be estimated. Currently they are only indicative but they can further developed for more accurate estimation in the future.

Following the above, the user can obtain the summary of the stress test study by clicking on the “Damage States Stats” button. This will spawn the damage state statistics (Figure 38).

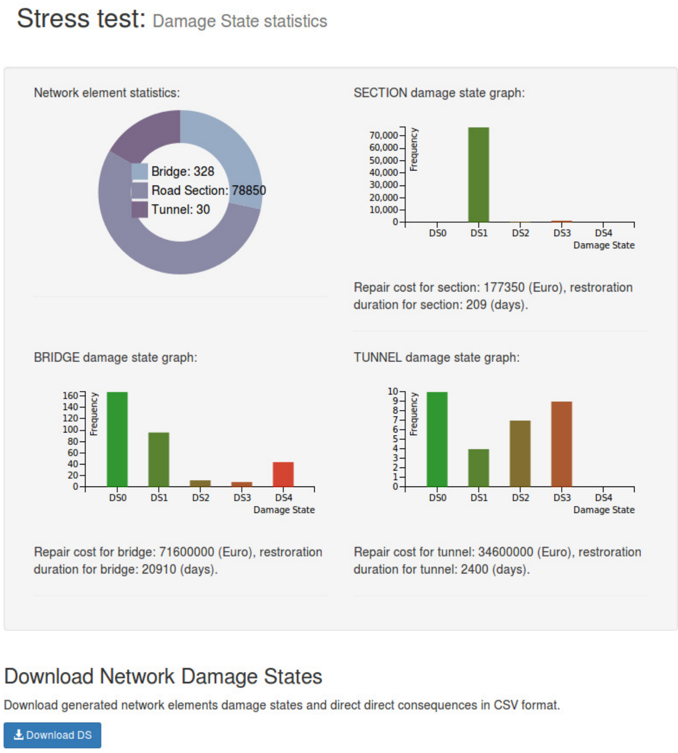


Figure 38: Damage state statistics

Figure 38 includes the following:

a) Network element statistics
b) Bridge damage state graph
c) Tunnel damage state graph
d) Road sections damage state graph

In addition, the network damage state data can be downloaded in .csv format by clicking on the "Download DS" button in the left bottom corner of the page. These are summarised in Table 5 below.

ID	Element id
Lanes	The number of lanes on the road
Expected_FCL	Functional Capacity Loss
Expected_FCLR	Functional Capacity Loss during Restoration
Expected_RT	Restoration Time
Expected_RC	Restoration Cost (indicative figure)

Table 5: Network damage state CSV output format

4.3.1 Report generation

By clicking on the “Stress Test Report” button the user can obtain a detailed account of the entire case study describing each stage of the IDST workflow and the relevant parametric values (Figure 39-Figure 41). The main categories included in the report are:

a) System Stress Tests
b) System Boundaries
c) Hazard Scenario
d) Network Elements
e) Risk Estimation

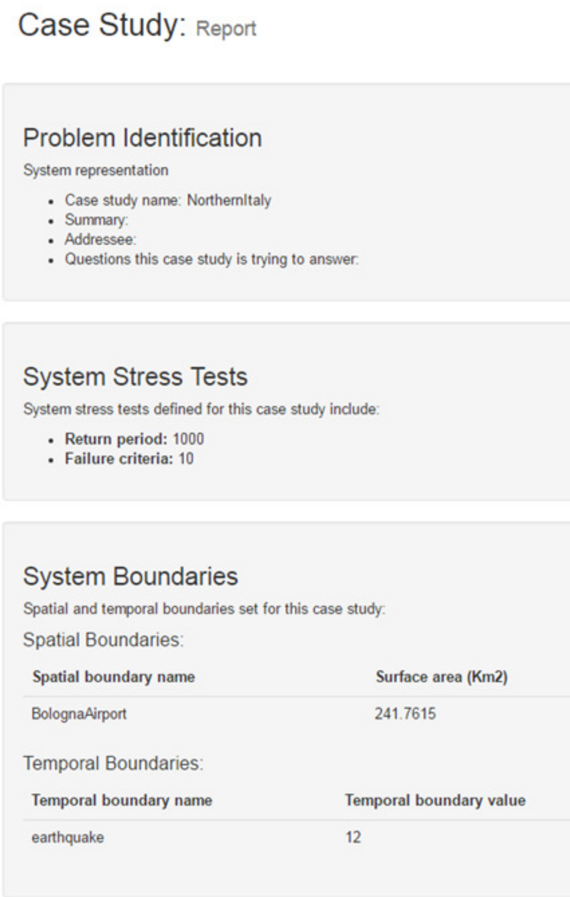


Figure 39: Stress test report – part 1

Hazard Scenario

This case study main hazard scenario is defined with:

Primary hazard source: Precipitation

Hazard central: 11.3784, i 44.4597

Identified hazard events:

Hazard event	Primary type	Binding hazard model
Ground Motion	True	CSIC PGA Seismic Model

Associated Concrete Hazard Model Setup

The PGA hazard model used in this case study is configured with the following parameters:

Seismic activity: Low activity

Ground-motion prediction model: Low attenuation

Hazard level (annual probability of ground motionn exceedance): 2500y mean Return Period

Fractile of extreme gound-motion: Extreme value at reference site exceeded by 50% of values

Random field: 6

Download hazard PGA grid in CSV format.

Download PGA Grid

Network Elements

The network infrastructure examined for this case study is the Road Network.

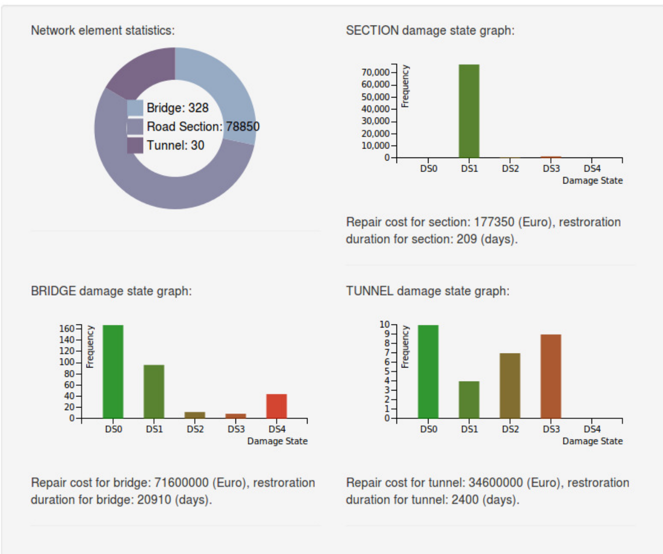
Network elements:

Network element	Associated hazard event	Binding network model
Bridge	Ground Motion	UCL bridge concrete model

Associated spatial boundaries: BolognaAirport.

Figure 40: Stress test report – part 2

Stress test: Damage State statistics



Download Network Damage States

Download generated network elements damage states and direct direct consequences in CSV format.

Download DS

Figure 41: Stress Test Report – part 3

5 CONCLUSION

In this document we have described the functionality of the IDST and provided a detailed account of software workflow. This workflow is a step-by-step process that allows stress tests to be performed for road or rail networks due to natural hazards. The workflow itself consists of four main stages, these are:

a) Stress Test Definition
b) System Representation Definition
c) Risk Estimation
d) Risk Evaluation

The output of IDST workflow is the estimated damage state of individual network elements. This information allows specialist to assess the expected damage in various hazard scenarios and consider measures that allow the level of disruption for road transport to be reduced. The user can also perform several “what if studies” that enable the investigation on the relationship between parameters, sensitivity studies and regional variations to various hazard scenarios.

REFERENCES

Clarke, J., Corbally, R., & OBrien, E. (2016). *INFRARISK Deliverable D8.2 Case Study Results.* European Commission.

D. D'Ayala, P. Gehl. (2014). *INFRARISK Deliverable 3.1 Hazard Distribution Matrix.* European Commission.

D. D'Ayala, P. Gehl. (2015). *INFRARISK Deliverable D3.2 Fragility Functions Matrix.* European Commission.

Hackl, J., Heitzler, M., Lam, J. C., Adey, B., & Hurni, L. (2016). *INFRARISK Deliverable D4.2 Final Model, Methodology and Information Exchange.* European Commission.

Jiménez, M. J., & García-Fernández, M. (2016). *Development of seismic hazard modelling for low-probability extreme ground motions. INFRARISK Technical Report.* European Commission.

van Gelder, P., & van Erp, N. (2016). *INFRARISK Deliverable D6.2 Stress Test Framework for Systems.* European Commission.

APPENDIX A: Case Study Italian Road Network

The presented case study applies the INFRARISK stress test methodology to a road network in Northern Italy. A stress test can be defined in various ways for example in terms of the hazards or consequences. Further option is to investigate whether a network element passes or fails a certain condition. We can also focus only on the most critical parts if the network and investigate the measures that allow to minimise the damage caused by an earthquake. For the critical network elements we consider the bridges, tunnels and road section that are along the most frequently used roads. The scenarios considered in this case study describe the earthquake event by using the following components:

a) SHARE Active seismic activity model
b) low attenuation ground motion
c) three hazard levels and three fractile values
d) Each combination of parameters corresponded to a GM-field that represented a deterministic 'scenario'.

The Northern Italy case study is part of the IDST portal and it is used as a tutorial. We use predefined data sets that are relevant for the selected region. We start the case study by clicking on the "Example Case Study: Northern Italy Road Network" button. This takes us to the map of the selected region in Italy (Figure 42).

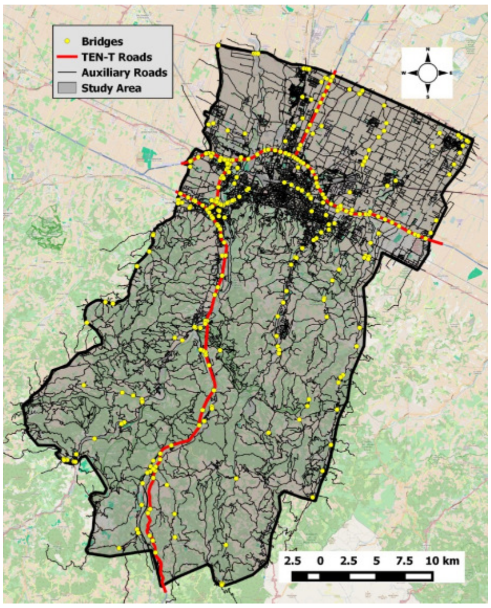


Figure 42: Selected region in Northern Italy

The road network for this region consists of 3410 km of roads that are classified as motorways, trunk roads, primary roads, secondary roads, tertiary roads, and unclassified roads. The network is located along the Scandinavian-Mediterranean corridor of the European TEN-T network which is one of the main European traffic corridors. The road network covers an area of 990km^2 in the vicinity of Bologna.

The following step is to create a new stress test as described in Section 4.1. After filling in the details we click on "Save and proceed" button.

The next step is to define system boundaries for this example, we use a predefined area around Bologna by selecting the "Northern Italy, case study borders" under "Pre-defined boundaries" section (Figure 43).

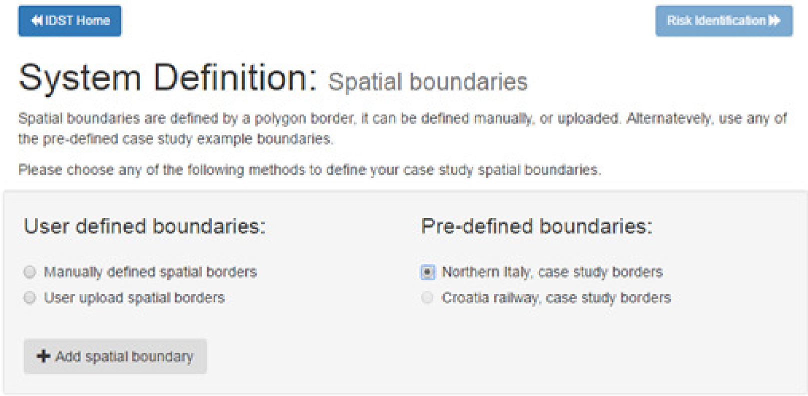


Figure 43: Selecting a pre-defined boundary

After clicking on "Add spatial boundary" in the dropdown menu we select the "Northern Italy" option. After defining the Spatial and boundaries we obtain the page in Figure 44.

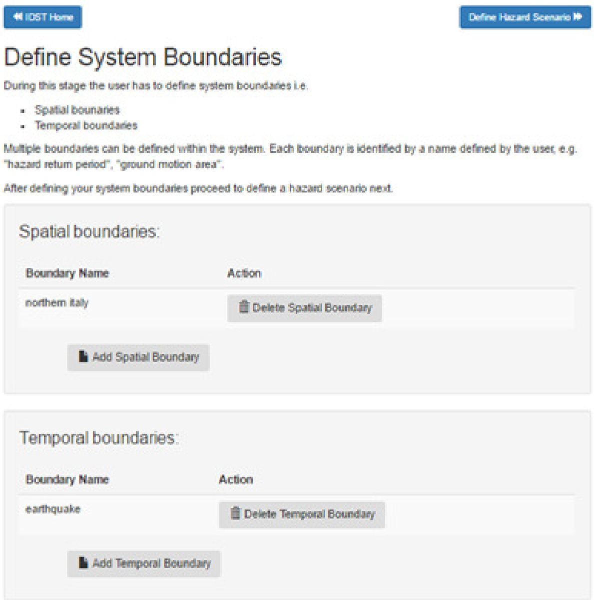


Figure 44: Defining system boundaries

The selected area is a seismically active region that is moderately susceptible to landslides. Therefore, earthquakes and earthquake-triggered landslides are the hazards considered in this case study. The sequence of steps required for this case study is similar to that described in Section 6. However, in this case we use predefined data specific for Northern Italy. For "Defining Hazard Scenario" we select hazard events that originate from the hazard source i.e. earthquake. In this case we select "Ground Motion" as the primary event by ticking the "Primary" option (Figure 45). By clicking on the "Store Hazard Event" we complete the definition of the primary event.

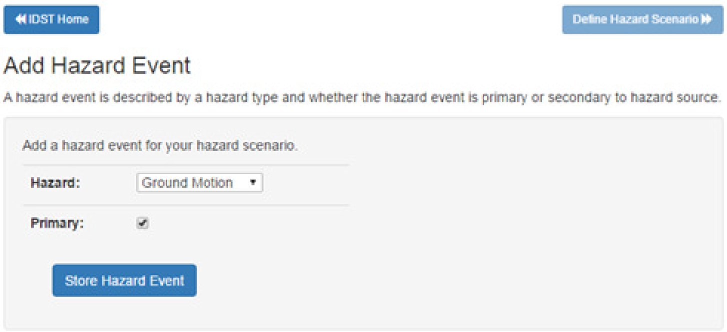


Figure 45: Defining primary hazard event

In the following we define further hazard events that originate from the primary hazard source, for example landslide (Figure 46). As a result we have two events: the main is the ground motion and the cascading event is the landslide.

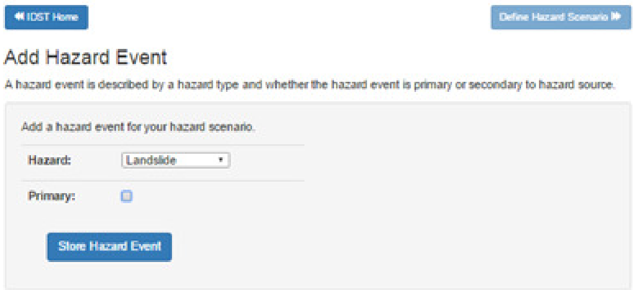


Figure 46: Defining cascading events

Next we need to bind the primary hazard event to a model. For the earthquake we use the PGA hazard model (Figure 47).

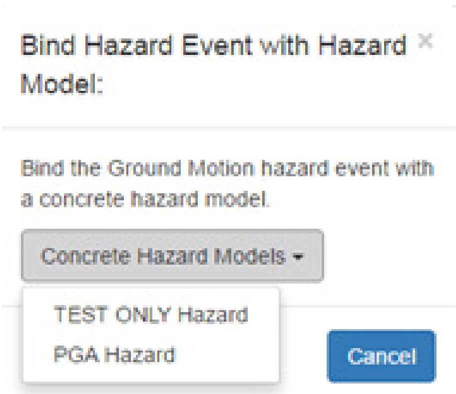


Figure 47: Selecting hazard models

In the following step we configure the hazard model by clicking on “Setup PGA” (Figure 48).

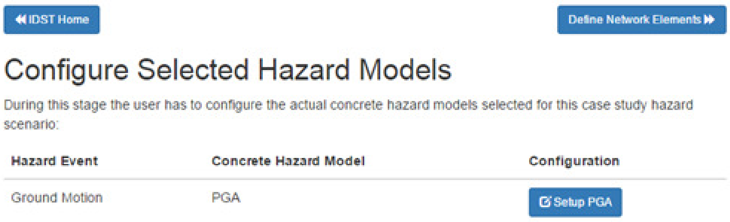


Figure 48: Configuring a hazard model

The “Setup PGA” takes us back to the configuration of seismic activity model that contains information about “Ground-motion prediction model”, “Hazard level” and “Fractile of extreme ground-motion” (Figure 49).

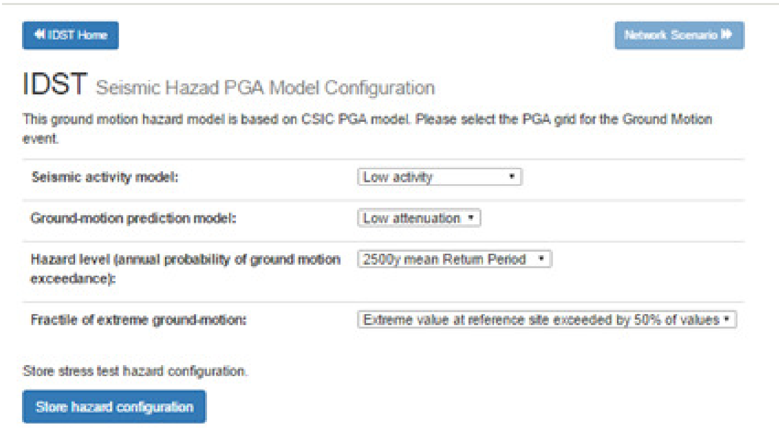


Figure 49: Configuring PGA model

After clicking on “Store hazard configuration” we can move to the specification of “Network Scenario”. This involves defining the network elements such as bridges, tunnels and roads for the selected region. Under the category “Network Infrastructure” we select the “Road Network” option and start adding network events by clicking on the “Add Network Events” button (Figure 50).

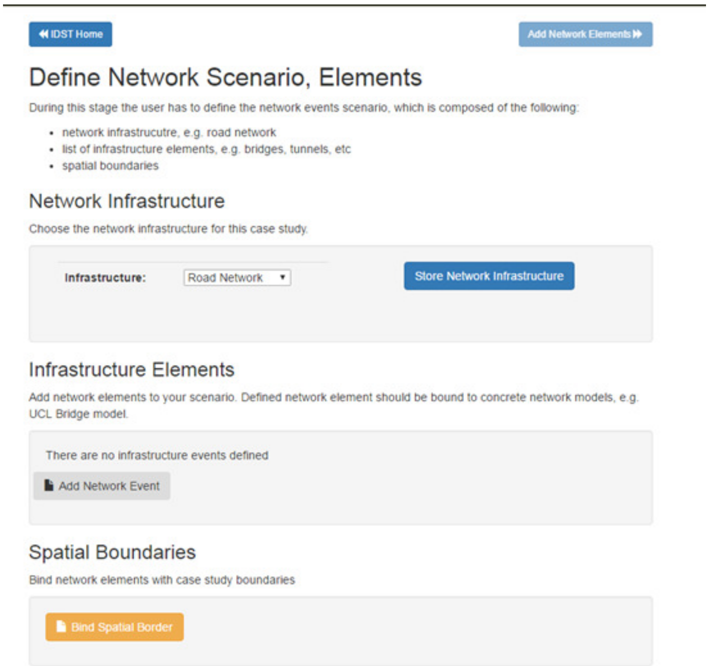


Figure 50: Adding network events

In this step for each network element type we assign a hazard event. For example to the “Bridge” (Figure 51) and “Tunnel” (Figure 52) elements we assign a “Ground Motion” hazard event. For a “Road Section”, we assign a “Landslide” event.

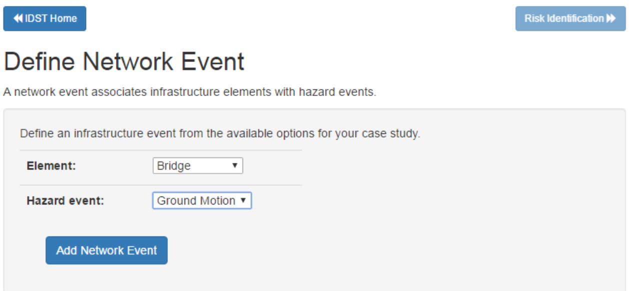


Figure 51: Assigning “Ground Motion” event to the “Bridge” element

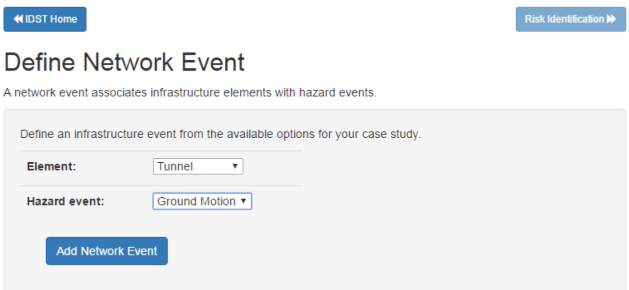


Figure 52: Assigning “Ground Motion” event to the “Tunnel” element

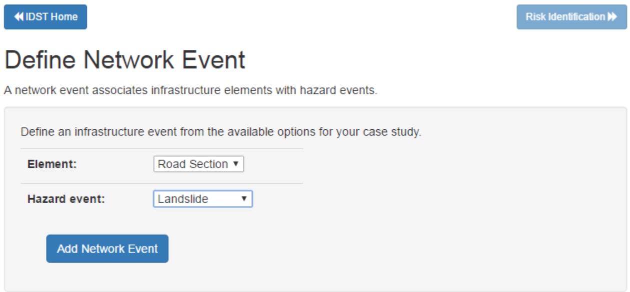


Figure 53: Assigning “Landslide” event to the “Road Section” element

We complete this step by clicking on the “Store Network Infrastructure” button. Each of these network element types and hazard events need to be bound to a model in order to calculate the damage state. By clicking on the orange button “Bind to model” we can select a suitable model for the given network type element and hazard event (Figure 54).

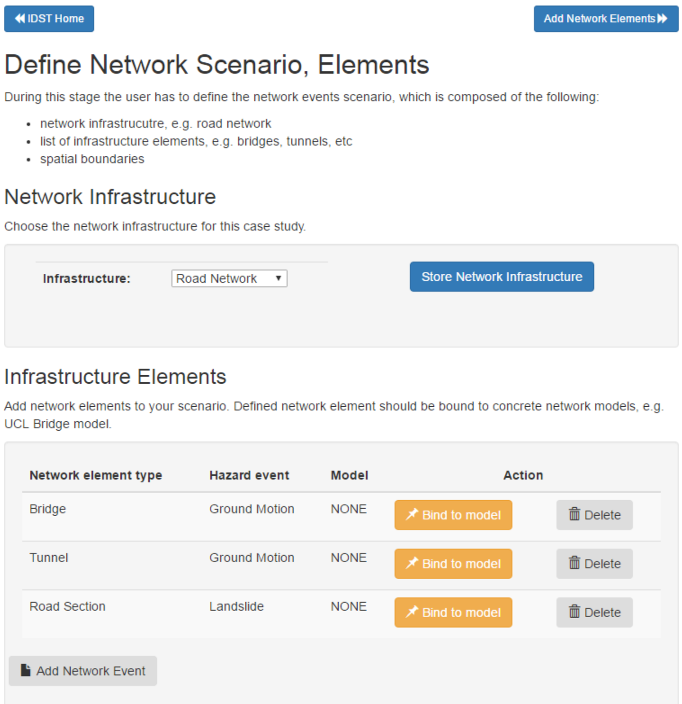


Figure 54: Binding network type elements and hazard events to a model

For the “Bridge” we select the “Bridge model”, for “Tunnel” the “Tunnel model” and for “Road” the “Road model” models (Figure 55). On completion of these steps the “Assign Model” buttons turn green.

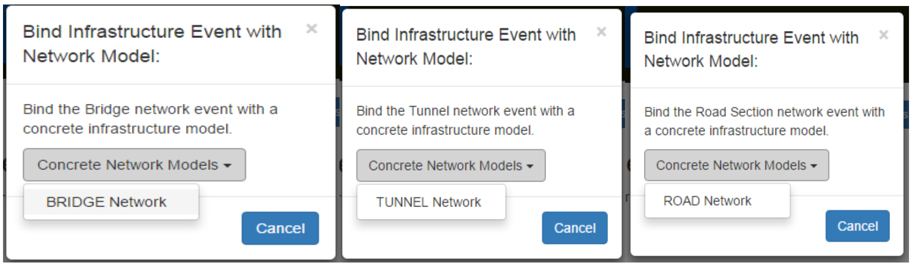


Figure 55: Selecting Network Models

The next step for defining the network scenario is adding the area of interest by clicking on the "Change Spatial Border" button (Figure 56).

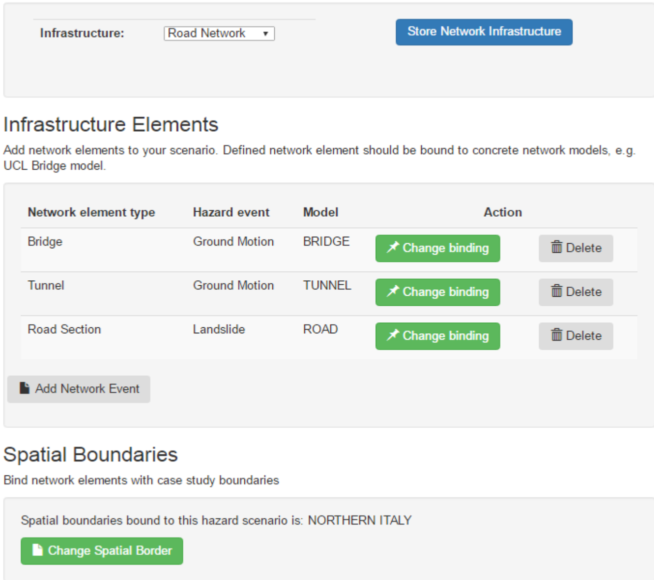


Figure 56: Define spatial border

In the following we select a region "Northern Italy" in the dropdown menu and bind it to the network scenario by clicking on the "Bind Spatial Boundaries" button (Figure 57).

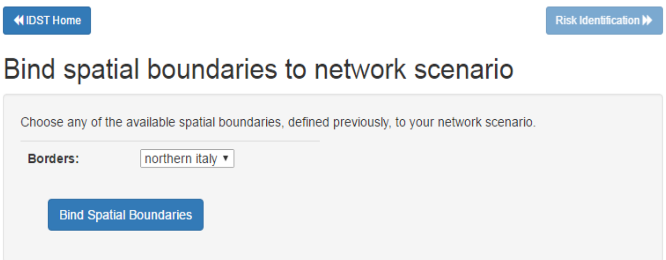


Figure 57: Binding spatial boundaries

The following step is adding Network Element Datasets to Bridge, Tunnel and Road Section events (Figure 58). By clicking on the "Add Network Dataset" under each event we can select the relevant dataset.

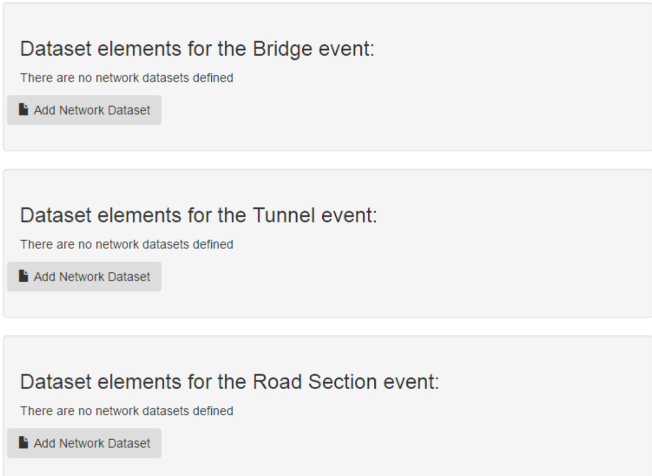


Figure 58: Adding dataset elements

Data for the Northern Italy is already in the database, we select the option "Use elements found in IDST database" and click on "+ Add network elements" button (Figure 59).

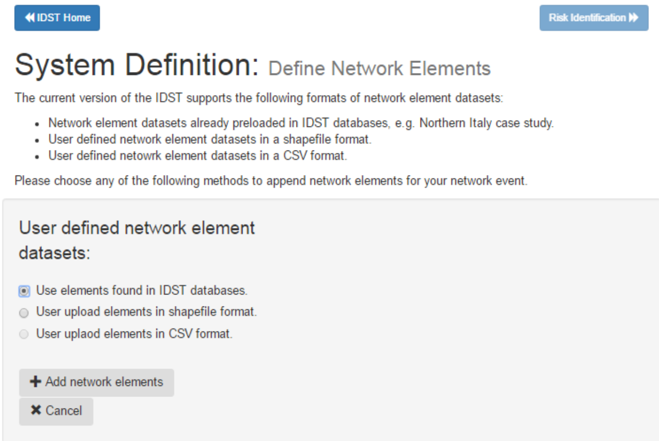


Figure 59: Defining network elements

We repeat the step for each network event and as a result we get a summary page (Figure 60).

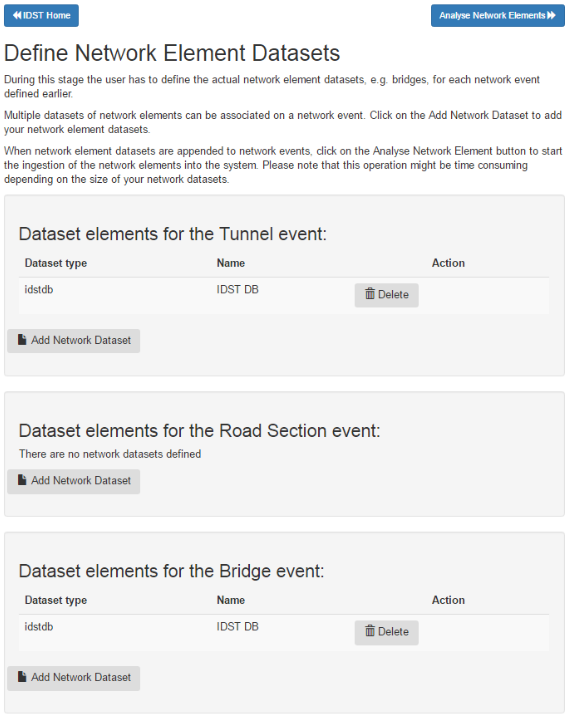


Figure 60: Summary page on binding Network Element Datasets to Hazard Events

The next step is to “Analyse Network Elements”, this involves uploading data, filtering out the network elements and producing the fragility data for each element (Figure 61). The damage state calculations might take a while depending on the number of elements and size of datasets.

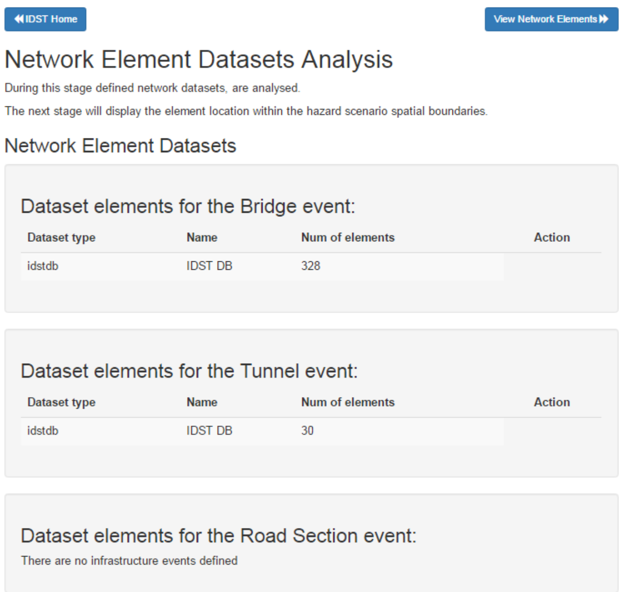


Figure 61: Analysing network elements

After the analysis we the user can visualise the network elements by clicking on the “View Network Elements on the map of the selected region (Figure 62).

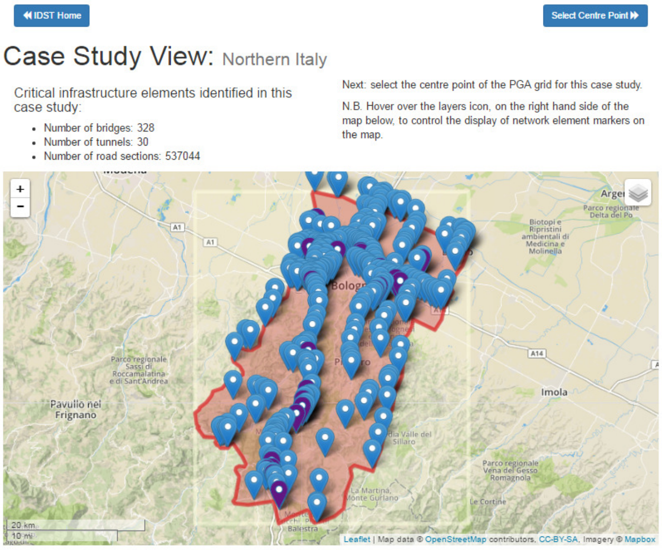


Figure 62: Visualising network elements on the map

By clicking on the “Select Centre Point” takes us back to the PGA setup. By selecting an element on the map we can see the corresponding fragility curve (Figure 63). To each network element (bridges, tunnels and road sections) a fragility curve is assigned that allows the structural vulnerability as described in INFRARISK Deliverable D3.2 (D'Ayala and Gehl, 2015) to be classified. Fragility curves provide the probability of exceeding a defined damage state for a given level of loading.

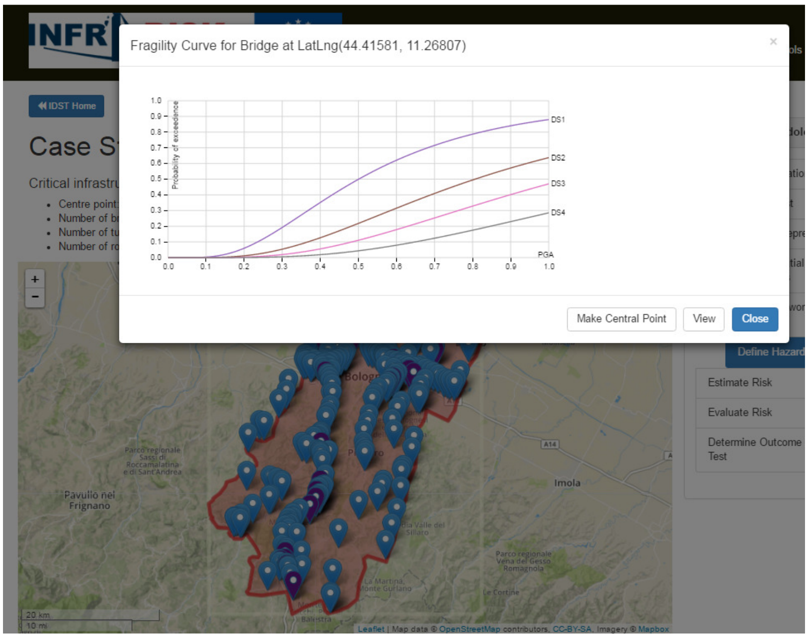


Figure 63: Selecting a centre point

By clicking on the “Make Central Point” button we line up the PGA grid with the centre point (Figure 64).

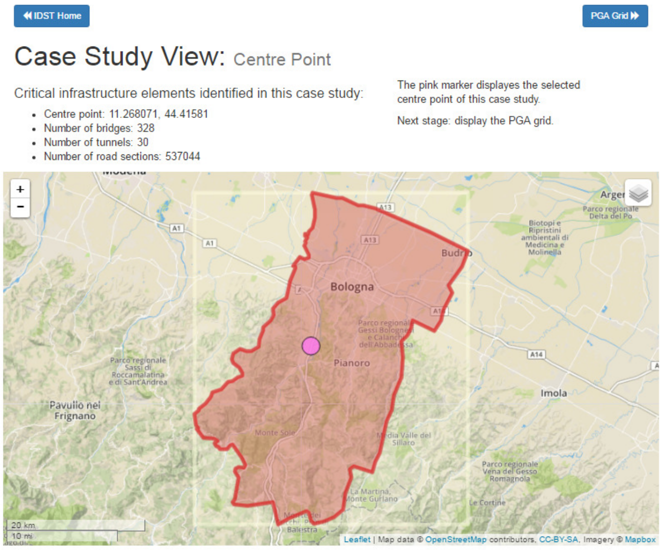


Figure 64: Aligning centre point with the PGA map

By clicking on the “PGA Grid” button (top right corner) we obtain the PGA values on the map (Figure 65).

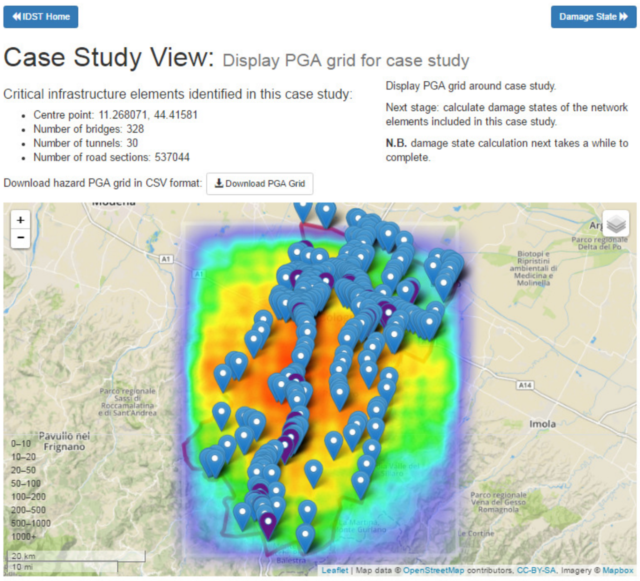


Figure 65: Visualising PGA values

At this point we are ready to perform the “Damage State” calculations (Figure 66).

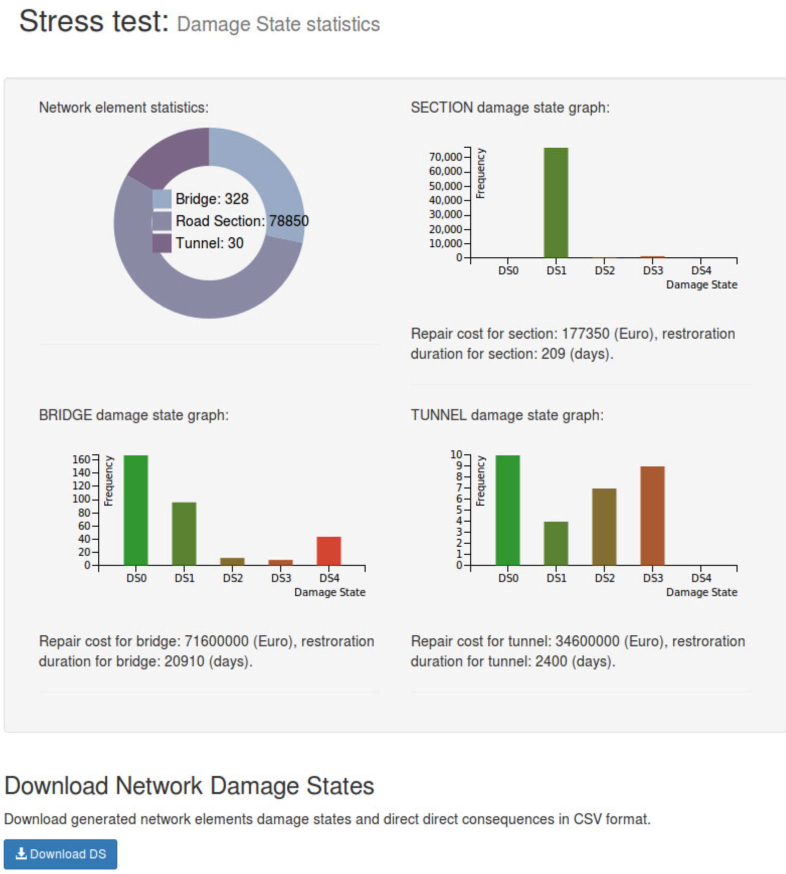


Figure 66: Damage state calculations

The results of damaged state calculations can be download in CSV format for further risk assessment and by clicking on the "Case Study Report" we generate the summary report of the case study (Figure 67).

Stress Test Report: Northern Italy 2016-09-30 12:30:43.333948

Problem Identification

System representation

- Stress test name: Northern Italy 2016-09-30 12:30:43.333948
- Summary: Predefined stress test for the Northern Italy case study. Created: 2016-09-30 User name: pmelas@gmail.com

System Boundaries

Assigned spatial boundaries for this case study:

Spatial Boundaries:

Spatial boundary name	Surface area (Km2)
Northern Italy	989.3063

Hazard Scenario

This case study main hazard scenario is defined as:

Primary hazard source: Earthquake

Hazard central: 11.3031, i 44.3982

Identified hazard event list:

Hazard event	Primary type	Assigned hazard model
Ground Motion	True	CSIC PGA Seismic Model
Landslide	False	

Associated Hazard Model Configuration

The hazard model used in this case study is configured with the following parameters:

Seismic activity: *High activity*

Ground-motion prediction model: *High attenuation*

Hazard level (annual probability of ground motionn exceedance): *10000 years*

Fractile of extreme gound-motion: *0.90*

Random field number: *3*

Download hazard PGA grid in CSV format.

Download PGA Grid

Network Characteristics

The network infrastructure examined for this case study is the Road Network.

Network events:

Network event	Associated hazard event	Assigned network model
Road Section	Landslide	ROD road section concrete model
Bridge	Ground Motion	UCL bridge concrete model
Tunnel	Ground Motion	UCL tunnel concrete model

Associated spatial boundaries: northern italy.

Selected datasets:

Network event	Dataset type	Dataset name	Size
Road Section	IDST Case Study Database	IDST DB	78850
Bridge	IDST Case Study Database	IDST DB	328
Tunnel	IDST Case Study Database	IDST DB	30

Figure 67: Northern Italy stress test summary report