Application of a Training Project in Turkey on Preventive Maintenance of Water Utility Networks Against Earthquakes

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SUMMARY:
As part of Leonardo da Vinci Program (LdV), a training project was completed recently on preventive maintenance (PM) of water utility networks against natural hazards. Seven organizations from four countries participated in this LdV-Development of Innovation type project. The objective of the project is to develop an innovative web-based platform and courseware for Vocational Education and Training (VET) on modern practices. With the products of this project, improved maintenance, increased reliability and decreased disruption of service are envisaged. The courses are available in four multi-lingual form at the project web site (http://www.teg.cti.gr/pm4wat). The project also produced a practical product which involves software that integrates Geographical Information Systems (GIS), Reliability Analysis (RA) and Database Query (DQ) to determine how ageing and natural hazards affect the reliability of the network under different environmental conditions. The new system was adapted from a prototype that was developed in an earlier FP5 project. As a pilot study, the simulation program was applied to part of the Denizli water supply system which is a medium sized urban water distribution utility and Denizli Water Works personnel were trained.

Keywords: Water distribution system, Reliability, Earthquake damage, PM4WAT Project, Training Simulator

1. INTRODUCTION

Most public water utilities use a regimen of “maintenance only when a breakdown occurs”. The logic behind Preventive Maintenance (PM) is that it costs far less to regularly schedule downtime and maintenance than it does to operate the network until breakdown at which repair or replacement is imperative. The consequences of “maintenance on the run” are unreliable service, customer dissatisfaction, and significant water losses of valuable resources due to leakage or pipe rupture.

The reliability of an existing urban water distribution network can, however, be improved significantly by adopting a systematic proactive strategy for replacement of worn components. This is the essence of PM, i.e. a schedule of planned maintenance actions aimed at prevention of major breakdowns and failures using advanced methods of statistical and risk analysis. The primary goal of PM is thus to prevent the failure of components of the network before they actually occur. To take full advantage of this, the utilities must have an accurate topological image of the network, the age and type of materials used in its various branches and past maintenance records.

In this paper, first of all the project entitled “Preventive Maintenance for Water Utility Networks” (PM4WAT) is introduced. The aims of the project, target groups and products are explained. Then, aging of pipes and effects of natural disasters on the pipes especially earthquakes are investigated. Finally, the training simulator which is one of the products of the PM4WAT Project is demonstrated.

2. PM4WAT PROJECT

PM4WAT is an European project under the Leonardo da Vinci program. The primary objective of the project was to develop an e-learning platform and courseware on Preventive Maintenance (PM) of water distribution networks for vocational training (VET) of water utility operatives and to instruct them how to increase the reliability of the network, decrease disruption of service and save valuable water resources. The project web site is http://www.teg.cti.gr/pm4wat (Figure 1).

The consortium is composed of seven organizations from four European countries, all Mediterranean that face similar problems with water resources and distribution. Some of these countries have old and non-homogeneous networks that are subject to ageing, massive water losses, seismic activity and other natural hazards. The consortium includes universities and research institutions, an ICT organization, VET providers and urban utility networks, selected with a view to their knowledge and experience. Their knowledge and experience is complementary and essential to the project. The partners have also extensive experience in national and transnational cooperation and have participated in numerous European research projects and Lifelong Learning projects. The partners provide the scientific knowledge, validation, deployment and integration of the results of the project. The distribution of tasks to the various partners in the Consortium, with their diverse knowledge and expertise, provides a significant European added value to the project.

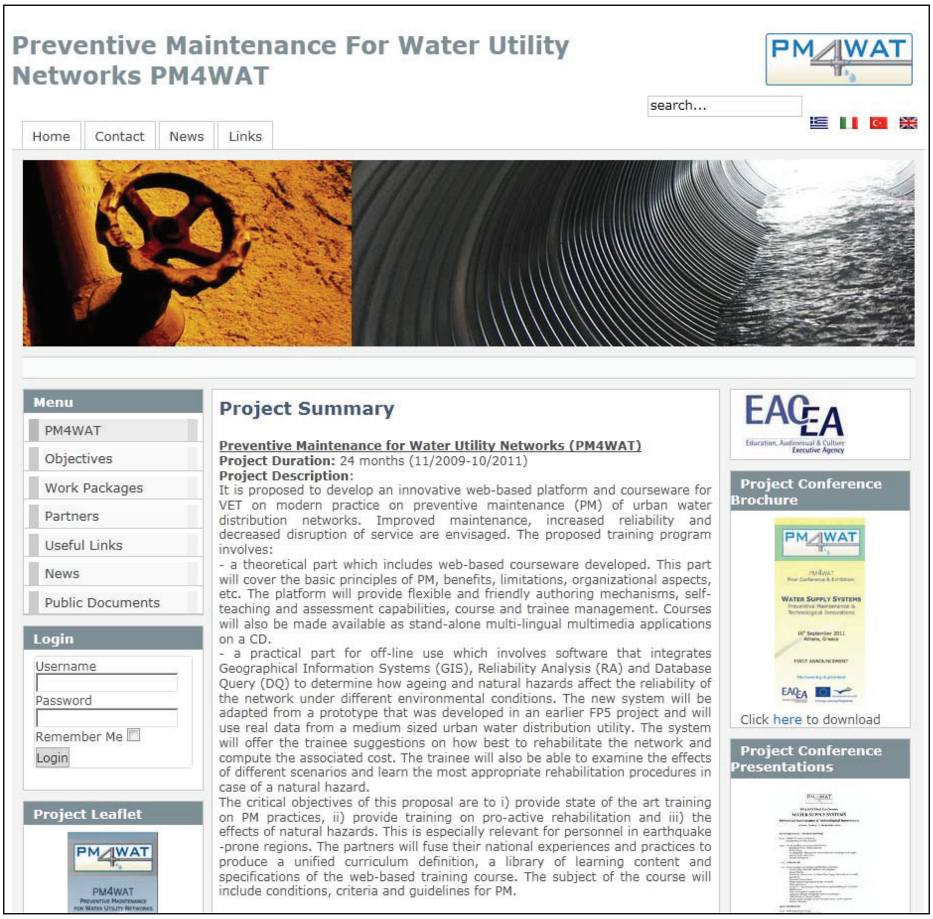

Figure 1. Web page of the PM4WAT project

The project results should be useful to urban water utility maintenance personnel, especially in earthquake-prone regions. The training simulator (TS) constitutes the pivotal product developed within the scope of the practical part of the project, while the courseware developed on the web-based platform is the theoretical part. The shell of the e-learning platform, following the specifications and design steps that were completed at earlier stages of the project was implemented in MOODLE allowing for ready seeding of the courseware. The web-based courseware and the training simulator constitute the two main products of the project. The end products of the project are expected to be universally applicable (Tsakiris et al., 2011). National experiences and practices have been amassed to generate a unified curriculum and a library of learning content. In particular the project objectives are:

- to transfer state of the art on preventive maintenance methodologies and practices from domain experts from the participating countries to personnel working in urban water utilities,
- to develop a training simulation (TS) platform that will advise trainees to estimate the reliability of a network and to examine various „what-if" scenarios,
- to provide training on pro-active rehabilitation and on the effects of natural hazards and
- to develop courseware for web-based and off-line training on preventive maintenance of urban utility networks, made available in the four languages of the participating countries (English, Greek, Italian and Turkish).

3. AGING OF PIPES

Buried pipes of a water distribution system are worn in the length of time because of the temperature, soil moisture, corrosion and other aging effects. Aging of pipes in a water distribution system may have three main results. First, aging of pipe material causes a decrease in the strength of pipe. Then pipe breaks are increased at the high pressure areas of the system. Second, aging of a pipe increases the friction coefficient of the pipe so the energy loss in that pipe rises. Then more pumping cost occurs and sometimes a gravity working system needs pumping. Finally, aging of pipes affect the water quality in the system and may cause discolored water. Aging of a pipe is unavoidable but this process may be delayed by some precautions. Cathodic protection for steel pipes, lining and coating for steel and ductile iron pipes are some anti-aging techniques.

In the design phase of a water distribution system, analyzing the temperature changes in the area, pressure values of the system, chemical components of the soil and ground water helps for the selection of long life pipe material and suitable burial depth of pipes.

4. EARTHQUAKE EFFECTS ON WATER SUPPLY SYSTEMS

Earthquake damage to buried pipelines can be attributed to transient ground deformation (TGD) or to permanent ground deformation (PGD) or both. TGD occurs as a result of seismic waves and often stated as wave propagation or ground shaking effect. PGD occurs as a result of surface faulting, liquefaction, landslides, and differential settlement from consolidation of cohesionless soil. The effect of earthquake loading on pipelines can be expressed in terms of axial and flexural deformations. At locations where the pipeline is relatively weak because of corrosion, etc., breaks and/or cracks may be observed on the pipelines. If deformations are high the damages can be in the form of separations of joints, wrinkling, buckling and tearing of pipelines.

There exist many studies which evaluate the effect of past earthquakes on water supply systems by using GIS. A comprehensive study can be found in O'Rourke and Toprak (1997) and Toprak (1998) which assess the Los Angeles water supply damage caused by the 1994 Northridge earthquake. There also exist many studies which predict the damage to water supply system of an urban area for the future earthquakes by using GIS. Such an example can be found in Toprak and Taskin (2007) and Toprak et al. (2009). They used 8 different scenarios caused by 2 different faults. Toprak et al. (2010) is another study that investigates the earthquake performance of Denizli water supply system but according to the Earthquake Resistant Design Codes in Japan (JSCE, 2000) and international standards such as Earthquake-and-Subsidence-Resistant Design of Ductile Iron Pipelines (ISO, 2006).

5. TRAINING SIMULATOR

The Training Simulator of the PM4WAT project is based on a Fifth Framework project SEISLINES (Age-Variant Seismic Structural Reliability of Existing Underground Water Pipelines) which was performed between 2000 and 2002. The product of SEISLINE was re-designed and adapted for the purposes of this project. The training simulator uses real geographical information on the topology of the water utility networks as well as real data on the properties of the elements in the branches of the network.

5.1. Technical Description of the Training Simulator

The system architecture was designed with a view to integration of all modules into a single working system (Stathaki, 2010). The decision support system (DSS) and the interactions of the DSS modules are given in the Figure 2. The kernel of the SEISLINES system is the DSS which includes:

- The *Seismic Structural Reliability module* for assessing the seismic structural reliability of deteriorating pipelines. The function of the reliability module is to estimate the performance of a specific branch of the network of underground water supply pipes. The network is restricted to predefined topologies, and performance is assessed by computing, either the probability of failure before a specific time or a complete reliability curve (probability of failure vs age). The analytical solution uses reliability analysis of a non-linear system subjected to stochastic loading and structural ageing (corrosion) and computation employs Monte Carlo techniques (Becker et al., 2002).
- The *Rehabilitation Lifecycle Cost* module for assessing the lifecycle costs of the various rehabilitation and replacement options for deteriorating water pipes with a view to increase their seismic resistance. The function of this Module is to estimate the Net Present Value (NPV) of the different lifecycle costs of rehabilitation and replacement options by taking into account not only the initial investment costs of the network but also the costs for any rehabilitation intervention required within the defined time horizon as well as the salvage value of the pipeline. According to the methodology followed requires that the potential alternative rehabilitation technologies be identified first. Once these technologies are identified, estimation of their costs follows readily.
- The *Coordinating system* that coordinates all the modules (agents) of the system and acts as an intelligent intermediary between the user and the system. The Coordinating System is responsible for the co-ordination and seamless co-operation of the various system modules. The end user accesses the system via a Graphical User Interface (GUI) which allows the end user to monitor the structural condition of the network. Invocation of the other modules is performed by the Query Execution component of the Coordinating System. The fact that these two functions are necessarily interleaved is shown by the two-way communication between them.
- The *Data Manager and Database.* All data used for the SEISLINES system is stored in the database. This refers not only to all essential input data but also to all intermediate and any output data that needs to be stored. In particular, this implies that no variables are stored as “constants” inside the programs implementing any of the modules and no “flat files” are used to store the output of experimental run. Thus, the database is the major repository for the following data:
    - Preliminary input data: This category covers geographic data (e.g. the positions of the nodes and links in geographical co-ordinates) as well as descriptive data (e.g. material, age, diameter of a link, material of the links and nodes, etc.) of the network. This data is made available from basic data sources and used as input to the Algorithmic Modules.
    - Intermediate input/output data: This category covers the intermediate results of the modules and made available for further processing. This may be particularly helpful if we need to analyse the behaviour of a module in stages, examining each individual calculation step.
    - Final output data: This category includes final results following heavy computation and these are stored for later use.

- Scenario input/output data: Experimental copies of the database are used for the purposes of "what-if" analysis (scenario-based experimentation).

5.2. Specifications and Design of the PM4WAT Training Simulator

The original SEISLINES system went several revisions to make it easier to use and serve as a training simulator in the PM4WAT project. The system was developed as a prototype which was optimized and upgraded in this project. However, there are several limitations imposed by the original system that confine the development of the simulator. 1) The main modules of the system, i.e. reliability and rehabilitation, are considered as black boxes because only the executable code is available as dlls. It is not intended to change the source code here as this is not the purpose of the current development. Since these modules have access to the database for retrieval of inputs and storage of outputs (results), this imposes strict requirements on the database structure which has to remain the same. 2) Another limitation is imposed by the GIS tool used in the original system, which is embedded in the integrated system, i.e. MapObjects (Version 2.1) from ESRI. MapObjects is no longer upgraded by ESRI and can be used only with Visual Studio 6 on MS Windows XP. The simulator is thus not supported by the newer versions of MS operating platforms, e.g. Vista or Windows 7. Also the database format requires the form of Microsoft Access 2000 or 2003 (Stathaki, 2010).

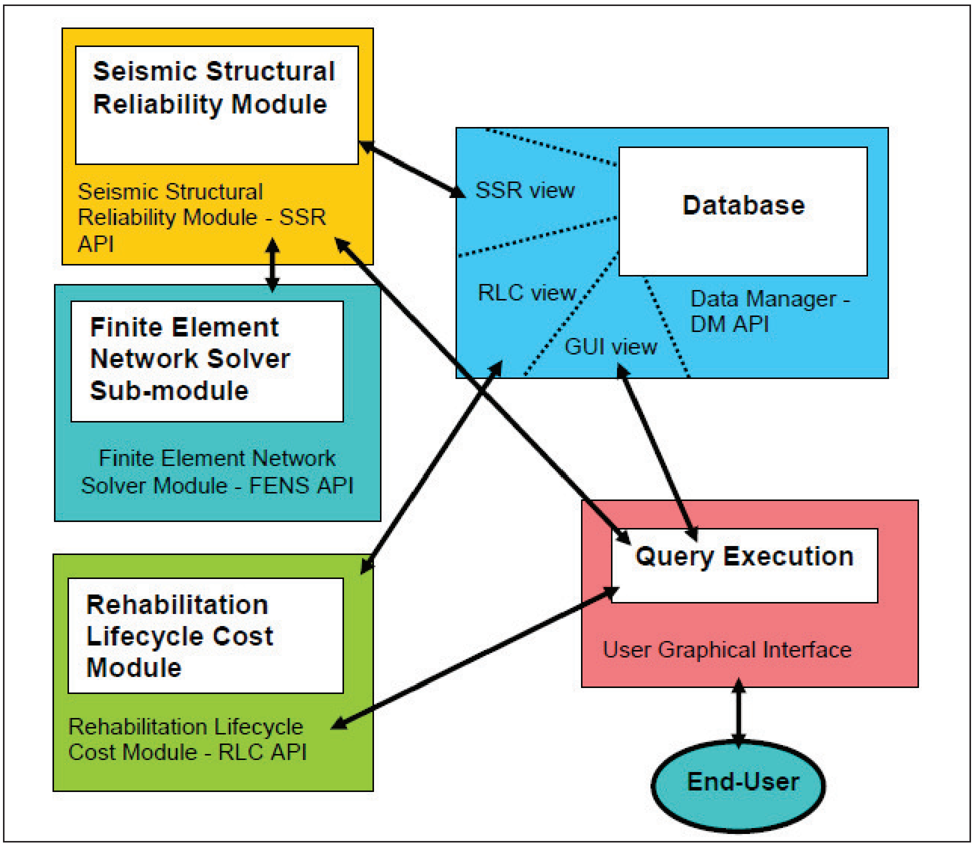

Figure 2. Interactions of the DSS modules

5.3. Loads of Pipes

There are four intermittent (surge pressure, frost, seismic and thermal) and four permanent (earth, water, traffic and working pressure) loads are considered by the simulator (Camarinopoulos et al., 2001).

5.3.1. Surge Pressure

Surge pressure refers to the extremes of the water pressure in the trunk main. These can occur during maintenance when valves open and close etc. From the above it gets obvious that surge pressure is an intermittent time-variable. Like every other intermittent load, in order to be determined, the distribution type of its magnitude and its arrival process have to be defined.

5.3.2. Frost Load

Frost load is a load acting on the trunk main, when mean daily air temperature remains below $0^{o}C$ for at least three days. It is assumed that it follows a Poisson arrival schedule and that its magnitude is normally distributed. This means that frost load is an intermittent time-variable load. If temperature was bellow zero for more than three days, a frost multiplier of 1.65 is applied to the earth load and evaluates their mean value, variance and duration. The user can supply the occurrence rate.

5.3.3. Seismic Load

Seismic load is intermittent load acting on a main during an earthquake. Its arrival times correspond to a Poisson process. The magnitude of Effective Peak Acceleration (EPA) A, can be modeled by a Type II (complementary) distribution of largest values

$$G_A(a) = 1 - \exp\left[-\left(\frac{a}{u}\right)^{-k}\right] \qquad (1)$$

In which $G_A(a) = P[A > a] = 1 - F_A(a)$, and u and k are distribution parameters.

5.3.4. Thermal Stress

Water pipes will contract or expand with a fall or rise of temperature, respectively. If contraction or expansion are restricted because of joints, service pipes or other structures adjacent to the pipe, thermal stresses will be induced in the material. If the temperature rises, the pipe tends to expand; However, the constraints prevent it from expanding, resulting in compressive stresses in the wall of the pipe. Similarly, when temperature decreases, tensile stresses will be induced. These are painful for AC pipes that have a high compressive strength, but cannot withstand high tensile stresses. Furthermore, rising temperature, and resulting compressive stresses may cause buckling of thin walled steel pipes and plastic pipes.

5.3.5. Earth Load

Earth load is the load acting on the main due to the earth above it. The mean value for this load will be given by the corresponding deterministic model. Uncertainty about the exact depth from the earth's surface to the top of the main and the actual soil density lead to small variations about its mean value.

5.3.6. Water Load

Water load is the load caused by the weight of the water carried by the trunk main. The AWWA standards do not take water load into account. In this study, weight of water is taken into account in order to estimate ring bending stresses in cases of pipes of size DN600 or greater. However, weight of water is always taken into account in order to estimate longitudinal bending stresses due to beam conditions.

5.3.7. Traffic Load

Truck loads exerted on a pipe vary with the depth of cover and type of pavement over the pipe. They are estimated by equations which apply reduction factors to the total wheel load (weight plus impact). There are greater reduction factors for rigid pavements than for flexible pavements. It should be noted, however, that while a greater depth of cover reduces the truck loads, this reduction may be offset by the increase in earth loads.

5.3.8. Working Pressure

Working or internal pressure produces a hoop stress in the wall of the trunk main

5.4. Training Simulator with GIS

The original software SEISLINES has been thoroughly revised with the view to simplify the sequence of steps necessary to view the water network, select the critical points at which the reliability will be estimated and finally the display of the results. The objective has been to transform the software package to a user-friendly wizard, which would guide the user and provide functionality, additional features such as exporting the archived reliability and rehabilitation results in Excel or text files for further investigation and analysis (Figures 3 and 4). Additionally, the software was modified by adding validation procedures and error traps to avoid erroneous data input that could obstruct the execution. The main elements of a water pipe network required for the training simulator are the links and nodes. A link is the segment of a pipe between two nodes. Links and nodes are defined by geographical and alphanumeric data. The first have the ESRI shapefile (shp) format and the second are stored in an MS Access database (Access 2000 or 2003).

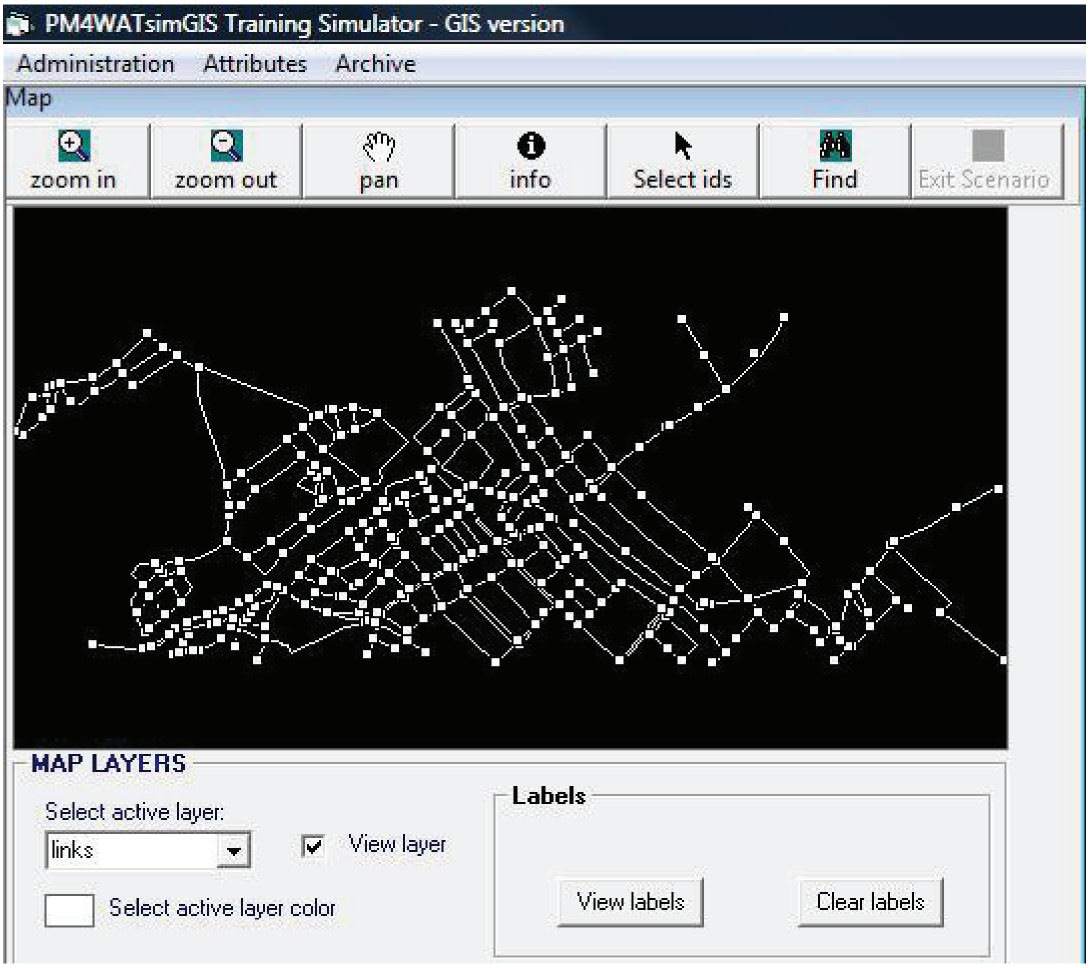

Figure 3. Training Simulator – GIS version

5.5. Training Simulator without GIS

During the implementation phase it proved necessary to develop two versions of the training simulator (TS) in parallel, one which incorporates a GIS component and the second without this feature because of software incompatibility of the initial version to run in later versions of Windows than Windows XP. Furthermore, the TS has been modified to handle water networks where GIS is not available. The second version, which can run under later versions of Windows and does not require GIS shape files of a water network, was developed with a view to enhance the graphical user interface and provide further functionality and features, such as exporting the results to Excel for future use, or to a user-friendly mechanism with which one can enter the scenario parameters. These additional features have also been incorporated in the first version. Both versions of the TS are of the same level of completeness.

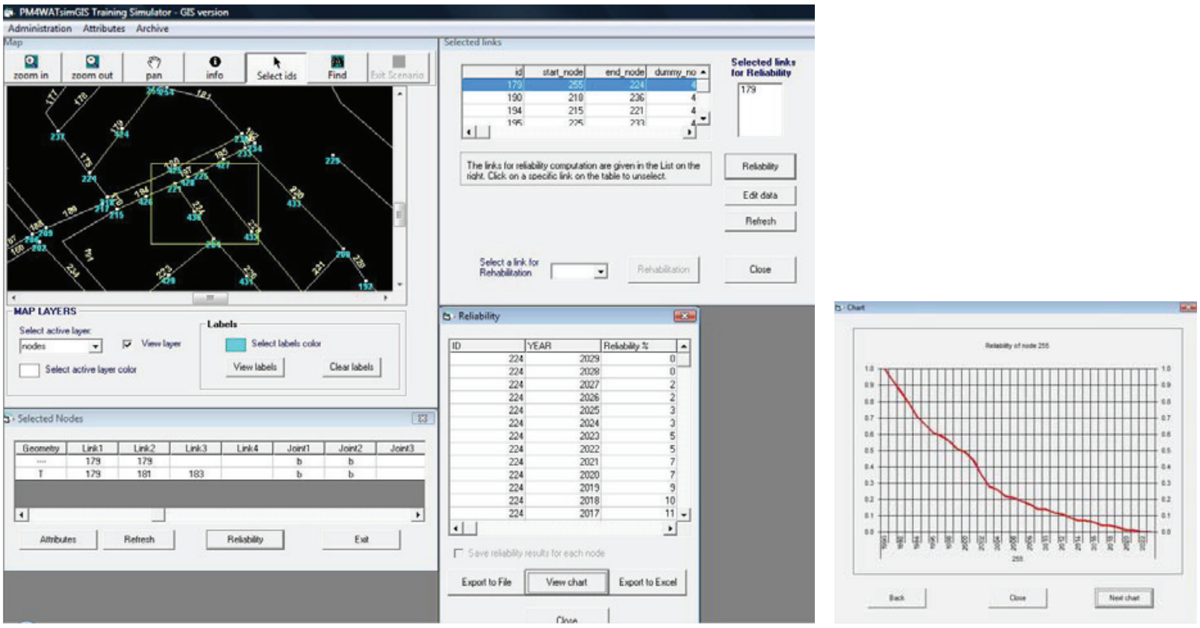

Figure 4. Training Simulator – GIS version Reliability Results

6. APPLICATION IN DENIZLI, TURKEY

According to discussion carried out with partners, before the pilot training test start, the number of about 10-15 trainees from each country were found to be appropriate for the purposes of this project. 14 trainees took the testing of Turkish training material. 3 participants are graduate students at Pamukkale University; 11 participants are employees of Denizli Municipality. The following procedure was used for the testing:

1. A two hours face to face training about the project, its objectives and how to use the web site for the training were conducted. Passwords were sent to trainees' e-mails.
2. The participants were given about a month to complete the pilot training.
3. Another two hours of face to face training were provided on the simulator.
4. The participants were given about two weeks to complete the simulation studies.
5. The participants were asked to complete the questionnairies.

The courseware was consisted of nine chapters covering the following subjects: 1. Urban Water Supply Networks; 2. Network Mapping; 3. System Hydraulic Modeling and Analysis; 4. System Performance Assessment; 5. Criteria and Objectives; 6. Technical Options; 7. Societal Options; 8. Best Practices; 9. Evaluation Questions. The courseware first prepared in English and used as the prototype for the translation of the courseware in Greek, Italian and Turkish, as required, and transferred to the e-platform. The training website for the courseware is available at: http://pm4wat.cti.gr/training/ in which the main window allows for selection of training language.

Both versions of the TS accompanied by the user manual were used in the pilot training phase of the project, during which the users were trained. Topological information and data on part of Denizli water distribution system have been used with training simulator (Figure 5). This group of users then evaluated the TS tool. User evaluations were important for "fine tuning" the product and led to possible improvements before release of the final version for dissemination and exploitation to a wide range of stakeholders. These evaluation figures were considered promising and indicated that the TS product developed is a useful training tool for other water networks as well and particularly those which involve old, asbestos cement pipes and they are deteriorating with aging and other forces, such as earthquakes.

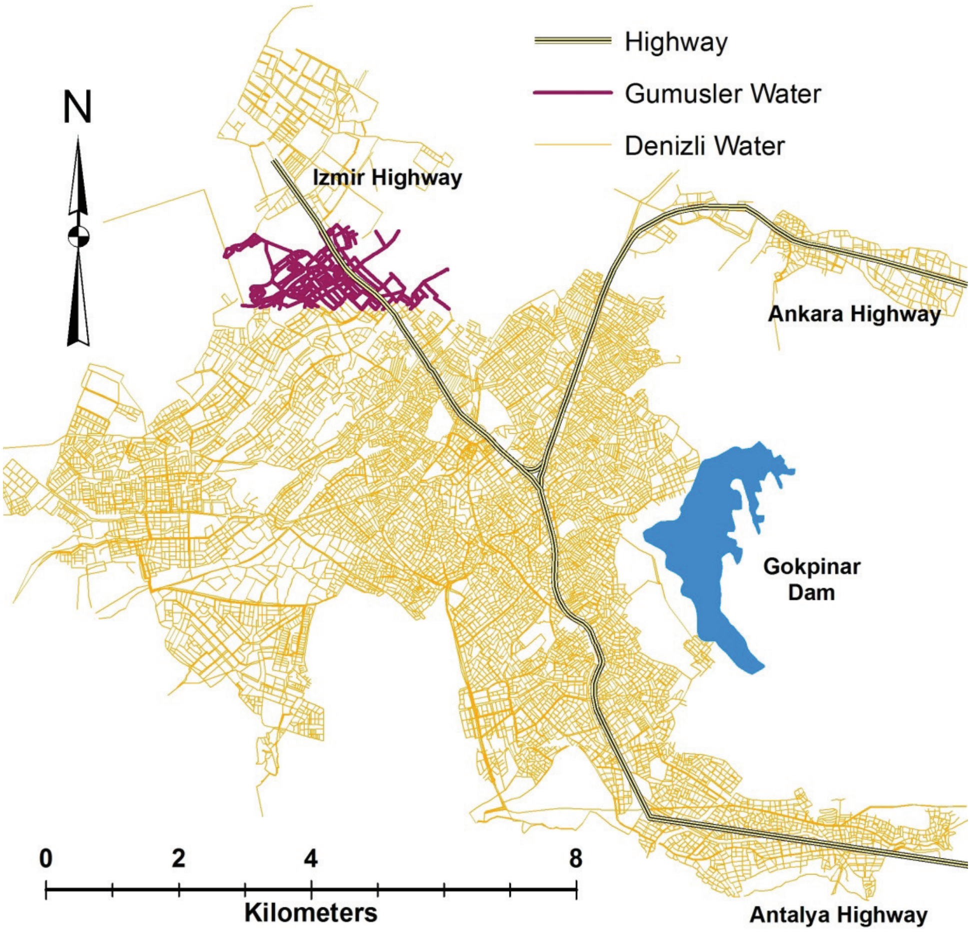

Figure 5. Selected nodes and lines at Gumusler area in Denizli, Turkey

7. RESULT

The primary target group of this project has been the utility maintenance personnel, inspection engineers and hydraulic engineers in public water utilities. It becomes imperative today to train maintenance personnel in state of the art PM and take advantage of the new methodologies for assessing the condition health and reliability of a municipal water utility network. The VET course level differs for each group. Pilot training groups from participating partners in four countries have been trained on the proposed system with a view to further diffusion to water utilities at large.

The sustainability of the project is focused on activities that relate to the dissemination and exploitation of the project products. To this end, the following activities are involved: i) intensification of the diffusion of the results of the project at technical conferences, specialist meetings, other LLP project activities and meetings, symposia etc. ii) Commitment to maintain the project website for a minimum of five years after the end of the project or until there is sufficient interest iii) Exploitation of the end results of the project through extended educational activities to a wider global audience through the web iv) Publication of results in technical journals and conferences proceedings and poster sessions v) Contact with public bodies with respect to partly or fully adopting the outcomes of the project in their current policies and practices. vi) The partners have signed a Copyright Agreement stating that the product results will be made available for at least three years for future training to interested parties and stakeholders. To this end, the coordinator, together with the partners, will offer support to the organization of future training sessions. This will further enhance the sustainability of the project.

ACKNOWLEDGEMENT

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