ISTANBUL NATURAL GAS NETWORK RISK MITIGATION SYSTEM (IGRAS)

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ABSTRACT

The natural gas brings easiness and comfort at many fields in human life, such as heating and cooking. For a long time, natural gas is being used in the world, that proves the natural gas as safe and sacure fuel. Natural gas poses a potential risk when not used in accordance with technical specifications, international and national standards as other flammable fuels. In addition to this, some of the cities using natural gas are located in the earthquake zone. This paper describes a real-time risk mitigation system, producing earthquake hazard maps, by considering deterministic (scenario based) earthquakes or real time earthquakes, by using 100 strong ground motion seismographs, placed in high risk areas, estimating the damage of natural gas network, exposed to earthquake hazard, at IGDAS jurisdiction area, producing damage distribution maps and sending of these damage distribution maps to relevant offices, agencies, for them to improve the natural gas inftastructure and/or to dispatch their rapid response teams towards high risk areas .

1. INTRODUCTION

Being established in 1986, Istanbul Gaz Dağıtım A.Ş.(IGDAS) provides service to 4 million 815 thousand subscribers as of the end of 2011 on an approximately 5400 square kilometer area. According to the 2010 activity report, 12% of the total annual natural gas amount used in Istanbul area was used by industrial subscribers, 88% by house, governmental agencies and offices, etc. A strong earthquake that may affect Istanbul may lead to damage in the natural gas distribution network as well as secondary earthquake damages due to the gas leaking from damaged pipelines (for example, building damages, deaths and injuries due to the fire and explosions) and production failures depending on the natural gas cut-off for the industrial subscribers. Due to the above mentioned reasons, it is necessary to determine the reliability of IGDAS pipelines in case of an earthquake, to measure the total economic loss arising out of a possible earthquake and to prepare an effective emergency response plans. When considering natural gas safety in case of an earthquake, the facilities where it goes through many processes and operations from drilling to its supply to the user devices should be taken into consideration.

Natural gas is being drilled from the underground wells and distilled in distillation units and transmitted to high pressure steel transmission lines through compressor stations or liquefied in the liquefaction plants and transported by ships as LNG (Liquefied Natural Gas) and referred to the transmission lines as gas. Transported by the transmission lines between the ranges of 40 – 70 bars, natural gas is forwarded to steel distribution network at 20 bar and 15 C reducing its pressure at the RMS-A type pressure reduction and measurement stations when entering a city. Entering the city through steel pipelines, it comes to the buildings via polyethylene pipes reducing its pressure to almost 4 bars at Regional Stations. Through the service regulators in front of the buildings, it is reduced to 21 mbar or 300 mbar depending on the usage pressure and it is transmitted and used by gas burning devices via indoor installations.

Following the loss and damage caused by the earthquakes on August 17th and November 12th 1999, the need for preparing elaborated earthquake response plans based on detailed earthquake analyses in Istanbul came out as an acknowledge fact by the local administration, governmental agencies, non-governmental organizations and academic circles and in this scope, studies on different periods were carried out. Among these studies, the last study on Updating of the Possible Earthquake Losses in Istanbul (2009) by Istanbul Metropolitan Municipality was the beginning of other studies which show the loss and damage Istanbul would face in the infrastructure and superstructure and socio-economic structure due to a possible earthquake in Istanbul using the Earthquake Loss Prediction Program to be developed by both the updated building stock and ground inventory (micro-zoning) and the opportunities brought by the developing technology.

One of the studies planned to be carried out in this scope is the development of a real-time risk mitigation system, producing earthquake hazard maps, by considering deterministic (scenario based) earthquakes or real time earthquakes, by using 100 strong ground motion seismographs, placed in high risk areas, estimating the damage of natural gas network, exposed to earthquake hazard, at IGDAS jurisdiction area, producing damage distribution maps and sending of these damage distribution maps to relevant offices, agencies, for them to improve the natural gas inftastructure and/or to dispatch their rapid response teams towards high risk areas. Within the framework of this project, the following tasks will be performed.

• Production of the Strong Motion Seismographs (SMSs) developed with the cooperation of IGDAS and Turkish Scientific and Technological Research Centre (TUBITAK),

• Disposition of the Regional Stations, where the SMSs are installed and supervision of their assembly; post installation test of all the system and designation of ground motion parameters and their threshold values to be used in shutting-off the valve at each regional station,

• Development of software producing earthquake hazard maps via scenario based earthquakes or real-time earthquakes by using SMSs (of IGDAS and The Kandilli Observatory and Earthquake Research Institute, Bogazici University (BOUN-KRDAE),

• Identification of ground motion parameters of natural gas network element groups, which controls the earthquake behaviours of them, by using the vibration table simulation tests, analytic modelling or literature studies of each group depending on the order of priority. Then, development of fragility functions,

• Development of software calculating the natural gas damage by using earthquake ground motion results, estimated via scenario based earthquakes or real time earthquakes, and fragility curves, identification of natural gas elements with high damage risk and recovery methods for different damage levels,

• By considering the results of the earthquake hazard and microzonation studies, conducted by Istanbul Metropolitan Municipality, preparing a report for the estimating the natural gas network damages and recovery methods depending on at least 3 scenarios earthquakes,

• Development of a GIS-based geographical database model in compliance with the measurement data from the SMSs of IGDAS and BOUN-KRDAE, natural gas infrastructure, administrative border, geoserver, map index, micro zoning project data, earthquake hazard analysis and infrastructure damage analysis and transferring of these datasets into this geographical database model,

• Developing of Web-GIS or Desktop-GIS based programs used by company employees to access and query the analysis results calculated by the system and datasets either out of/ from the company,

• Integration of IGDAS Strong Motion Monitoring, Recording and Controlling System with the BOUN-KRDAE Early Warning and Rapid Response system,

• Developemnt of a program preparing/issuing analysis result maps to be sent to the relevant offices, agencies and institutions,

2. DEVELOPING NEW SMSs

The SMSs to be used for the development of IGRAS System are being developed in cooperation with Turkish Scientific and Technological Research Centre (TUBITAK) and IGDAS. While the research and development studies on the SMS the first prototype of which has been produced are going on, its mass production will start in July 2012. The SMSs will produce the following parameters and these parameters will be used in shutting down the valves at the Regional Stations where the SMSs are installed in case of an earthquake and also be used in the manufacture of the real-time earthquake hazard maps. These are;

• PGA, PGV: Peak Ground Acceleration, Peak Ground Velocity is the largest absolute value of the acceleration and velocity in the time series.

• Ia: Arias intensity for ground motion in the x direction (IaX), is calculated as follows.

$$I_{aX} = \frac{\pi}{2g} \int_0^t [a_X(t)]^2 \, dt$$

• CAV : Cumulative absolute velocity is defined as the integral of the absolute value of ground acceleration over the seismic time-history record.

$$\mathrm{CAV} = \int_0^t |a(t)| \, dt,$$

• CAV5 : Cumulative absolute velocity integrated with a 5 cm/sec2 lower threshold appears to better reflect the longer-period (lower-frequency) components of the motions.

$$CAV_5 = \sum_{i=1}^{n} \int_{t_{i-1}}^{t_i} \langle x \rangle |a(t)| \, dt, \quad \langle x \rangle = \begin{cases} 0 \rightarrow (|a(t)| < 5 \; m/s^2) \\ 1 \rightarrow (|a(t)| \geq 5 \; m/s^2) \end{cases}$$

• PSa, PSv, Sd: Pseudo-Spectral acceleration (PSa), Pseudo-Spectral Velocity (PSd) and Spectral Displacement (Sd) are the response spectral parameters given by the following expressions

$$PSa = \frac{2\pi}{T} PSv = \omega PSv \qquad PSa = \left(\frac{2\pi}{T}\right)^2 Sd = \omega^2 Sd$$

SI : Spectrum intensity as originally proposed by Housner (1952) may be expressed as the average spectral velocity within the period range [0.1, 2.5], namely,

$$SI = \frac{1}{2.4} \int_{0.1}^{2.5} Sv(T, \zeta) \, dT$$

The analogue momentum data in the SMSs to be produced are illustrated with 32-bit ADC. In this regard, SMS displays a far better performance than its counterparts. In addition, averaging the momentum data at an adjustable time interval (i.e. 1 minute) and if there is no motion level, updating the zero-g level constantly at the designated interval are the advanced features of the SMS. It can also transmit the data to the system via the 3G modem it has, which shows that it is one move ahead of its counterparts. The SMS, dimensions: 229 x 152 x130 mm, allows an easy assembly and can be mounted around or inside the regulator.

The SMSs to be manufactured 100 pieces under the mass-production are a part of the system and individual shutting down threshold levels will be determined according to the location and ground risks of each regional stations where they will be installed within the scope of the parameters obtained and calculated.

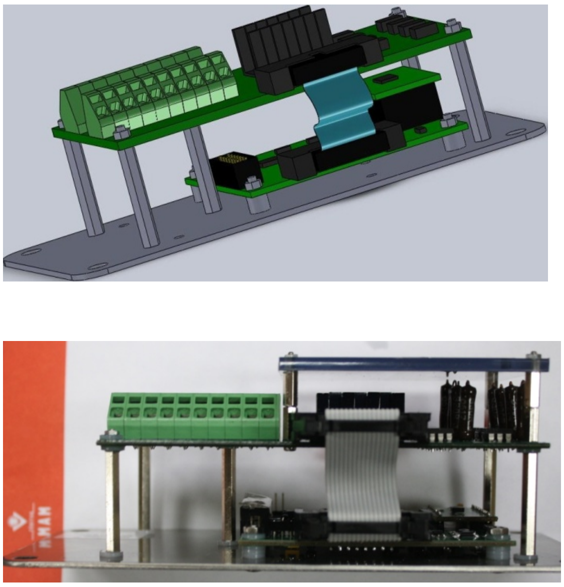

Figure 1: KYHKC Prototype Model

3. ENGINEERING STUDIES

Under the engineering studies within the scope of the development of the IGRAS System, the following procedures will be carried out:

• Determination of the regional stations where 100 SMSs will be installed: Determination of the 100 regional stations with the highest risk among 714 regional stations of IGDAS in total. The device assembly places will be determined considering the following factors for the determination of the regional stations.

a. IGDAS Natural Gas Infrastructure Network,
b. Earthquake ground motion parameters which may occur due to a possible earthquake scenario on the main Marmara fault,
c. Field observations and ground risk data,
d. Distribution of the existing immediate response system stations for Istanbul earthquake,
e. Istanbul settlement-population density distribution,

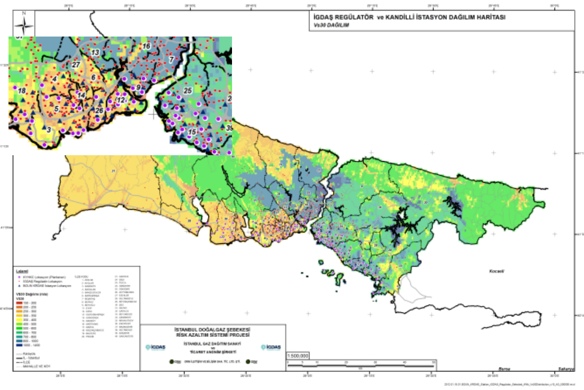

Figure 2: SMS Locations Planned

• Designation of ground motion parameters and their threshold values to be used in shutting down the network at each regional station where 100 SMSs are to be installed: According to the results of a possible earthquake scenario which would happen on the main Marmara fault, the parameters which should be considered in order to shut off the network on each station basis will be identified and the threshold values will be found for these parameters.

• Identification of earth-dependent ground motions which the natural gas network is subjected to in scenario-based earthquakes: The ground motions which the natural gas network may be subjected to will be taken into consideration based on the scenario-based earthquakes for Istanbul. The earth conditions will be considered in the analyses.

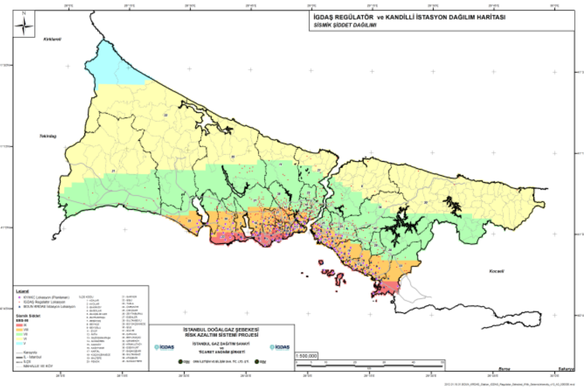

Figure 3: Istanbul Seismic Intensity Map

• Classifying natural gas network elements and analysing earthquake behaviours by using the vibration table simulation tests, analytic modelling or literature studies of each group depending on the order of priority: The network elements will be classified in order to predict the behaviours of each network element for making the risk analyses of natural gas infrastructure as a result of the earthquake hazard analyses to be carried out according to the possible earthquake scenario and to determine the characteristic input parameters to be used in the damage assessment. For each network element group for determining the stated parameters, vibration table simulation tests, analytic modelling or literature studies will be carried out depending on the order of priority. The vibration table simulation tests were performed under different dynamic loads (4 different earthquake ground motion and impact test) on a sample Regional Station in cooperation with IGDAS and The Kandilli Observatory and Earthquake Research Institute in 2008.

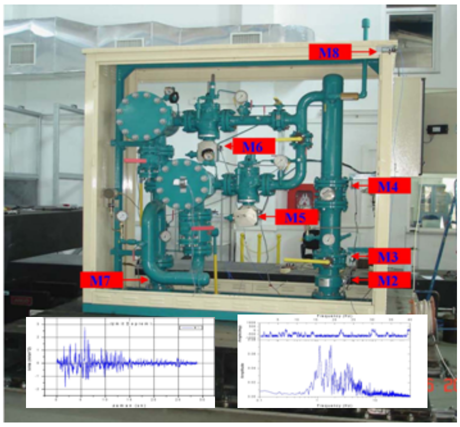

Figure 4: Vibration Table Simulation Experiment on a Regional Station (earthquake record below and Fourier amplitude spectrum)

• Designation of ground motion parameter which controls the earthquake behaviours for each natural gas network element group: in scenario-based earthquakes, ground motion parameters which control the earthquake behaviours for each natural gas network element group will be designated considering the results of the earth-dependent ground motions which the natural gas network is subjected to.

• Determination of vulnerability curves (ground motion – damage rate) for each natural gas network element group: considering the ground motion parameter which controls the earthquake behaviours for each natural gas network element group, the generalized damage levels will be found using primarily the vibration table simulation tests, analytic modeling or literature studies of each IGDAS natural gas network element group. Considering the damage levels found for the natural gas network elements, damage surves which will give information on reaching or exceeding these damage levels and which are dependent on the earthquake ground motion identified will be developed.

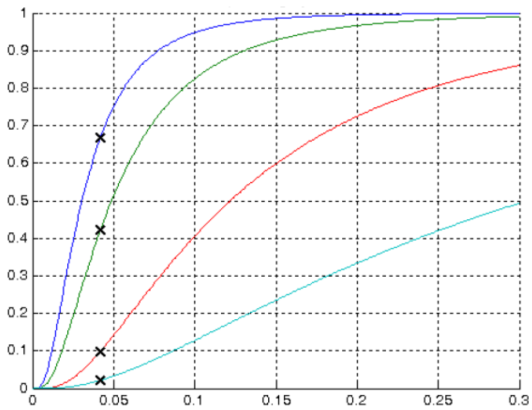

Figure 5: A sample ground motion - damage rate curve

• Designation of the damage rates in the network for real-time and scenario-based earthquakes: Considering the real time and scenario based earthquake hazard analysis results, the software required to determine the damage rates in the network should be developed. This software will be developed under the Natural Gas Damage Module. Basically, this software will be developed in order to determine the areas where the damage in the natural gas systems is concentrated so that the loss of lives and economic losses which may arise from an earthquake to occur possible in Istanbul at a minimum level.

• Determination of network elements with a high damage risk and the necessary recovery methods: Considering the damage and economic loss results identified for each natural gas infrastructure element according to the natural gas infrastructure analysis results, the best and most applicable recovery methods will be determined depending on the order of priority taking certain criteria of the future damages into consideration in order to minimize the earthquake damages.

• Identification of Service Box Damages: Service box damages will be calculated according to the building damage results to be performed on the basis of an analysis grid. Among the building damage methods, the one which presents the service box damage in the best way will be selected and at first, the analysis grid based damage results will be obtained considering the real-time or scenario based earthquake hazard maps and then the building damage level to create the damage in the service box will be determined and the number of damaged service boxes will be calculated on the analysis grid basis.

• Integration with IGDAS Natural Gas Network Risk Mitigation System and Immediate Response System: Under the project, it will integrate the earthquake ground motion data calculated and measured by SMSs to be sent to the BOUN-KRDAE by IGDAS with the Early Warning and Immediate Response System. the earthquake ground motion data calculated and measured by SMSs to be sent to the BOUN-KRDAE will be sent to IGDAS by BOUN-KRDAE and the Contractor firm will ensure the integration of these data in the IGRAS system (in order to be used in the production of Earthquake Hazard Maps).

4. SOFTWARE DEVELOPMENT STUDIES

The software development studies included in the IGRAS System development are as follows.

• Earthquake Hazard Map Module is a module which produces scenario-based and real-time earthquake hazard maps. The scenario-based and real-time earthquake hazard analysis results produced by the Earthquake Hazard Map Module will be written in 400 X 600 m. analysis cells which cover Istanbul Metropolitan Municipality Administrative Borders No: 5747. The earthquake hazard analysis results obtained will be displayed in the system using these analysis cells.

• Natural Gas Infrastructure Damage Module is the one which relates the earthquake hazard data produced by the Earthquake Hazard Map Module with the natural gas infrastructure elements and analytically calculates the damage on the natural gas infrastructure elements.

• Natural Gas Building Damage Calculation Module is the one which related the earthquake hazard data produced by the Earthquake Hazard Map Module with the building inventory at first and calculates the building damages and then related the building damage results with the natural gas service boxes and calculates the number of damaged natural gas service boxes on the basis of analysis cells.

• A GIS-based geographical database which enables the management of all the data in the IGRAS System will be based and all the data will be kept in this model.

• A GIS-based web application in which the scenario-based and real-time earthquake hazard, damage and loss estimation results are monitored on the internet or intranet under the IGRAS System will be developed.

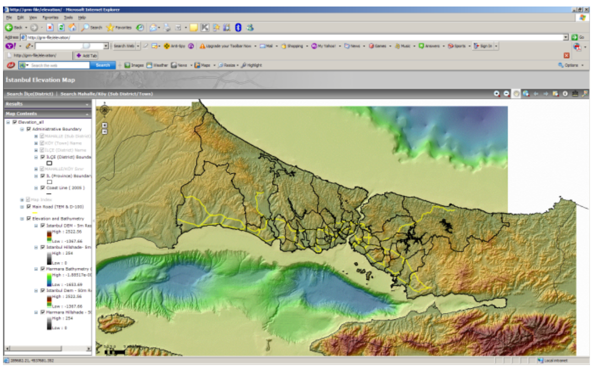

Figure 6: Web-GIS based Risk Imaging Software

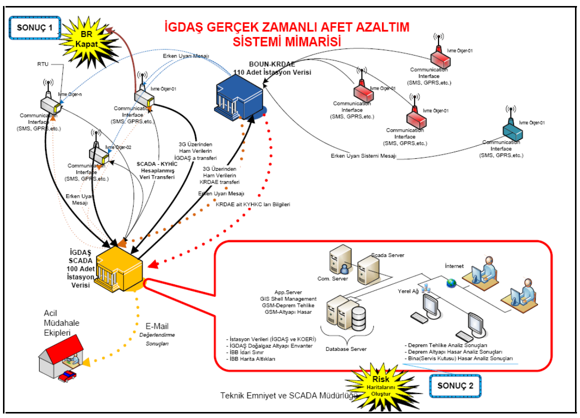

Figure 7: IGRAS System Architecture

5. CONCLUSION

Within the scope of the Europe and European Side Micro-Zoning Project carried out by Istanbul Metropolitan Municipality, the ground motions and building damage data which would be caused by a possible earthquake in Istanbul are associated in the Natural Gas Regional Station Locations of IGDAS and geographical data systems atmosphere in the cooperation with The Kandilli Observatory and Earthquake Research Institute, Bogazici University and Japanese/Turkish Engineers and the effect of the earthquake and the Regional Stations which may be subjected to damage will be determined and then after this determination, the studies on cutting off the gas flow automatically in the regional station found to be in the risky areas receiving an early-signal from the system elaborated with the 5 strong ground motion device installed by The Kandilli Observatory and Earthquake Research Institute on the fault line situated in the Marmara Sea are going on so as to be completed as soon as possible.

The "Strong Motion Monitoring, Recording and Controlling System" Project carried out in cooperation with The Kandilli Observatory and Earthquake Research Institute, Bogazici University and TUBITAK, which is another pillar of our ongoing project, was launched and the feed valves located in the regional station will be automatically shut down by the SMS in case the seismic parameter threshold levels defined by any earthquake activities are exceeded. (TUBITAK carried out and produced the Earthquake Censors Development.)

Following the start-up of the Strong Ground Motion Devices, it will calculate the damage to be created by the hazard in the natural gas infrastructure in the jurisdiction of IGDAS within a very short period of time by producing real-time earthquake hazard maps using the data obtained from Strong Ground Motion Recorder before or during the earthquake under the "IGDAS Natural Gas Network Risk Mitigation" System Project. Accordingly, the studies on installing a real-time risk mitigation system which enables the natural gas infrastructure to be improved and the field teams to respond are still going on.

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