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A PROCEDURE FOR RISK MITIGATION OF WATER SUPPLY SYSTEM IN LARGE AND POPULATED CITIES

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ABSTRACT :

The complexity of lifeline systems and their operation, their high number of components, and the variety of age in an old existing lifeline system, such as Tehran water supply, cause that all parts of the system can not be upgraded to the same level of performance. In this paper a procedure is proposed for mitigating the seismic risk of water supply system in large cities in which all important factors with regard to system components, including seismic resistance to various seismic hazard levels, component's age, importance of the component role in the function of the whole system, reparability of the component and so on are taken into consideration. Furthermore, as applying the mitigating measures are very costly in case of large cities, and the required technology for applying the measures is not always available in all countries the economical and technological situations of the country at hand are also included in the propose procedure. One of the main features of the proposed procedure is considering the total value of mitigation costs and earthquake induced losses as a target function for minimization, and also considering the variation of costs with passage of time. On this basis the mitigation measures can be divided into three -short-, mid-, and long-term categories, and the optimal upgrading level for every component in every part of the city in each time window can be obtained by a high level of confidence. To show the efficiency of the proposed procedure it has been applied to Tehran metropolis.

KEYWORDS: Operation level, Mitigation costs, Technological considerations, Tehran

1. INTRODUCTION

Earthquake occurrence in large and populated cities, which are like Tehran highly vulnerable, can be disastrous. Therefore, every mitigative measure which can decrease the seismic vulnerability of a large city is very well acknowledged. Obviously, mitigation is more important with regard to lifeline systems, such as water supply system, as they can have a disaster creative role if they can not withstand the earthquake effects. On the other hand, applying the mitigative measures in an existing lifeline system is much more difficult than a building. In fact, the complexity of lifeline systems and their operation, their very high number of components, and the variety of age in an old existing lifeline system, such as Tehran water supply, cause that all parts of the system can not be upgraded to the same level of performance. In many cases the old components, which do not have acceptable operation situation, are continuously, or on a regular basis, replaced or renewed. Therefore, it is not reasonable and, in many cases, possible to apply the same upgrading measure to even similar component which have different ages. On this basis, it would be reasonable to look for some new upgrading methodology to be employed for such cases.

Up to now, several guidelines and commentaries have been presented by researchers with regard to seismic design or upgrade of water supply systems. As one of the earliest works in this regard the monograph which has been published in early 90s, although not dedicated to just water systems, can be mentioned (Central United States Earthquake Consortium, 1993). In that monograph there is one chapter discussing on water and sewage systems, however, it gives just some general guidelines which is not enough for upgrading purposes, particularly for cases mentioned above. It is also worth mentioning that there are two relatively recent publications, specifically dedicated to water systems. One is "Seismic Design and Construction Guidelines for Water Supply Facilities" (Japan Water Work Association, 1997), and the other is "Guidelines for the Seismic Evaluation and Upgrade of Water Transmission Facilities" (Eidinger and Avila, 1999). However, as their titles show, the first one is related to design and construction, not to seismic evaluation and upgrade, and the other one addresses only the transmission facilities, not the whole water system. In the following sections of this paper, at first current state of art and practice in seismic evaluation and upgrading of water supply system are briefly presented and then the proposed method for upgrading of old water supply system in large and populated cities is described and its application to Tehran metropolis is explained.

2. CURRENT STATE OF ART AND PRACTICE IN SEISMIC EVALUATION AND UPGRADING OF WATER SUPPLY SYSTEMS

To realize the state of art and practice in seismic evaluation and upgrading of water supply systems it is useful to have a brief review at the related publications. As one of the first works with regard to seismic upgrading of water systems Eidinger and Young (1993) have discussed preparedness, performance and mitigation for East Bay Utility District water distribution system for scenario earthquakes. They have described actions the East Bay Municipal Utility District in northern California has taken to prepare for and mitigate the effects of earthquakes. They have used seismic hazard models to predict levels of ground shaking, liquefaction, landslides, and surface faulting due to scenario earthquakes. Probabilistic methods have been used to predict damage to facilities and buried piping, and post-earthquake levels of service have been predicted for each scenario earthquake. They have mentioned that a preparedness and mitigation plan is balanced between reducing life safety risk and maximizing post-earthquake service levels, and that the implementation of that plan requires action by both the water utility and other local agencies.

Another document in this regard, used for examining the overall seismic performance of gas and water lifelines, is systems analysis for Memphis Light, Gas and Water can be mentioned (Shinozuka, 1994). He has studied the seismic performance of mechanical and structural components including pipelines, storage tanks, pumping stations, treatment facilities, etc., measured in terms of fragility quantities; reliability and interactive nature of system functionality under severe seismic conditions with the aid of Monte Carlo techniques utilizing component fragility information; and the socioeconomic impact arising from system failure.

Schiff and Buckle (1995) in a study, entitled the critical issues and state-of-the-art in lifeline earthquake engineering, have described earthquake performance of various lifeline systems. The earthquake damage of the systems has been reviewed, major vulnerabilities have been identified, and mitigation methods have been described. The most important issues affecting earthquake performance have been discussed and research needs have been identified. In that study the lack of earthquake performance standards has been noted as a common shortcoming for most lifelines, which makes it difficult to rationally establish equipment and facility seismic specifications.

Based on the intention of the East Bay Utility District, which provides potable water for approximately 1.2 million people in San Francisco's East Bay, to seismic upgrade of Mokelumne Aqueduct System, Dodge and Pratt (1995) have worked on improvement of the pipe joints, support bents, pile foundations, and river crossings in order to reduce the chances of an extended water outage. The design of that project has encompassed soil stabilization, soil/structure interaction modeling, pipeline and frame analysis, and environmental permitting. A similar work has been done for the bulk water supply system in Wellington, New Zealand, which serves over 300,000 people, under the title of "Securing Wellington's water supply 20-year mitigation plan based on seismic risk assessment" (Hopkins, D. C.; Leslie, 1995). In that study a priority order of mitigation measures has been established based on vulnerability, importance, and assessed cost of mitigation measures.

The seismic damage to water supply systems during several earthquakes throughout the world, such as the 1975 Haicheng, the 1976 Tangshan, the 1989 Loma Prieta, the 1994 Northridge, and the 1996 Baotou, has been investigated for proposing some countermeasures against earthquake (Sun, 1998). He has described the assessment of existing water supply systems, including the source, facilities and pipelines, and so forth for suggesting the countermeasures.

Hose lining technology is another technique used for earthquake damage reduction to buried water supply pipes and their renovation (Sato et al., 1998). They have introduced a technology for renovating old pipes, based on the examination of seismic durability of hose-lined pipes with joints through static and dynamic cyclic loading tests. They have surveyed damage to water distribution pipes during the 1995 Hyogoken-Nanbu earthquake, especially values of openings at breaks, to grasp the deformability that is necessary for pipe joints subjected to strong ground shaking.

The use of rubber ring type U-PVC (polyvinylchloride) pipe for water distribution pipelines is another proposed technique for earthquake resistant performance (Takada et al., 1998). They have verified the earthquake resistance of a rubber ring (RR) type of U-PVC pipe used for water distribution pipelines through both a full-scale experiment and numerical analysis. Their experiment has shown that the expansion performance and slip-out prevention capabilities of the new RR pipe are superior.

Shumuta and his colleagues (1998) have studied long-term infrastructure/lifeline renewal planning and management with a focus on power and water. Their study has been on optimization method for replacement or retrofitting of power facilities on the basis of risk management. The common perspective of the project in their study is integrated management for urban disaster risk. In that project, the Japan Central Research Institute of Electric Power Industry (CRIEPI) has been in charge of long-term infrastructure/lifeline renewal planning and management with a focus on power. In that project, CRIEPI has planned to carry out a cooperative research with the Electric Power Research Institute, China, and the Kansai Electric Power Company, Japan. Shumuta and his colleagues have presented the issues that need to be addressed, the objectives of the sub-team, the research subjects, and the expected research results.

Hosseini and Mirza-Hessabi (1999) have studied the lifeline interaction effects on the earthquake emergency response of fire departments in Tehran metropolis, and have mentioned that not only any serious damage to urban water system can result in failure of fire department missions in the aftermath of earthquake, but also the most adverse effect on the functionality of transportation system, which is necessary for successful action of fire department, is due to damages to water system.

Miyajima and his colleagues (2000) have studied on retrofit prioritization of water supply pipeline considering required performance after earthquake. Their paper focuses on a system performance of a water supply system after an earthquake and prioritization of the retrofit. First, a flow analysis of water supply pipelines has been conducted in order to estimate undersupply points of a network after a scenario earthquake. Then, a loss of water has been defined to evaluate the effects of the degree of water shortage on civic life. Finally, strengthening of water supply pipelines has been investigated to reduce the water shortage due to the suspension and undersupply of water after an earthquake. It has been clarified that the total loss of water is one of the important indices for evaluation of retrofit prioritization.

Finally, Hosseini (2003) has done a review on the latest achievements in the seismic evaluation methods and upgrading techniques for gas and water lifelines, and has mentioned that in the case of seismic evaluation methods the following issues have been taken into consideration so far:

- Obtaining the fragility quantities; reliability and interactive nature of system functionality under severe seismic conditions with the aid of Monte Carlo techniques utilizing component fragility information
- The use of finite element models for some component of the system such pipe connections
- The use of different damage levels for various components of pipeline systems
- The effect of strain rate on stress/strain properties of pipelines

He has also mentioned that with regard to mitigation techniques the following matters have been addressed:

- Mitigation plan should be balanced between reducing life safety risk and maximizing post-earthquake service levels, and the implementation of that plan requires action by both the utility and other local agencies.

- Pipeline replacement should not be done without a feasibility study.
- Mitigation measures should be prioritized based on vulnerability, importance, and assessed cost of mitigation measures.
- Hose lining technology, and the use of rubber ring type U-PVC (polyvinylchloride) pipe for water distribution pipelines are suitable mitigation measures.
- Ground densification by vibro-replacement can be used to reduce the risk of ground deformations to reduce pipeline damages
- Pipeline installation by using the method of horizontal directional drilling (HDD) is useful for avoiding potentially liquefiable zones.

It is seen that despite the large number of publications on seismic evaluation of gas and water systems, a systematic procedure, which take into consideration all of the system components' roles in the seismic vulnerability of the whole system, has not been developed so far. In the case of seismic upgrading there is a similar situation. Although many remedies have been suggested, they are mostly focused on emergency warning for disaster management actions rather than upgrading the system components' seismic capacity, or the use of seismic isolation and control techniques. Therefore, it can be concluded that more researches are needed to achieve systematic evaluation procedures as well as appropriate upgrading techniques for various components of gas and water systems, particularly in their distribution networks.

3. THE PROPOSED SEISMIC RISK MITIGATION PROCEDURE

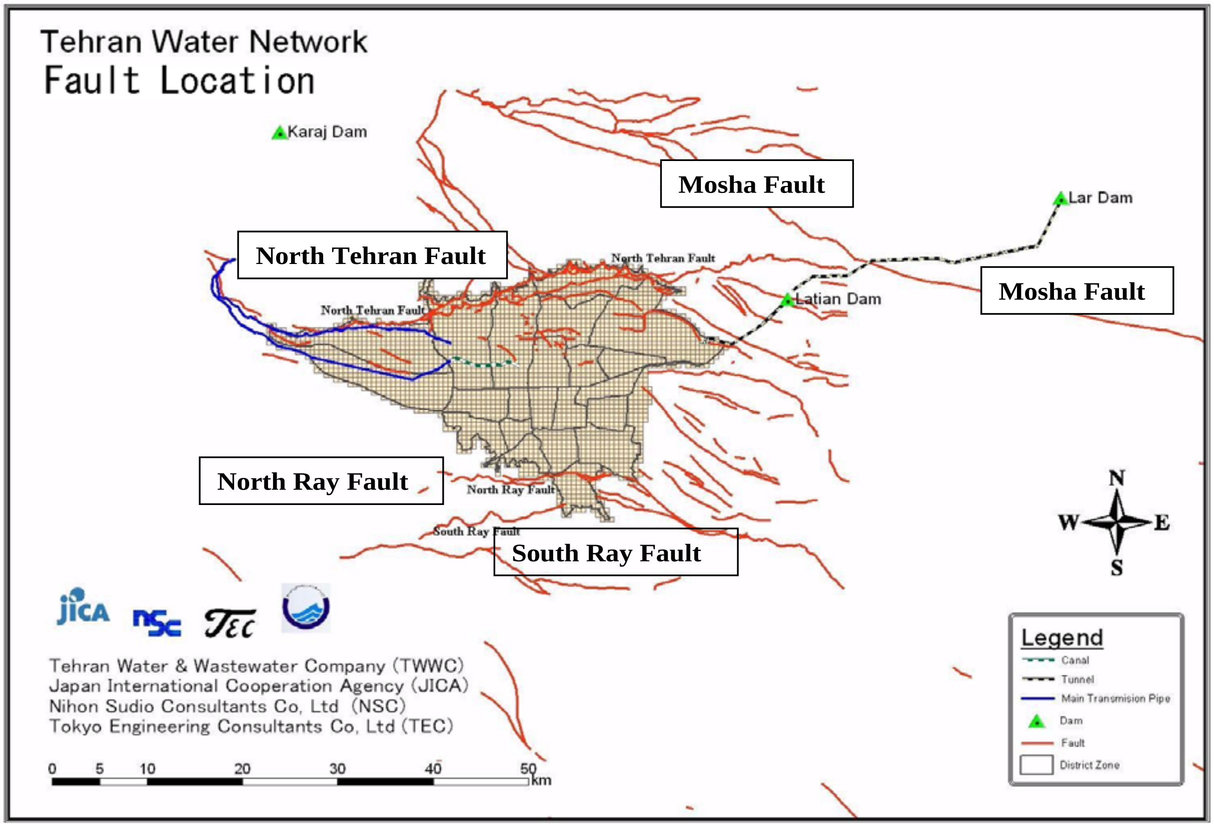
An appropriate procedure for mitigating the seismic risk of water supply system in large cities should have the following features:

- Can take into consideration all important factors with regard to system components, including seismic resistance to various seismic hazard levels, component's age, importance of the component role in the function of the whole system, repairability of the component and so on.
- Since applying the mitigating measures are very costly in case of large cities, and the required technology for applying the measures is not always available in all countries the economical and technological situations of the country at hand are also included in the propose procedure.
- Can consider the total value of mitigation costs and earthquake induced losses as a target function for minimization, and also consider the variation of costs with passage of time.

Based on the third feature mentioned above the mitigation measures can be divided into three -short-, mid-, and long-term categories. In this way the optimal upgrading level for every component in every part of the city in each time window can be obtained by a high level of confidence. More details of the proposed procedure are discussed in its application to Tehran metropolis is the next section of the paper.

4. APPLICATION OF THE PROPOSED MITIGATION PROCEDURE TO TEHRAN METROPOLIS

Tehran metropolis with around 10 million populations is located in the zone of high seismic hazard on the macrozonation seismic hazard map of Iran, and the occurrence of a big earthquake in this city can create a very tragic event. The weak performance of water supply system of the city is believed to have a major role in the creation of disastrous conditions in the city, both because of lack of water for extinguishing the post earthquake fires which are very likely to happen, and because of flow of water on the main streets and in the subway tunnels which can create several difficulties for the transportation system and therefore for the rescue and relief teams. On this basis, seismic risk reduction of Tehran water supply system is of very great importance from the seismic risk reduction point of view. Figure 1 shows the situation of Tehran water supply system with respect to the seismic faults in and around the city.



Figuer 1. Tehran water network and seismic faults (JICA 2000)

Tehran water network covers an area of 533 square km, and is divided into three main parts based on the pipelines service categories as shown in Table 1.

Table 1. Types and lengths of water pipes in Tehran metropolis (TWWC 2000)

Pipeline Service Category	**Length (m)**
Transmission Main (for transmitting the water form main sources to water treatment plants)	399,346
Distribution Trunk Main (for transmitting form treatment plants to the main city reservoirs)	768,179
Distribution Sub Main (for transmitting the water from city reservoirs to districts)	6,385,927
Total Length	**7,553,452**

There are five types of materials in Tehran water network, including: steel, ductile iron, cast iron, reinforced concrete, and asbestos. Based on the JICA report (2000) the main earthquake hazard for water pipes in Tehran in fault movement. On this basis and using three scenario earthquakes corresponding to North Tehran Fault, South Rey Fault and Mosha Fault, the percentage of water supply interruption in all neighborhoods have been calculated for each scenario. For example Figure 2 shows the interruption for North Tehran Fault scenario. More results can be found in the JICA report.

To show how the proposed risk mitigation procedure can be applied to large cities like Tehran, neighborhood No. 28, which has the highest percentage of interruption based on JICA study, as can be seen in Figure 2, has been considered. Three time conditions can be defined for implementing the mitigative measures, discussed in the previous section of the paper, including short term or the present time, in which no mitigative measure has been implemented, mid term, in which some mitigative measures have would have been implemented, and long term, in which all the possible mitigative measures are supposed to be implemented.

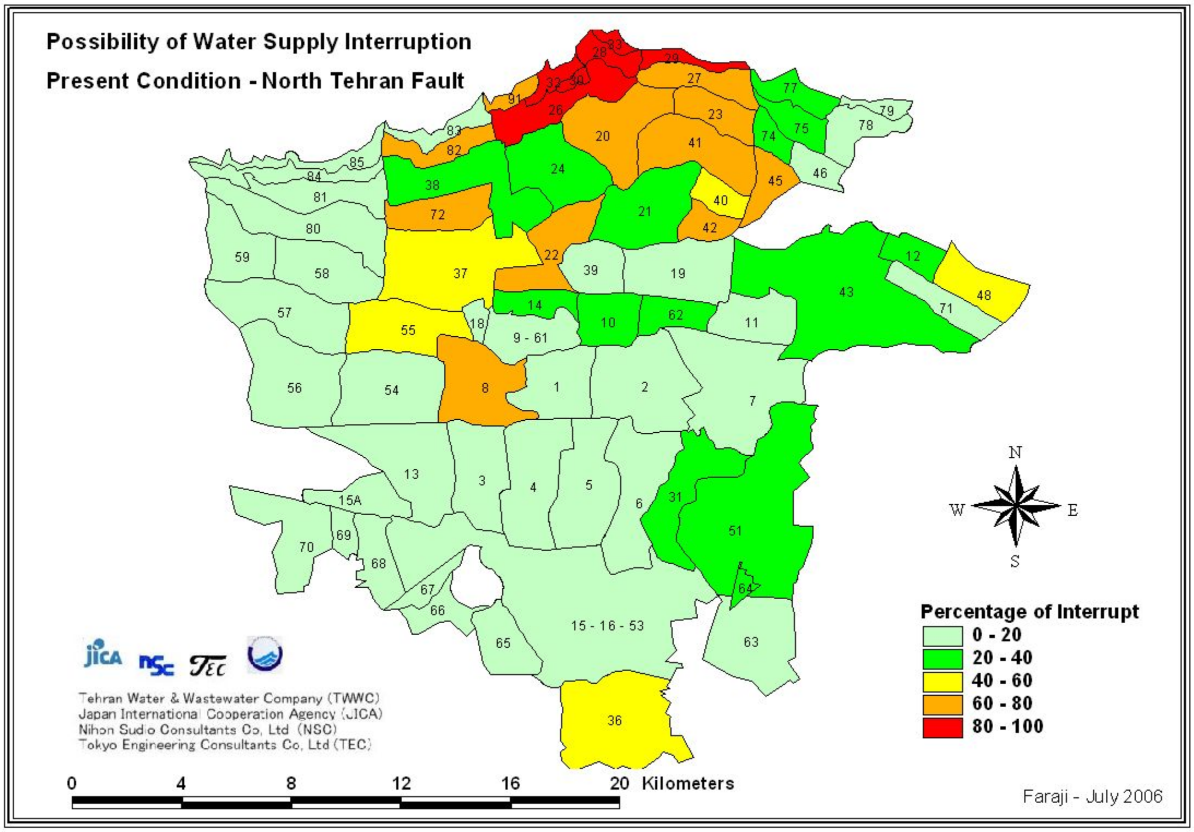


Figure 2. Percentage of water supply interruption for North Tehran Fault scenario (JICA 2000)

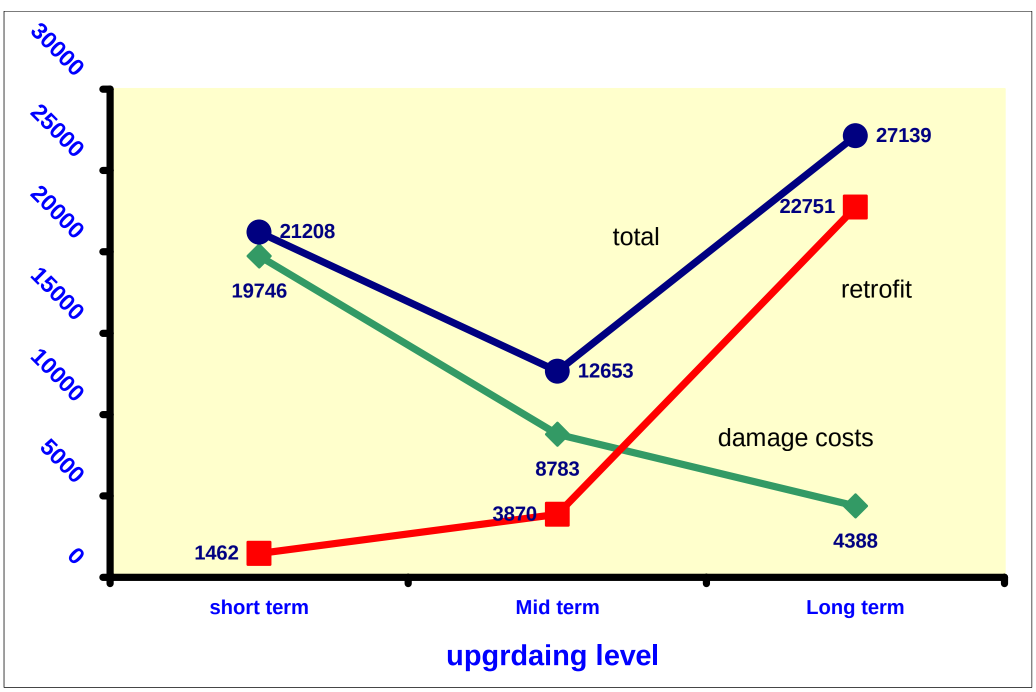


Figure 3. Various curves of retrofit costs and damages costs (in USD) vs upgrading level for main transmission lines in neighborhood No. 28 of Tehran Metropolis for finding the optimum level of upgrading

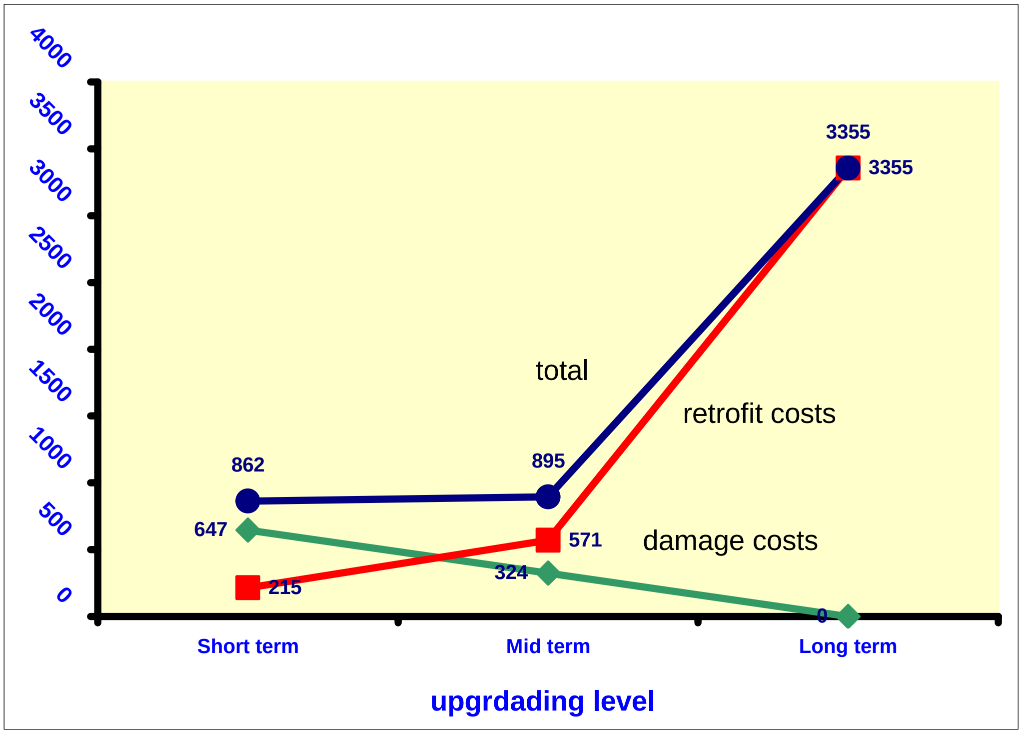


Figure 4. Various curves of retrofit costs and damages costs (in USD) vs upgrading level for main distribution lines in neighborhood No. 28 of Tehran Metropolis for finding the optimum level of upgrading

The costs of implementation of mitigative measures vs upgrading level as well as the costs or losses due to damages because of the occurrence of scenario earthquake vs various upgrading levels, and finally the summation of these two costs for each upgrading level can be calculated in each neighborhood and then plotted. A sample of these graphs for the main transition lines in neighborhood No. 28 is shown in Figure 3, and another sample for main distribution lines in Figure 4. By plotting similar graphs for all neighborhoods the optimum upgrading level can be obtained for the whole city. Of course, for different category of pipes services different curves and accordingly different optimum level of upgrading may be obtained. For example, Figure 3 shows that the optimum upgrading level for transmission lines is the mid term activities, while as Figure 4 shows, the optimum upgrading level for distribution lines is the present conditions. The complete results of these calculations can be found in the main report of the study (Moshirvaziri 2007).

5. CONCLUSIONS

Based on the presented results it can be said that the proposed seismic risk mitigation procedure is quite useful and applicable to all large cities, located in earthquake prone areas of the world. To increase the precision of obtaining the optimum upgrading level, more time conditions can be considered. Even it is possible to consider a continuous trend of upgrading. If the costs are calculated for the whole network instead of each category of pipes, the optimum upgrading level may change. It is important to take into account the inflation rate in costs estimations, which is not always an easy task, especially in countries with unpredictable rates.

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