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SUMMARY/ABSTRACT

EXECUTİVE SUMMARY

"Istanbul Metropolitan Municipality, Istanbul Province Probable Earthquake Loss Estimates Update Project" was carried out by Boğaziçi University, Kandilli Observatory and Earthquake Research Institute, Earthquake Engineering Department, within the scope of the contract signed between Istanbul Metropolitan Municipality, Directorate of Earthquake and Ground Research and Boğaziçi University Rectorate.

"Istanbul Possible Earthquake Loss Estimates" is the last study on the estimation of earthquake losses in Istanbul at urban scale was conducted in 2009 carried out by Istanbul Metropolitan Municipality, Earthquake Risk Management and Urban Improvement Department, Directorate of Earthquake and Ground Research and Boğaziçi University, Kandilli Observatory and Earthquake Research Institute, Department of Earthquake Engineering.

In the 10 years since 2009, significant urban change/transformation processes have been experienced in Istanbul. Population, superstructure and infrastructure element in the city is rapidly growing, developing and changing. Approximately 30% of Istanbul's building stock consists of relatively new buildings built after 2000. Urban transformation projects continue rapidly. Mass housing/site type construction continues in empty areas and around of the city, many 20-storey high buildings have been built or are being built. Important infrastructure projects (Yavuz Sultan Selim Bridge and connection roads, Marmaray, Eurasia tunnel, new metro lines) have been activated. In addition to all these changes in the infrastructure and superstructure, new scientific research has been carried out on the earthquake hazard of Istanbul in the past 10 years, new information and findings have been revealed. All these developments and changes have revealed the need to update the earthquake loss estimates covering the entire province of Istanbul.

In this project, It is aimed to renew the earthquake damage and loss estimates using the current population, building and infrastructure inventories of Istanbul. In the 20th anniversary of the Kocaeli and Düzce earthquakes, the results obtained by using the latest superstructure and infrastructure inventory information in the light of the latest earthquake hazard information and models, in planning studies for all kinds of urban functions, in disaster response plans, in structural improvement against earthquakes and in the determination of priority regions studies within the framework of urban transformation, are very important.

The project includes earthquake hazard analysis, risk analysis of urban superstructure and infrastructure elements and earthquake risk assessment studies of Yenikapı and Maltepe meeting areas. Urban earthquake hazard and risk analyzes were carried out with deterministic

and probabilistic approaches, and various vibration measurement and modeling approaches were used in the earthquake risk assessment of Yenikapı and Maltepe meeting areas.

In this report, a scenario earthquake of Mw=7.5 magnitude, 15 different earthquake scenarios obtained by simulation, and probabilistic earthquake ground motion distributions corresponding to recurrence periods of 72, 475 and 2475 years, probable building damage, loss of life and number of injured, and Infrastructure damage estimates are included. Studies on Yenikapı and Maltepe meeting areas, the results and evaluations are presented in a separate report in order to ensure the integrity of the subject and presentation.

RESULTS AND EVALUATION

In this study, the building, population and infrastructure damage and loss estimates that can be expected in Istanbul under probabilistic earthquake hazard distributions and as a result of scenario earthquakes are presented. Three recurrence periods of 72, 475 and 2,475 years were used for probabilistic earthquake hazard, and a scenario earthquake of Mw=7.5 magnitude and 15 earthquake simulations separated from each other according to source properties and calculation method were used for deterministic earthquake hazard. All numerical details of the results obtained and the evaluations made are given in the sections within the report. Maps regarding the spatial distribution of damage estimates within the boundaries of the Istanbul municipality are also presented in the report. In order to get an idea about the variability in damage and loss estimates, different models and approaches have been used and the related results are given in the relevant sections of the report. In this section, the numerical results obtained will be presented using the average values of the estimates, taking into account the ease and simplicity of expression.

Deterministic (Mw=7.5) scenario, the average of the 15 scenario obtained from earthquake ground motion simulations and the estimation results of the number of damaged buildings calculated for earthquake ground motions with recurrence periods of 72 years, 475 years and 2,475 years obtained from probabilistic earthquake hazard analyzes are presented in Table 8-1.

It is estimated that an average of 57% of the buildings in Istanbul will not be damaged in the scenario earthquake with a magnitude of Mw=7.5. On average, 26% of the buildings are expected to be damaged lightly, 13% moderately, 3% heavily, and 1% severely damaged. The total number of buildings analyzed in Istanbul is 1.166.330. The earthquake damage of heavily and very heavily damaged buildings is beyond repair, and the buildings at these damage levels need to be demolished and rebuilt. On the other hand, it is often more convenient to demolish and rebuild moderately damaged buildings instead of repair. In the scenario earthquake, it is estimated that an average of 17% of the buildings in Istanbul (approximately 194,000 buildings) will be moderately and above damaged. Approximately 972,000 buildings are expected to be undamaged or slightly damaged.

Earthquake ground motion distributions obtained by the simulation method show significant local differences according to the earthquake source characteristics (such as slip pattern,

rupture direction, size, number of ruptured segments). The damage estimates for these scenarios differ significantly from each other. Damage results obtained for 15 simulation scenarios can be seen in detail in Chapter 4. The results obtained the average damages consisted of the simulation scenarios are seen that it was not very different from Mw=7.5 deterministic scenario (Table 8-1). However, as the simulation results indicate, there is a possibility that the damages to occur depending on the earthquake's occurrence will occur significantly below or above the average values given.

Table 8-1. Building damage estimation results (numbers in brackets given as % of total number of buildings analysed)

Damage Status	Scenario Earthquakes		Probabilistic Earthquake Ground Motions		
	Deterministic Scenario (Mw=7,5)	Average of Simulation Scenarios	72 years	475 years	2.475 years
Very Heavy Damage	13.495 (%1,2)	21.221 (%1,8)	4.728 (%0,4)	57.468 (%4,9)	217.682 (%18,7)
Heavy Damage	34.345 (%2,9)	42.003 (%3,6)	16.957 (%1,5)	103.655 (%8,9)	221.515 (%19,0)
Moderate Damage	146.552 (%12,6)	145.973 (%12,5)	95.521 (%8,2)	274.048 (%23,5)	332.663 (%28,5)
(Very Heavy + Heavy + Moderate) Damage	194.392 (%16,7)	209.197 (%17,9)	117.206 (%10)	435.171 (%37,3)	771.860 (%66,2)
Slight Damage	301.626 (%25,9)	273.906 (%23,5)	248.791 (%21,3)	354.188 (%30,4)	257.100 (%22,0)
Undamaged	670.312 (%57,5)	683.227 (%58,6)	800.334 (%68,6)	376.971 (%32,3)	137.370 (%11,8)

The damage estimates made using the earthquake ground motions obtained with the probabilistic earthquake hazard approach are also given in Table 8-1. While the difference between the damage below the earthquake level with a recurrence period of 475 years and the deterministic damage is 3-4 times at the heavy and very heavy damage level, it closes as it decreases to low damage levels. Deterministic damage levels are at a point between 72 and

475 year recurrence periods and correspond to approximately 250-300 years, which is estimated as the recurrence period of major earthquakes that may occur in the Marmara Sea.

Financial losses due to structural damage can be expected to be around 68 Billion TL on average. Considering the losses due to non-structural damages, the financial loss is expected to be around 120 billion TL. This estimate is valid for the Mw=7.5 scenario earthquake. The assessment of the impact of the different earthquake hazard calculation approaches we have presented above for damages also applies to financial losses.

Estimations regarding the loss of life and the number of injured were made by considering the night and day population distributions of the city for the probability of the scenario earthquake to occur during day and night. If the scenario earthquake with a magnitude of Mw=7.5 occurs at night, it is estimated that around 14,150 casualties may occur in Istanbul. If the earthquake occurs during the daytime, the expected loss of life is around 12,400 on average. It is expected that 8,100 people will be seriously injured in the night earthquake and 7,450 people in the day earthquake. In addition, estimates of the number of injured people who need to be treated in hospital conditions are 39,650 for night earthquakes and 37,500 for day earthquakes.

When simulation scenarios and probabilistic earthquake movements in loss of life and casualty estimates use, significant changes can occur in the numbers. The deterministic (Mw=7.5) scenario, the average of 15 scenarios obtained from earthquake ground motion simulations, and the night population loss of life and number of injured estimation results calculated for earthquake ground motions with recurrence periods of 72 years, 475 years and 2,475 years obtained from probabilistic earthquake hazard analyzes, It is presented in Table 8-2.

Table 8-2. Estimation results of night population loss of life and number of injured

Injury Level	Scenario Earthquakes		Scenario Earthquakes		
	Deterministic Scenario (Mw=7,5)	Average of Simulation Scenarios	72 years	475 years	2.475 years
Loss of Life (Level 4)	14.148	23.350	4.104	53.101	206.148
Seriously Injured (Level 3)	8.088	13.464	2.260	31.825	121.675
Hospital Treatment (Level 2)	39.641	62.503	12.965	139.857	516.634
Slightly Injured (Level 1)	75.245	111.550	28.353	241.956	839.495

The simulation scenarios average loss of life and injury estimations are approximately 1.5 times the estimates for the deterministic scenario. Estimation for the recurrence period of 475 years correspond to roughly 3.7 times the deterministic scenario. It is necessary to underline that the numbers obtained from the simulation scenarios show significant differences according to the scenario characteristics. The outputs regarding the injured and loss of life indicate that the total numbers are affected by the earthquake scenario rather than the earthquake occurring during the day or night.

Experiences in past earthquakes have shown that death and injury rates are higher in women and children. The vast majority of casualties occurred during the earthquake, the others occurred while trying to get out of the building or waiting to be rescued according to historical earthquake statistics. About half of the injuries occurred during the shaking, and the other half when trying to get out of the building during or after the earthquake. observed to occur.

One of the most important effect of building damage caused by earthquakes is the loss of buildings' hosting characteristic. Because of this reason, it is significant to determine the emergency shelter areas before an earthquake especially in densely population areas in metropolitan regions. After the earthquake, mostly people don't enter the their house and choose to stay outside and this cause to make matters worse. It can be estimated that after the Mw=7.5 scenario earthquake in Istanbul, approximately 640,000 households and 2,000,000 people considering people per household need an emergency shelter.

It is estimated that 25 million tons of debris could occur because of the possible building damage. If it is assumed that trucks with a load capacity of 25 tons will be used for debris removal, it will be possible to lift a wreck of this size only in 1 million trips. It is clear that the process of debris removal will be difficult and long considering the adverse post-earthquake conditions at the urban scale. During this process, different solutions for debris removal such as sea and air transportation should also be taken into consideration.

Assessment made for high-rise buildings (buildings with 20 or more floors) in the Istanbul for the Mw=7.5 scenario earthquake indicates that 78% of such buildings will not exceed the maximum interstory drift limits with 50% probability. This is an indicative estimation based on the number of floors and construction years of tall buildings only, and is an initial assessment. Assessment for probabilistic earthquake hazard levels are also presented in Chapter 4. High-rise buildings should be examined individually under the effects of earthquakes. Structural and non-structural damage and and other socio-economic loss possibilities should be carefully examined.

Estimation of the expected damages in İGDAŞ natural gas network, İSKİ drinking water and waste water networks and BEDAŞ-AYEDAŞ electricity networks were made in two main groups for the elements. One of them geographical scale point (such as distribution stations, transformer centers) and the other one is counted/extended elements (pipelines, power lines) as a result of scenario earthquake in Istanbul.

It is estimated that there may be a need for repair at 355 points across the city in İGDAŞ pipelines. This figure represents the sum of the calculated number of repair needs per cell, rather than the number of individual leaks or ruptures in natural gas pipelines. It is estimated

that approximately 60% of İGDAŞ stations will not be damaged or will be slightly damaged as a result of the scenario earthquake. It can be expected that approximately 40% of the stations will suffer moderate and higher damage, predominantly moderate. It is possible that the natural gas service boxes located in around 86,500 moderate and higher level damaged buildings are out of service. It has been calculated that repair needs may occur at 463 points in İSKİ drinking water network and at 1045 points in the waste water network according to scenario earthquake. These figures represent the sum of the calculated number of repair needs per cell, rather than the number of individual leaks or ruptures in drinking water or wastewater pipelines. It is expected that 95% of Istanbul power grid transmission lines continue its functionality in undamaged or slightly damaged condition. Moderate damages can be expected in 5% of the network. It is estimated that 69% of the electric network are undamaged and slightly damaged and 31% of the transformers will suffer moderate damage and more than it. Damage estimates for probabilistic seismic hazard levels are presented in Chapter 5.

In cities such as Istanbul with narrow roads, numerically dense and highly vulnerable building stock, road bloackage is a signigicant problem for rescue and aid operations after the earthquake. In this study, a road closure model has been developed for Istanbul. The results showed that the roads in the historical peninsula, districts such as Fatih Beyoğlu, Şişli, Alieyköy, Zeytinburnu, Bayrampaşa, Esenler has possibilities road blockage 30 points in per cell. Roads with three or more lanes are not expected to be completely closed, and there is a possibility of partial closure at some points. After the earthquake, it is estimated that bridges and viaducts will be functional if there are no damage. Figures and maps on this subject can be seen in Chapter 5.

It is of great social and economic importance that urban functions such as education, health, sports, culture, religion, accommodation, trade and industry must be restored as soon as possible after the earthquake. It is understood that more than 60% of the buildings being in commercial areas, industrial and production zones, and accommodation facilities are located in regions where the maximum ground acceleration is greater than 0.2g by looking at the distribution of buildings on the ground motion map calculated for the scenario earthquake of Mw=7.5. Nearly 50% of educational and cultural institutions, health and sports facilities and religious institutions are located in this ground motion zone. These ground motion levels can cause damage to educational institutions, health facilities, commercial areas, accommodation facilities, cultural institutions and religious facilities that have to maintain their functionality during an earthquake and continue their functions afterward.

All estimates presented in this report are based on empirical models from the earthquake engineering literature, either from analytical studies or from experience in earthquakes. These models, like all statistical models, are based on acceptance. and contains various uncertainties. The results presented are average values from the models used. The losses caused by a real earthquake could be different from the results presented in this report.

The estimations are made for the municipal boundaries of Istanbul. The possible damages in Tekirdağ, Kocaeli and Yalova municipalities as a results of the effects of the scenario earthquake are not presented in this report. In other words, the shared predictions are related

with Istanbul not for Marmara Region. Therefore, if the earthquake occurs, the damage will be likely to be higher and more widespread than those presented in the report.

In all earthquake risk determinations made in Turkey so far, population distributions have been determined based on census data. The population distribution determined by this approach represents the night population of the city. It is obviously that population dynamics during the daytime in cities are very different from those at night. The daytime population distribution were made for a single hour (14:00) in this report. Urban population distribution changes during the day depending on urban dynamics. It is likely that there will be a large population affected by transportation infrastructure damage, especially during commuting hours.

After the 1999 Kocaeli Earthquake, the existing highway bridges and viaducts were reinforced in Istanbul. Although current regulations have been used in the designs of newly built bridges and viaducts and metro lines in Istanbul, It is recommended to carry out detailed risk assessment studies considering damages in transportation infrastructure damages caused by the earthquakes in the regions (for example, the Northridge 1994, Kobe 1995 earthquakes).

It is also of great importance that such studies are updated periodically, as in the example of Istanbul - IMM (2001, 2009, 2018). The most important factor that increases the reliability of the estimation is the inventory information. The effective updating and sharing of the required data groups by the relevant institutions will increase the accuracy in earthquake risk analyzes and thus the decision-making processes will be directed in the most accurate way.

The existence of specially developed vulnerability functions for all physical elements for which loss estimates are made is another important factor that increases the reliability of the results. Scientific studies should be supported to reduce the lack of knowledge on this subject.

Industrial facilities are an important building group that increases the risk of urban earthquakes in Istanbul. Within this group, businesses using, storing or producing flammable, explosive, flammable or toxic materials are located in the urban fabric.Evaluations for the determination of the earthquake risk of this group, even if they are intertwined with the urban fabric or arranged and separated as medium and large-scale industrial zones/parks, It is thought that studies and analyzes are not done with the necessary intensity. It is thought that earthquake risk analysis related with these groups must be examined in details.

Likewise, there is a need to expand the studies on reducing the earthquake risk of monumental and historical buildings. In addition, it must be aimed to reduce risks in historical areas and protect them.

With this study, the consequences of a possible earthquake that could affect the whole of Istanbul were revealed and the spatial distribution of the losses was produced and the regions with high risk throughout the city was determined. With the loss estimates, the most basic core knowledge for an integrated assessment of the current risk level in Istanbul were produced. In the "Megacity Indicator System for Disaster Risk Management - MegaIST - Project" carried out by IMM-DEZİM, the current earthquake risk in Istanbul is evaluated integratedly at the neighborhood and district scales. Earthquake loss estimation of physical

elements are the most important factor contributing to the integrated earthquake risk. Thanks to the updating of possible earthquake loss estimation, priority risk areas throughout Istanbul have been revealed and guiding data has been produced in all steps of decision makers to reduce disaster risk.

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