POLICY, PLANS OR STATEMENTS

- **TITLE:** INVESTIGATION OF POSSIBLE ACTIVE FAULTS AND PRIORITY LANDSLIDES AREAS IN THE ISTANBUL TERRITORY BY DOING MULTI-DISCIPLINARY RESEARCH DEVELOPMENT OF LANDSLIDE DETECTION AND MONITORING METHODS WITHIN THE SCOPE OF SCIENTIFIC AND TECHNICAL COOPERATION PROTOCOL
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INTRODUCTION

In cooperation with Istanbul Metropolitan Municipality (IMM) Earthquake and Soil Investigation Directorate (DEZİM) and TÜBİTAK MAM Earth and Marine Sciences Institute (YDBE), this project aim is to investigate possible active faults in the Istanbul land area, to determine the morphology of the shallow seabed between Büyükçekmece and Ataköy, to develop methods for landslide detection and monitoring by conducting multidisciplinary research in priority landslide areas,

In line with these objectives, the works carried out within the scope of the project are given below under the main headings:

- Faults (between Büyükçekmece-Küçükçekmece and Tuzla-Kartal) located within the Istanbul Metropolitan area and whose activity is suspected, were investigated by seismological/geodetic methods.
- In order to reveal the details of the sea/land transition zone in terms of landslides, studies were carried out to determine the shallow seafloor morphology (up to 20 meters water depth) between Büyükçekmece and Ataköy.

- In priority landslide areas (Yeniköy and Çatalca-İzzettin Yolu landslides), multi-disciplinary methods have been applied with high efficiency in landslide detection and monitoring, but not widely used in our country. With the information obtained from these applications, the methods for investigating and monitoring landslides were examined, and their advantages and disadvantages were revealed.
- A methodology to be taken as a reference in studies to be carried out in landslide areas has been created and the methods have been classified.
- By using all the data obtained from the priority landslide areas, the developmental stages of the landslides were modeled.
- Suggestions for concrete measures for improvement, which should be considered before and after any construction work to be carried out in priority areas, were defined by the competent experts whose opinions were taken.
- Information on earthquakes in the region, based on scientific findings obtained through continuous geochemical and microseismological studies, was provided to IMM DEZİM and AKOM to obtain information on disaster coordination and vigilance in the medium term.

In the first part of the report, the areas worked within the scope of the project are defined. The results of the multidisciplinary study of faults whose activity is suspected are given in the Second Chapter. The use of the methods and analysis approaches are also described in detail in this section.

The studies conducted for the detailed definition of the landslides belonging to the sea/land transition zone between Büyükçekmece and Ataköy, where the landslide problem is most common in Istanbul, constitute the content of the third chapter.

The definition of the methodology to be taken as a reference in the studies to be carried out in landslide areas and the findings regarding the priority landslide areas studied within the scope of this methodology (Yeniköy and Çatalca-İzzettin Yolu landslides) are given in the Fourth Chapter. In this section, the strengths and weaknesses of the methods used in practice are also questioned and classified. In addition, in the problems in the priority landslide areas, the outputs of all methods were questioned by using integrated recommendations are given.

Chapter five contains an overview of the entire project and recommendations for the future.

1.GENERAL EVALUATION AND RECOMMENDATIONS

1.1 General Evaluation

The project has been designed as an umbrella project covering three main subjects, and in the following section, the main results obtained from these studies have been grouped and evaluated as items:

1) **General evaluations for the investigation of faults suspected of activity in the Istanbul land area**
    - In order to investigate the activity of faults in the potentially active land area with GPS, PSInSAR and seismology studies, primarily between Büyükçekmece-Küçükçekmece and Tuzla-Kartal were studied with the existing knowledge.
    - At the beginning of the project, the GPS observation network, which was created within the scope of previous projects (Implementation of New Methods for Earthquake in the Marmara Region 2001-2003; Earthquake Prediction Studies in the Marmara Region, 2004; Gebze-Kartal Seismic Zone Earthquake Risk and Seismic Hazard Assessment 2003-2005; Monitoring the Earthquake Activity of the Marmara Region with Multidisciplinary Methods and Investigation of Its Possible Effects on the Istanbul Coastline/Continental Shelf Ground 2007-2008) for İBB DEZİM, was expanded and a local network of 22 points was created to identify possible discontinuities in the west of Büyükçekmece and east of Küçükçekmece and in the Tuzla region.
    - While creating new points, the data is different by IMM, Pillars belonging to the Istanbul triangulation network were also used in order to use it in studies. The data obtained were analyzed systematically and the changes in the speed area of the Marmara Region were taken under control. The number of points analyzed in the project is 101.
    - The area between Büyükçekmece-Küçükçekmece and Tuzla-Kartal has been continuously monitored by 16 seismology stations throughout the entire project to reveal the micro-scale (magnitude > 0.5 ML) earthquake activity.

- Archival (ERS1/2) and current (ENVISAT) data were analyzed for the PSInSAR study, which was conducted to display the deformation changes in Istanbul. Archival (ERS1/2) and current (ENVISAT) data were analyzed for the PSInSAR study, which was conducted to display the deformation changes in Istanbul. The results were checked by integrating with the time series from continuous GPS stations.
- According to the GPS and InSAR results, It is seen that the most deformation area is between Büyükçekmece and Küçükçekmece. As we know from all the work we have done in the region, the main source of deformations in the region are landslide areas that develop on land extensions of faults that are generally mapped in the sea r (Ergintav et al; 2011). Possible causes of observed surface changes, lithological changes (for example, water-saturated levels shift weak material over them) and small-scale activities on these faults trigger landslides.
- Strain anomalies detected by GPS and PSInSAR around Tuzla are predominantly related to post-earthquake deformations already continuing in the region after the 1999 earthquakes. The results obtained are seen as the result of elastic loading in the area close to the northern branch of the North Anatolian Fault (NAF) and post-earthquake changes in the far area.
- The combined analysis of GPS and PSInSAR results for before and after the 1999 earthquakes shows that there was no significant stress increase in the region, contrary to what was expected after the 1999 earthquake. The reason has been discussed for this is different possibilities in the report. the western end of the 1999 fracture. The strongest possibility is which is the western end of the 1999 fracturein the segment of Islands, emerges as observing a creep event or having a shallow lock-in depth. Low earthquake around the islands seğment activity supports the possibility of creeps. In order to give certainty to the subject, it is necessary to establish geodetic control points around the fault segments in the Marmara Sea and to increase the number of seabed seismological observation stations specifically for the region.
- Tuzla region is the area where the most seismological activity was observed during the project period. No evidence of a possible active fault was found in the field that is suitable for the combined fault plane solution of the earthquakes in this region. However, a possible fault is shown in the geological map made by Prof. Dr. İhsan Ketin (January 1990 - April 1991) in the region where the earthquake cluster is located. Earthquakes in this region may be related to this fault, but sufficient scientific evidence

should be available to make a further interpretation. However, considering that the region is under the control of the right-lateral strike-slip North Anatolian Fault system, it is a fact that secondary structures can be seen. Basically, two fault planes were obtained in Tuzla region. As it is known, it is not clear which of the nodal planes is the fault plane from pure seismology data. If the fault plane dips to the north and strikes WNW-ESE which is belongs to the nodal plane, this solution is suitable for the right lateral “Redel (R)” structure. On the other hand, if the fault plane is associated with the N-S left lateral faulting nodal plane, it conforms to the "anti-Riedel (R')" structure. Observations should be continued in order to interpret the activity in the region properly.

- The seismic activity between Küçükçekmece and Büyükçekmece is very low and a significant part of it occurred in the sea. Some of the small earthquakes observed on land are thought to be related to the Küçükçekmece Fault. For the activity observed during the project, a healthy fault plane solution for the region could not be obtained. In addition, since the earthquakes did not show a certain sequence and distribution, a combined fault plane solution could not be made. In order for the activity in this region to be determined properly, observations need to be continued. By increasing the number of seabed seismological observation stations specific to the region, it will be possible to obtain clearer findings regarding the source of the activity in the sea.

2) General evaluation of the researches on the determination of the shallow seafloor morphology (up to 20 meters water depth) between Büyükçekmece and Ataköy

- Within the scope of the project, the shallow bathymetry of the section between Büyükçekmece and Ataköy was determined for the first time.
- The unmapped parts of the shallow depths along the shoreline that the research vessel cannot enter were filled with special data processing techniques and no empty space was left in the coastal/sea transition zone. In this way, morphological changes in land and sea were mapped and interpreted by associating them.
- In the support of the seismic data collected during the previous studies in the region, sediment accumulating regions and rocky areas were defined.
- The detail of the sea/land transition zone has been revealed, especially in terms of landslides, and different structural elements have been defined. For example, when the bathymetry map of the junction area of Büyükçekmece Lake and Büyükçekmece Bay is examined, the existence of a different topographic change

is striking. It has been interpreted that this topographic structure represents the spreading area of the sediments entering the northern shores of Büyükçekmece Bay from Büyükçekmece Lake, especially during flood times. This structure, which reflects a typical fan shape, can be observed in different shapes and sizes in many parts of the research area. This observed area is located between two ports in the region. These ports have been affected by the excess sediment inputs coming to the region are thought to be possible.

- The effects of landslides on both the terrestrial topography and the sea floor are exemplified with the sections that cut the structural elements. When the sections were examined, the areas where material (soil) loss occurred on the coast as a result of landslides or sea erosion were determined.
- Bathymetry is the basic data set in studies to determine the tsunami hazard. Morphological changes, especially in shallow areas, it dramatically changes the wave height that may occur after tsunami. There is a need to renew the tsunami hazard models of the region with the bathymetry data obtained as a result of this study.
- The obtained data were delivered in a way that could be queried in the GIS environment and formed a basis for different projects.

3) **General evaluation of the studies on the development of methods for landslide detection and monitoring by conducting multidisciplinary research in priority landslide areas**

- Although the research areas of Yeniköy and Çatalca, which are considered as a priority, are far from each other, they have similar characteristics in terms of soil structure and meteorological conditions. The most distinctive feature that distinguishes these areas from each other is that the Yeniköy landslide area was shaped under the influence of the Kara Sea in the north and the Çatalca landslide area was shaped under the influence of the Karasu River in the northeast.
- Topography changes, slip tracks and landslide topography in Yeniköy and Çatalca study areas were monitored by making periodic (exampling seasonal changes) and continuous observations in geodetic observation networks. Strain analyzes were carried out Systematically for topography changes in the region with the collected data. In this way, the temporal and spatial control of the problem in question was realized.

- A total of 7.6 km seismic reflection studies were carried out in order to reveal the depth information of landslides in Çatalca and Yeniköy. Two different data processing approaches were developed for shallow and deep sections for the analysis of seismic data and the results were interpreted in order to control the depth dimension of the landslide areas. In order to support the findings obtained, Multi-Channel Analysis of surface waves (MASW) was carried out in both areas by considering the surface waves in the shot data of seismic sections. By taking electrical sections, the effectiveness of this widely used method in landslide areas was questioned.
- The locations of 6 inclinometer wells in Yeniköy research area and 8 in Çatalca research area were determined by geological, geodetic and seismic studies. 5 of the wells drilled in both regions, continuous observation studies were carried out. In the remaining, one well in the Yeniköy research area and three wells in the Çatalca research area, periodic measurements were carried out.
- Continuous monitoring of deformations in landslides as a function of depth was carried out with the help of inclinometer indexes placed in 5 wells in Yeniköy and Çatalca, where continuous observation was made. The locations of the inclinometer elements in the indexes are positioned to control the different structural changes in the depths. Elements ranging from 3 to 5 were used in each well. Inclinometer data collected at 1 minute intervals on site can be monitored with 1-hour sampling from a web interface and IMM can follow these data instantly.
- In Çatalca and Yeniköy, Time Domain Reflectivty (TDR) measurements were applied as a cheap and practical method to support inclinometer measurements. The use of TDR within the scope of this project constitutes the first application example on the subject in our country.
- In Çatalca and Yeniköy, some wells drilled near the inclinometer wells for coring and ground control are arranged to allow water level observation. Monthly measurements were carried out in 4 water observation wells in Çatalca and 2 in Yeniköy.
- The results of the strain analysis, which were carried out to monitor the topographic changes recorded in the landslide areas, were questioned in the light of the water level changes and the data obtained from the digital meteorology

stations established within the scope of the project in Yeniköy and Çatalca. Generally, the places where landslides are dominant are under the control of the topographic slope.

- SPAC Index and H/V, which are frequently used in engineering applications SPAC Index and H/V Microtremor analyzes in Yeniköy and H/V analyzes in Çatalca were carried out in order to question the contribution of microtremor analysis methods to the solution of problems in landslide areas, to reveal the changes in S velocity with depth, and to identify weak zones with high potential slipping potential. The findings compatible with the results of seismic reflection and electricity.
- In addition to inclinometer and TDR observations, landslides were monitored with a new approach. A digital compass placed in a non-magnetic container was lowered with its special wheels along the periodically observed inclinometer wells to monitor the torsion of the wells (i.e., the angular change of strain) as a function of depth. In this way, a new approach has been developed for the continuous detection of deformations that can be observed in perpendicular (only 90 degrees) directions at all angles (0-360 degrees). This developed system was designed by YDBE within the scope of the project.
- Methods for investigating and monitoring landslides were examined, and their advantages and disadvantages were revealed. A methodology aimed to be taken as a reference in studies to be carried out in landslide areas has been created and the methods have been classified. The created classification is given in brochure format for effective use and it is ensured that it can be used independently of this report. (App 5). Each step of the methodology is detailed in items to assist the practitioner. It is also possible to use it as a specification if desired. The priority study areas were studied by following this mentioned methodology.
- The results of the multi-disciplinary researches were examined in an integrated manner, and with the contribution of the results of the continuous monitoring studies carried out in the fields throughout the project, primarily the study areas were interpreted in terms of landslides.
- After long-term observations in the Yeniköy research area, it has been determined that there is a close relationship between the precipitation periods of the region and the periods of landslides and landslides. Both the GPS

measurements carried out in landslide areas and flows detected after the inclinometer studies are in close relationship with both the rainy periods and the rising periods of the underground water table, which develops in parallel with these periods. In addition, the coast is eroded by the effect of the wave and current regimes of the sea, collapses and overturns are experienced in the coastline, the lower part of which is carved, and the coastline changes.

- In the studies carried out in the Yeniköy research area, it has been evaluated that the environment has a heterogeneous structure and that the heterogeneity may possibly arise from the complex material accumulations related to the old landslides (or soil flows) in the region. In addition, the seismic reflection profiles made in this field apart from the local and shallow anomalies in the existing sections, it is clearly observed that the deeply stratified structures are horizontal and close to horizontal. Obtained data show that openly observed sandy/clay levels on the surface create shallow slides and flows due to precipitation triggering the slide and these changes control the topography in the region. During the field studies, it has been observed that the movements generally occur at sandy and silty levels close to the surface. At this stage of the slip, the upper levels it is in the form of minimal creep; In the sections below this, it is likely that the groundwater developed as a result of the interaction of the cracked units, usually in small quantities and with varying unit limits, it is understood that it exhibits compatible ductile behavior.
- In the Çatalca research area, it was determined that the units at the upper levels were much more deformed than the units at the lower levels. It is also stated that the vertical discontinuities observed in the sections may also be transitions caused by landslides at shallow elevations and/or possible old landslides. A general slip plane controlling the entire area of the current landslides has not been observed, and it has been stated that the changes observed at depth are highly likely to be related to paleo-landslides. It has been determined that the sandy and clayey levels observed on the surface, especially due to their saturation with precipitation, trigger flow structures and cause the formation of shallow landslides. At this stage, slip movements indicate ductile behavior at levels close to the surface and shallow landslides, and at lower levels, generally negligible, with the effect of groundwater.

- By using all the data obtained from the priority landslide areas, the developmental stages of the landslides were modeled. According to these studies, in reaching the present topography of the Yeniköy region, and the ground experienced from time to time, the effect of the Black Sea, located in the northeast of the Yeniköy research area, is great. As a result of the long-term erosion and transport effect of the Black Sea in the coastal area, the region has reached its current state of instability. In order to be able to control the ground movements in the region with the most basic method, it is necessary to control the erosion effect of the Black Sea on the coastal area of the region and at the same time to prevent the transport of materials from the terrestrial area to the sea area. For the Çatalca research area, the Karasu Stream and this creek located in the northeast of the region, the sea level of the Sea of Marmara, into which it flows, has a great effect. The region has reached its current state of instability as a result of the long-term erosion and transport effect of the Karasu Stream on the valley sides. In order to be able to control the ground movements in the region with the most basic method, it is recommended to control the bed where the Karasu Stream flows and to prevent material transport from the region by eroding the valley sides during flood periods. In addition, reclamation of landslide areas and prevention of material coming from the slopes after flooding and washing in rainy periods are among the top priority measures to be taken for the rehabilitation of the region.
- Suggestions for concrete measures for improvement that should be considered before and after any construction work to be carried out in priority areas have been defined with the contribution of competent experts. In any case, single or multiple solution proposals that can be produced should be evaluated by the responsible administrations in terms of technical feasibility and economic cost, and the appropriate solution should be implemented.

1.2 Future Recommendations

Some of the studies carried out within the scope of the project include measurements that require continuity. Another part will be a starting point for new studies. In this section, suggestions that will form a basis for possible new studies are defined below.

- The operation of the seismological and GPS observation networks created in order to question the existence of active faults between Büyükçekmece-Küçükçekmece and Tuzla-Kartal should continue. The three-year project duration is not long enough to question the existence of the activity.
- In order to question the causes of low earthquake activity around the islands segment of the NAF and the possibility of creeps, it is necessary to establish geodetic control points around the fault segments in the Marmara Sea and to increase the number of OBS specific to the region. In this study, the expected Istanbul earthquake necessary to determine the size.
- The bathymetry study carried out should be expanded to cover the entire coastline of Istanbul with the same quality. Currently, the data obtained within the scope of the project covers only 10-15% of the shallow parts of the continental shelf of Istanbul.
- Tsunami studies that have been done should be updated using new bathymetry and shallow seismic data.
- In order to make effective plans for the construction works to be carried out along the coast, studies similar to microzonation on land should also be carried out in the shallow parts of the continental shelf.
- The methodology created for the study of landslide areas should be used as a reference document for a basic specification on the subject. For the tenders to be made, training programs and consultancy system should be established for an effective evaluation.
- Practical training programs should be established in order to spread the use of effective methods for the analysis of landslide areas.
- The effectiveness of new methods such as LIDAR, which are not yet widely used in our country, should be constantly questioned, and the number of available methods should be constantly enriched with new techniques.
- According to PSInSAR results, the regions with the highest deformations in Istanbul (between Büyükçekmece and Ataköy) should be controlled with continuous inclinometer and GPS systems, and an early warning system for landslides should be established for Istanbul in general.
- The information from the early warning system should be use to proactive measures to reduce the landslide hazard.

- Effective use of manpower and resources for disasters should be ensured by integrating the early warning system for landslides and the early warning system for earthquakes.