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# ADAPAZARI-KARASU DEVLET YOLU GÜZERGAHINDAKİ ZEMİNLERİN DİNAMİK ETKİLERİNİN ARAZİ DENEYLERİ VE SAYISAL YÖNTEMLERLE DEĞERLENDİRİLMESİ

# ASSESMENT OF DYNAMIC EFFECTS OF SOILS WITH IN-SITU TESTS AND NUMERICAL METHODS ON ADAPAZARI-KARASU STATE ROAD

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## ÖZET

Depremler engellenemeyen büyük doğa olaylarıdır, alınan geoteknik önemlerle yaşanan can ve mal kayıpları azaltılabilir. Çalışma alanının tamamı Sakarya Nehrinin taşkın alüvyon ovası içerisinde yer alan akarsu ve göl çökelleri üzerine gelişmiş çakıl, kum ve kil birimlerden meydana gelmektedir. Genel olarak, silt, kil ve kumlu karakter içeren bu birimler organik madde içeriği açısından da zengindir. Ova Sakarya Nehrinin su seviyesine çok yakın olup yılın önemli bir bölümünde yeraltı suyu seviyesinin yüzeyde olduğu görülmektedir. Bu çalışmasında Sakarya ilinde Adapazarı-Karasu Devlet Yolu Sinanoğlu-Limandere geçişinde bulunan ve yukarıda bahsedilen oturma ve sıvılaşma potansiyeli olduğu düşünülen zayıf zeminlerin statik ve dinamik koşullarda etkileri araştırılacaktır. İlgili bölgedeki konsolidasyon oturması ve sıvılaşma sonrası oturmalara önlem olarak yol geçkisinde farklı alternatifler düşünülmüştür. Ekonomik olan çözüm olarak öngörülen köprü alternatifi üzerinde çalışılmıştır. Köprü alternatifi çalışılırken dinamik etkilerin incellenmesi için sahaya özel deprem kayıtları seçilmiş ve bir boyutlu olarak serbest saha analizleri gerçekleştirilmiştir. Daha sonra ilgili köprü alternatifi üç boyutlu olarak sonlu elemanlar yöntemiyle modellenmiştir. Elde edilen serbest saha deplasmanları üç boyutlu sonlu elemanlar programında kullanılarak dinamik deplasmanlar altında köprü kazıklarındaki etkisi araştırılmıştır. Yapılan tüm bu geoteknik değerlendirmeler sonucunda yapılan çalışmalar ilişkin olarak uygun önlem ölçümleri önerilmiştir.
***Anahtar Kelimeler:*** *Geoteknik Arazi Deneyleri, Kuzey Anadolu Fay Hattı, Sıvılaşma, Sahaya Özgü Sismik Tehlike Analizi, Serbest Saha Analizi, Üç Boyutlu Sonlu Eleman Modeli*

## ABSTRACT

Earthquakes are natural events that cannot be prevented; however, with the required geotechnical measures taken, the loss of life and property in earthquakes can be reduced. The entire study area consists of gravel, sand, and clay deposits in flat-lying areas that have been developed in older depressions in streams and lake beds located in the flooded alluvial plain of the Sakarya River. In general, these units containing silt, clay, and sandy character are also rich in organic matter content. The flat plain elevation is very close to the water level of the Sakarya River, and it is seen that the groundwater level is at the surface for a significant part of the year. In the study, the soils that are thought to have liquefaction and settlement potential and which are located at the Adapazarı-Karasu State Road Sinanoğlu-Limandere transition will be investigated in static and dynamic conditions. Alternatives to the road crossing have been considered to prevent settlements and liquefaction that would occur. The bridge alternative, which is seen as the most economical solution, has

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been studied. While studying the bridge alternative, earthquake records specific to the region were selected. One-dimensional free-field analyses were carried out. Then, finite element modeling has been used to model the related bridge alternative in three dimensions. Bridge piles under dynamic displacements have been investigated based on the free field displacements obtained. As a result of all these geotechnical evaluations, appropriate remedial measures have been proposed for the studies carried out.
***Keywords:*** *Geotechnical Field Test, North Anatolian Fault Zone, Liquefaction, Site Specific Seismic Hazard Analysis, Free Field Analysis, Three-Dimensional Finite Element Model*

## 1. INTRODUCTION

The purpose of the study is to assess the effects of seismic events on problematic soils located in the flooded alluvial plain on the Sakarya province Adapazarı-Karasu State Road, Sinanoğlu-Limandere route. This area is one of the most dangerous areas in terms of earthquakes. 1999 Kocaeli and Düzce Earthquakes confirm this situation. The entire study area consists of gravel, sand, and silt deposits in flat-lying areas that have been developed in older depressions in stream beds located in the flooded alluvial plain of the Sakarya River. It consists of floodplain sediments that have not undergone little or no consolidation. In general, these units containing silt, clay, and sandy character are also rich in organic matter content. The ground elevation is very close to the water level of the Sakarya River, and it is seen that the groundwater level is at the surface for a significant part of the year. The soil sediments that are thought to have the liquefaction potential mentioned above and located at the Sinanoğlu-Limandere crossing of the Adapazarı-Karasu State Highway in Sakarya province have been investigated. Regarding these alluvial sediments located along the highway route, soil characterizations have been performed with the aid of analyzes developed depending on the geological environment by evaluating the geotechnical data obtained from in-situ boring studies and geotechnical laboratory experiments from the study area. In-situ field test results (SPT, CPT, etc.) have been used to analyze soil characteristics and behavior in sedimentary environments. By using the data obtained from the geotechnical field tests, empirical liquefaction analyses and then post-liquefaction deformation analyses have been performed by using the new code regulation of Turkey (TBEC, 2018). Within the scope of this research, A total of 7 boreholes were drilled along the highway route in the study area, four of them on the left and three of them on the right of the route. The total depth of the boreholes is about 243 m.
Geotechnical characterization of the study area was carried out using field experiments and laboratory test results. In addition to this, shear wave velocity was obtained by using correlations of SPT and CPT data obtained from field experiments. In this way, data were obtained to assess the dynamic sediment characteristics of problematic soft lake deposits. After examining the study area as a highway route, alternative solutions have been discussed for the problematic soil ground. As a solution appraisal, the relevant study evaluated whether it is appropriate to construct a bridge along the highway crossing in the problematic area. In recent years, soil-structure interaction (SSI) has been increasingly studied concerning the responses of active control structures. The effects of (SSI) on the responses of structures to earthquake excitations are widely acknowledged (Luco, 1998). To properly analyze structures situated in seismically active areas, it is crucial to consider SSI effects. The dynamic characteristics of the structural reaction can be greatly changed. The dynamic study of structures in the soil medium must therefore take into account how these impacts interact (Kim & Yun, 2000). In Turkey, after the TBEC (2018) legislation, research studies on this subject have increased rapidly. In this study, according to the Turkish Building Earthquake Code specifications (2018), the dynamic analyses of the soil condition have been assessed considering this issue in detail along the highway route in Sakarya province near the Adapazarı Region.

### 1.1. Purpose and Scope

The study area, located on the highway route within the borders of the Sakarya – Adapazarı district, is located in an area where seismic activity is high and which has the depositional setting of many fluvial lake sediments. The North Anatolian Fault Zone (NAFZ) is one of the largest currently active strike-slip faults in Turkey and constitutes the most prominent part of the deformation belt formed by a medium-sized strike-slip fault. The Hendek Fault, which extends between Sapanca Lake-Hendek-Cumayeri in the west of the Düzce basin, extends from the Northeast to the Southwest.
In the study area, geotechnical in-situ testing and laboratory experiments have been performed to characterize soil sediments. These data were collected to define soil parameters and determine the nonlinear

behavior of the local site conditions. And also, empirical correlations have been used to characterize the shear wave velocities of the soil ground.

The study area with loose soil deposits and loose sediment transitions in fluvial activity has been primarily considered as a highway road. First of all, the problems that are thought to arise depending on the existing soil properties were analyzed if this transition was designed as a highway road. It has been assessed in terms of settlement and liquefaction concerning those mentioned in the route. Consolidation settlement and liquefaction problems were observed along the road crossing, and large deformations were calculated. Different remediation methods have been considered in the study area. Jet grout, deep mixing, wick drain, stone column, and bridge alternatives were briefly considered. According to the results of the analysis obtained, the problems that may occur in the road route have been evaluated, and then a bridge crossing was designed in the environment where the mentioned loose sediment transitions were present. By designing the piled bridge, settlement and liquefaction problems expected to occur in the road design were tried to be solved. Rock socketed piles were designed for the weathered rock located under the 10-15 m deep alluvial sediment so that the weathered rock was reached by crossing with the alluvial sedimentary piles, which are expected to have settlement and liquefaction problems. The dynamic analyses of the rock socket bridge, for which static calculations were performed, were also carried out within the scope of the study. While designing the pile, site-specific earthquake records were selected, and free-field soil behaviors were calculated. Using the distance of the study area to the NAFZ and the shear wave velocity profiles of the study area, 17 site-specific earthquake records were selected. Of the 17 selected earthquake records, the 7 earthquake records most suitable for the average spectrum were determined to be used in the analyses. Free field displacements were obtained for all 7 different earthquake records selected. Average free field displacements were obtained.

There are different methods for performing dynamic analysis of the bridge. By creating the p-y curves in the literature for the soil and rock units, the spring is given along the pile by using the p values corresponding to the displacements obtained in the free field displacements in the structural software. After the spring is given along the pile, push-over analysis is performed to obtain the shear force, bending moment, and axial loads that occurred in the dynamic condition of the piles.

Another method is by modeling the three-dimensional soil ground. The bridge substructure is modeled separately from the superstructure. A three-dimensional model is established so that the free field displacements affect the piles. The shear force, moment, and axial force values that occurred in the piles are obtained. In this study, dynamic soil analyses were made with a three-dimensional numerical model. The pile behavior under the displacements obtained from the results of the free field analyses was investigated by creating a three-dimensional numerical model. Pile designs were made according to dynamic effects.

The pile reinforcements were calculated by using the shear force and bending moments obtained as a result of the analysis. In this way, a solution was obtained for the weak ground transition, and it was seen that the bridge solution was sufficient for the problematic soil transition (**Hata! Başvuru kaynağı bulunamadı.**).

### 1.2. Methodology

The methodology used in this study can be divided into six stages:

1. Collection of comprehensive data, including geological field characterization, deep engineering geological and geotechnical borings, standard penetration tests, cone penetration tests, and geotechnical laboratory tests.
2. Evaluating the engineering geology, geotechnical, and geophysical characteristics of the study area and determining the lateral and vertical variations in the soil conditions of the region.
3. Evaluation of road alternatives of the route, settlement analysis under road embankment, and performing empirical liquefaction analysis.
4. Analyzing 1D soil responses and determining the locations of site response considering the period and spectral amplitudes.
5. Evaluation of bridge alternative and 3D dynamic analysis of bridge pile.
6. Comparison of the design of the relevant route as a road and a bridge.

### 1.2. Site Characterization

The geological profile from engineering boring studies reveals the following layers:

Alluvium deposits, up to 33.0m thick:
The upper 11.0m layer is MH-OH soil with low consolidation (SPT(Nave) < 5) and organic matter. Below, near the depression basin, sand and gravel accumulations are consolidated as SM-SC-GM soil (SPT(Nave) > 25). Further down, clay silt sedimentation is observed, consolidated as MH soil (SPT(Nave) > 20). At the base of the alluvium layer, conglomerate units (GC-GM-GW) composed of clay-sand grain size binder, gravel, and block fragments are found. The basement rock is flysch-type succession rock

## 2. NUMERICAL MODELLING

The bridge alternative, which is assumed to have optimum cost and is quite effective for the relevant segment, has been evaluated. In the following chapters, the behavior of the bridge foundation under static and dynamic loading conditions has been examined.

### 2.1. Dynamic Analysis

Soil profile in the field was created in the DEEPSOIL software by using shear wave velocities and soil and rock parameters obtained from geotechnical field experiments correlations. After the idealized site profile was created in the software, the site-specific earthquake record selection was performed. While selecting site-specific earthquake records, features such as surrounding faults and distance to the fault were taken into account. . A total of seventeen earthquakes were scaled (**Hata! Başvuru kaynağı bulunamadı.**), and seven of them were used to create suits using the criteria outlined above. Scaling was performed on the h1 components of each record.

| ID | Record | Earthquake Name | Year | Station Name | Mw | Mechanism | Rrup (km) | Vs30 (m/sec) | Scale Factor |
|---|---|---|---|---|---|---|---|---|---|
| 1 | RSN180 | "Imperial Valley-06" | 1979 | "El Centro Array #5" | 6.53 | SS | 3.95 | 205.63 | 0.9242 |
| 2 | RSN723 | "Superstition Hills-02" | 1987 | "Parachute Test Site" | 6.54 | SS | 0.95 | 348.69 | 0.7503 |
| 3 | RSN821 | "Erzican_ Turkey" | 1992 | "Erzincan" | 6.69 | SS | 4.38 | 352.05 | 0.9811 |
| 4 | RSN1106 | "Kobe_ Japan" | 1995 | "KJMA" | 6.9 | SS | 0.96 | 312.0 | 0.7671 |
| 5 | RSN1119 | "Kobe_ Japan" | 1995 | "Takarazuka" | 6.9 | SS | 0.27 | 312.0 | 0.8459 |
| 6 | RSN1120 | "Kobe_ Japan" | 1995 | "Takatori" | 6.9 | SS | 1.47 | 256.0 | 0.6241 |
| 7 | RSN1602 | "Duzce_ Turkey" | 1999 | "Bolu" | 7.14 | SS | 12.04 | 293.57 | 0.8606 |
| 8 | RSN1605 | "Duzce_ Turkey" | 1999 | "Duzce" | 7.14 | SS | 6.58 | 281.86 | 0.859 |
| 9 | RSN3968 | "Tottori_ Japan" | 2000 | "TTRH02" | 6.61 | SS | 0.97 | 310.21 | 0.6049 |
| 10 | RSN4040 | "Bam_ Iran" | 2003 | "Bam" | 6.6 | SS | 1.7 | 487.4 | 0.692 |
| 11 | RSN4116 | "Parkfield-02_ CA" | 2004 | "Parkfield - Fault Zone 14" | 6.0 | SS | 8.81 | 246.07 | 0.807 |
| 12 | RSN5827 | "El Mayor-Cucapah_ Mexico" | 2010 | "MICHOACAN DE OCAMPO" | 7.2 | SS | 15.91 | 242.05 | 0.8848 |
| 13 | RSN5992 | "El Mayor-Cucapah_ Mexico" | 2010 | "El Centro Array #11" | 7.2 | SS | 16.21 | 196.25 | 0.9282 |
| 14 | RSN6906 | "Darfield_ New Zealand" | 2010 | "GDLC" | 7.0 | SS | 1.22 | 344.02 | 0.5741 |
| 15 | RSN6911 | "Darfield_ New Zealand" | 2010 | "HORC" | 7.0 | SS | 7.29 | 326.01 | 0.7103 |
| 16 | RSN6927 | "Darfield_ New Zealand" | 2010 | "LINC" | 7.0 | SS | 7.11 | 263.2 | 0.8894 |
| 17 | RSN6962 | "Darfield_ New Zealand" | 2010 | "ROLC" | 7.0 | SS | 1.54 | 295.74 | 0.8932 |

Figure 1 A summary of the pulse-like ground motion records that were chosen (PEER Ground Motion Database, NGA- WEST 2)

After the earthquake records suitable for the site were obtained, the relevant earthquake records were entered into the software. By using DEEPSOIL software, free field displacements were obtained for each selected earthquake record. Average free field displacements were obtained.

In the dynamic analysis, a three-dimensional soil model has been developed to define horizontal deformations by using the displacements obtained from the free field. In this study, shear force, bending moment, and axial force values that occurred in piles in dynamic conditions were obtained by making 3D modeling.

## 3. RESULTS

For the dynamic analysis of the bridge, seventeen earthquake records were selected first, and then the most suitable seven earthquake records were chosen for the analyses. The average target spectrum was determined and given in Figure 2. Seven previously selected earthquake records were defined in the

DEEPSOIL program. Using the idealized soil profile, free field displacements were calculated separately for each of the seven records. Dynamic pile analyses were performed using the mean of the calculated displacements as prescribed displacements (Figure 3). As a result of the free field analysis, large displacements were observed after 15 m depth. In particular, the horizontal displacements in the areas where liquefaction is expected suddenly increased between 15 and 18 m representing the transition between the liquefiable layer and clayey soil (Yaşar, 2023).

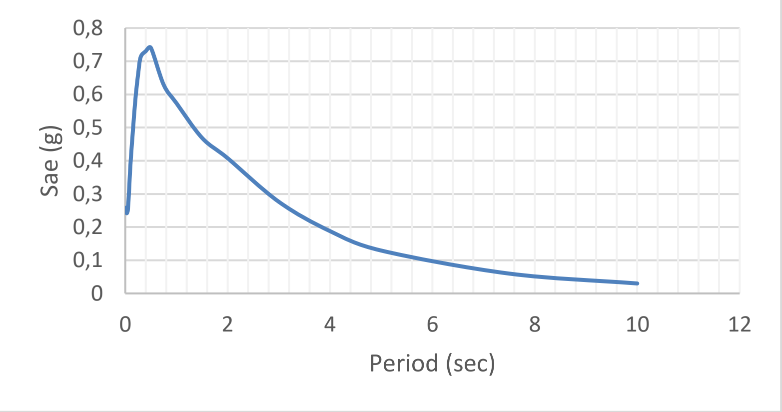


Figure 2 The mean match spectrum developed by averaging the spectra of the seven earthquakes (target spectrum).

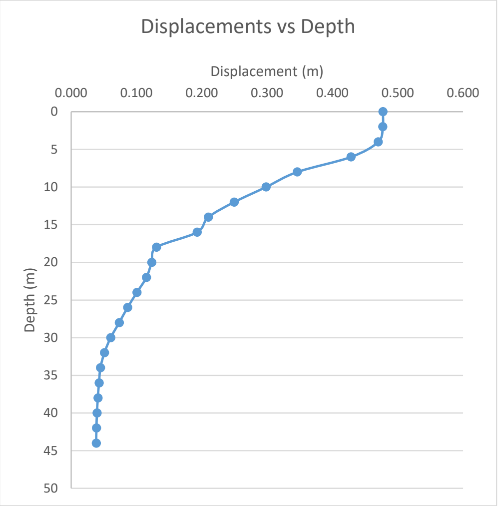


Figure 3 Free field displacements vs. depth

Using Midas GTS NX software, the bridge foundation, piles, and soil profile were modeled in three dimensions. Bridge construction stages were defined separately in the three-dimensional model. The mean free field displacements obtained from the selected earthquake records were factored into the model. Therefore, the determined prescribed displacement was given in scale from the model edges to obtain them in the middle of the relevant model (Figure 4). In this way, the damping property of the ground was also considered. As a result, the effects of the free field prescribed displacements on the piles have been analyzed in the three-dimensional model (Figure 5).

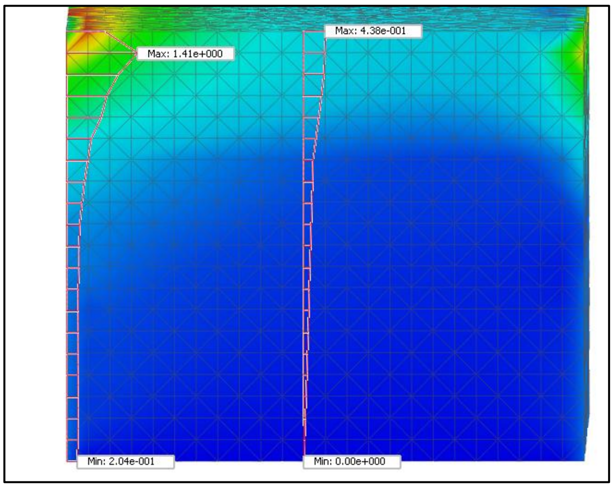


Figure 4  Free field displacements

With the implementation of piled bridge remediation, the previously observed horizontal displacements of around 50 cm in the free field have been reduced to approximately 30 cm. This remediation technique has effectively mitigated the displacements, resulting in improved stability. Furthermore, the displacements that occurred in a pile have created shear and moments. Shear and axial force results, as well as bending moment results, have been obtained. By using the obtained shear and moment, the pile reinforcements were determined. The maximum shear force obtained is in the region where the unit passes from the stiff to the liquefied sediments. Therefore, the frequency of stirrups reinforcement is due to the horizontal deformation of the piles during liquefaction. The shear and bending moment that occurred during liquefaction was covered by the pile reinforcements capacity. It has been seen that the obtained results for the designed pile bridge were also sufficient in terms of dynamics and static conditions (Yaşar, 2023).

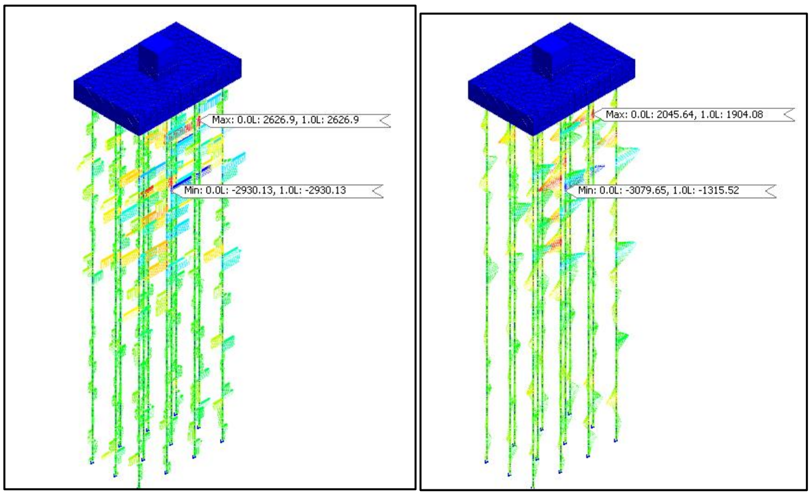


Figure 5 Shear force results / Bending moment results

## 4. CONCLUSION

Geotechnical investigations have been conducted to assess the problematic soil conditions along the highway on the Sakarya province Adapazarı-Karasu State Road, utilizing both static and dynamic analysis methods. The study has also involved the use of analytical and numerical approaches. Along the designated road route, significant consolidation settlements were identified under a 2.5-meter layer of road fill. Liquefaction analyses conducted in the study area indicated a high liquefaction potential as well, leading to substantial deformations following such an event. To address the identified issues, various solutions have been proposed, including jet grouting, deep mixing, wick drains, stone columns, and bridge alternatives. Among these options, particular focus was given to the bridge alternative, which was deemed the most optimal. Static loading analyses were performed to evaluate the pile foundation, leading to the determination of appropriate pile lengths. Then, dynamic analyses were then carried out for the bridge, complementing the former analyses. A 3D numerical model was utilized to simulate the free field displacements, which were scaled from the model boundaries. Furthermore, the free field displacements in the central region of the model were calculated. Subsequently, the numerical model was subjected to the construction stages of the bridge. Through dynamic conditions, the resulting shear forces and bending moments within the piles were determined. These findings informed the reinforcement measures implemented for the piles, ensuring their structural integrity and stability.

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