DOKUZ EYLÜL UNIVERSITY
GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

UTILIZATION OF RELIABILITY-BASED METHODS IN THE ALLOCATION OF FAULT BETWEEN THE RESPONSIBLE PARTIES IN INADEQUATE GEOTECHNICAL WORKS

by
Gökhan İMANÇLI

December, 2023
İZMİR

UTILIZATION OF RELIABILITY-BASED METHODS IN THE ALLOCATION OF FAULT BETWEEN THE RESPONSIBLE PARTIES IN INADEQUATE GEOTECHNICAL WORKS

A Thesis Submitted to the
Graduate School of Natural and Applied Sciences of Dokuz Eylül University
In Partial Fulfillment of the Requirements for the Degree of Doctor of Philosophy in Department of Civil Engineering, Geotechnical Engineering Program

by

Gökhan İMANÇLI

December, 2023

İZMİR

Ph.D. THESIS EXAMINATION RESULT FORM

We have read the thesis entitled **"UTILIZATION OF RELIABILITY-BASED METHODS IN THE ALLOCATION OF FAULT BETWEEN THE RESPONSIBLE PARTIES IN INADEQUATE GEOTECHNICAL WORKS"** completed by **GÖKHAN İMANÇLI** under supervision of **PROF.DR. GÜRKAN ÖZDEN** and we certify that in our opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Doctor of Philosophy.

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ACKNOWLEDGMENT

I would like to express my deepest and sincere gratitude to my supervisor, Prof. Dr. Gürkan ÖZDEN for his consistent guidance and advices throughout the period of this thesis. His support and directions have contributed to the quality of this thesis.

I would also like to thank Prof. Dr. Mehmet Yalçın KOCA and Prof. Dr. Yeliz YÜKSELEN AKSOY for their valuable contributions to improve my thesis.

My special thanks are also for Prof. Dr. Ş. Murat ŞENEL for his undeniable support and encouragement.

My young and talented engineer friend Berk YAĞCIOĞLU, thank you for your valuable time and effort.

Dear friend Mehmet KARAKAŞ, thank you for your help.

My dear wife Hidayet İMANÇLI, you are the greatest chance in my life. It was not possible for me to succeed without you. I can't dream of a life without you.

The last but not the least, I would like to thank my parents. Thanks them for always encouraging me to go on my way. Special thanks to my parents İbrahim & Nevriye İMANÇLI for raising me and for always trying to reach the best for my; nothing really compares to them.

Gökhan İMANÇLI

UTILIZATION OF RELIABILITY-BASED METHODS IN THE ALLOCATION OF FAULT BETWEEN THE RESPONSIBLE PARTIES IN INADEQUATE GEOTECHNICAL WORKS

ABSTRACT

Increasing number of problems and disputes resulting from these problems have been observed in the construction and utilization phases of the residences, infrastructures and engineering structures that have been accelerated recently in our country. As there are no competent persons or organizations that might be referee between the parties, settlement of these legal disputes is looked for in the jurisdiction system. According to the Turkish Law system, the "legal expertise" is frequently consulted for the settlement of a case requiring special knowledge and technical legal expertise within the aim of helping the judge to understand the related case, to analyze the complex and contradictory parts of the case and to the make the best judgment.

Risk and uncertainty is indispensable in the design, application or management issues related to geotechnical engineering. Compared to the uncertainties present in the other divisions of the civil engineering, one can see that the uncertainties and risks are at a much higher level in geotechnical engineering. Despite the huge contribution of the scientists in the theoretical issues and to the quality increased in the practice thanks to the developed technology; there are still structural damages that may end up with collapse or destruction in the field of geotechnical engineering applications. Naturally judicial rights are researched not only for the indemnification of these damages but also for the penal sanctions. The disputes related to the geotechnical engineering applications faced in Turkish Law System as well as the role and solution suggestions of the expert are presented in this study.

Keywords: Disputes, expert witness, Turkish Law System, geotechnical related damages, risk, uncertainties

YETERSİZ KALAN GEOTEKNİK ÇALIŞMALARDA KUSURUN SORUMLU TARAFLAR ARASINDA PAYLAŞTIRILMASINDA GÜVENİLİRLİĞE DAYALI YÖNTEMLERİN KULLANILMASI

ÖZ

Son yıllarda ülkemizde yapımı hız kazanan konut, altyapı ve sanat yapılarının, imalat ve kullanım aşamalarında birçok problemler ve bu problemlerden kaynaklanan uyuşmazlıkların ortaya çıktığı gözlenmektedir. Bu hukuksal uyuşmazlıkların çözümü, taraflar arasında arabuluculuk yapacak yetkin özel şahıslar veya kurumlar bulunmadığı için adli yargıda aranmaktadır. Türk Hukuk Sisteminde özel bilgi ve teknik uzmanlık gerektiren uyuşmazlık konularında, yargıcın uyuşmazlık konusu ile ilgili vakıayı anlayabilmesine, olayın karmaşık ve çelişkili noktalarını irdeleyerek karar verebilmesine yardımcı olmak amacıyla yaygın bir biçimde "Bilirkişilik" müessesesine başvurulmaktadır.

Geoteknik mühendisliği ile ilgili projelendirme, uygulama veya yönetim söz konusu olduğunda risk ve belirsizlik kaçınılmazdır. İnşaat mühendisliğinin diğer anabilim dallarındaki belirsizlikler göz önüne alındığı zaman geoteknik mühendisliğindeki yüksek belirsizlik düzeyi, yüksek riskler ortaya çıkarmaktadır. Bilim insanlarının teorik konularda yapmış oldukları büyük katkılara ve gelişen teknoloji sayesinde uygulamada artan kaliteye rağmen, geoteknik mühendisliğinin uygulama alanlarında halen birçok göçme-yıkılma düzeyine varabilecek yapısal hasarlar meydana gelmektedir. Doğal olarak bu zararların gerek tazminat, gerekse cezai yaptırımları için adli yargıya başvurulmaktadır. Bu çalışmada Türk Hukuk Sisteminde karşılaşılan Geoteknik mühendisliği uygulamaları ile ilgili uyuşmazlıklar, çözümde bilirkişinin rolü ve çözüm önerileri sunulmaktadır.

Anahtar kelimeler: Uyuşmazlık, bilirkişi, Türk hukuk sistemi, geoteknik ile ilgili hasarlar, risk, belirsizlik

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CHAPTER ONE
- INTRODUCTION

1.1 General

Judges, when they are involved in cases where expert opinion is necessary, often call for the help of technical persons who are competent in their profession. Such technical persons are known as expert witnesses in the judicial system. The term “expert witness”, however, does not only stand for a person with special expertise knowledge, but also defines a technical person with a firm and outstanding character supported by integrated professional knowledge. It has been stated in Turkish Civil Law that the judge shall benefit from scientific suggestions and jurisdictional decisions (Anonim, 2001). If the judge needs a specialist support while giving his (her) decision, he or she may assign a technical person (i.e. expert witness) (Turkish Civil Litigation Procedure Act article #275, 1981) One shall note that the term “expert witness” is adapted from the Anglo-Saxon judicial terminology. It may be a better practice to use “expert person” within the context of the Turkish Judicial system.

The jurisdictional decision defines a work pursued with delicate and busy study in order to obtain the essence of a case so that the dispute could be successfully resolved with the jurisdiction (Yılmaz, 2012).

According to the article 275th of the Turkish Civil Litigation Procedure Act, “Expert person (witness) is a person with technical and special knowledge, which is not known by the judge in detail, and may present his/her expert opinion and jurisdiction when asked for (Anonim, 1981). The specialist knowledge to be attained by the expert person is defined as the any kind of knowledge except the one covered by the general jurisdictional discipline (Gürelli, 1982). Cases related to the engineering and architectural disciplines are considered as the specialist knowledge.

The term “expert” stands for the integrated special technical knowledge, whereas “person” defines a human being with outstanding ethical character and background (Duman, 2006). The presence of only of these terms without the other does not make an “expert person”. The Turkish Court of Appeals denies assessments made by expert persons with insufficient technical background and expertise (Köroğlu, 1995).

Turkish judicial practice requires that the assessments of the expert person should be in accordance with the truth and science. The expert persons should also make explanatory and informative assessments. Expert persons who pursue contradictory actions such as intentionally assessments and reports are penalized according to Turkish Criminal Law article #290. The expert person should be unbiased according to Turkish Civil Litigation Procedure Act article #276/4.

The expert person shall only be assigned upon the decision of the judge from third party persons who are not involved with the case. Ideally the defendant and the plaintiff are desired to have a common decision regarding the expert person(s). If there is a dispute about the expert person, then the judge appoints the expert person himself according to Turkish Civil Litigation Procedure Act article (TCLPA) #276/1. The judge determines the questions to be asked to the expert person(s) following the talks with the attorneys of the two sides (TCLPA article #279). The number of the expert person shall be one or three. The TCLPA does not accept two or five expert persons in a case (TCLPA article #281). The current practice, however, may involve five expert persons if there is a need for larger body of specialist persons and there is no disagreement during the reporting process (Pekcanıtez, Atalay, & Özekeş, 2001). If there is not an agreement among the expert persons the person who disagrees with the rest of the group may submit a dissenting report. The time period allowed for the submission of a report is generally limited by three months. It can be prolonged up to six months (TCLPA article #281-III).

The expert person concept has a very essential role in the Turkish Judicial system. Turkish laws state that the judge shall decide upon the assessments of the expert person(s). Any decisions contradicting with this rule are rejected by the Turkish Court of Appeals. There are several examples regarding this situation such as traffic accidents and similar cases (Yargıtay 4. Hukuk Dairesi, 21.10.1991, 1990/8857, 1991/8988; Yargıtay Hukuk Genel Kurulu, C.18, S.1, s.54). Probably the most significant side of involving as an expert person in a case is the requirement that the expert person shall make a jurisdiction regarding the responsibility share among the parties that are in dispute (Yargıtay 3. Hukuk Dairesi, 31.10.1979-6260/6521).

Reliability based design approaches and risk estimates can also be used to prepare an effective forensic geotechnical report, to find out the liability allocation between the site investigation report and the project and allocate the liabilities between the parts of disputes. In this case, forensic geotechnical engineer must be able to think as a lawyer and present complex statistical concepts in such a way that a judge can understand achieved results. Forensic geotechnical engineer should also consider how best and simple present and summarize the probabilistic concept that is used for liability allocation.

The application of statistical and probabilistic concepts to geotechnical analysis is a rapidly growing area of interest for both academics and practitioners. Reliability theory can be applied to geotechnical engineering through simple procedures, and need not require more data than is required for conventional deterministic analysis. Any form of reliability analysis requires at least two probabilistic parameters, mean (expected value) and variance; noting that variance is square of standard deviation. Mean and coefficient of variance are the first two moments of the probability density function.

In the light of the above mentioned regulations and laws, it can be stated that geotechnical engineers should be appointed as an expert person for the solutions of disputes, which need special and technical knowledge of geotechnical engineering. However, this is not the case in most cases since there are several problems in expert person mechanism in Turkish Judicial system. These problems can be listed as the lack of knowledge among the judges about the expertise areas, insufficient knowledge about the technical jargon, expert person fees that vary significantly even for a certain specialist area, appointment of incompetent persons, late reports, etc. (Köroğlu, 1995). Besides, the lack of special construction law regulating the industry further complicates the situation since the cases regarding the construction disputes are being covered only by some portions of the Law of Obligations (Kostakoğlu, 2006).

The objective of this study is to propose methodologies in order to improve geotechnical expert person practices for the discipline area and Turkish Judicial System. The motivation behind this thesis is the fact that the current situation is unacceptable as proven by observations, literature survey and personal communications with the experienced academic and practicing engineers of the geotechnical area. In order to achieve this task the following work scope was pursued:

a) A comprehensive and exhaustive literature survey was performed in order to scan available expert person (witness) regulations, laws, procedures and similar in the literature.

b) Turkish judicial traditions and procedures regarding the expert person concept was investigated in depth. While doing this, references is made to academic and acting legal persons.

c) Adaptations was suggested from the foreign country traditions and regulations regarding expert person practices in order to improve the condition of this concept in Turkish Jurisdiction.

d) The Turkish laws require that the expert person shall allocate the fault of a case among the involved parties. This requirement, however, brings a very significant overburden to the expert person appointed to make assessments for the cases since there are no commonly accepted analytical tools for this purpose. Although probabilistic approaches are quite developed in geotechnical engineering discipline, they are not applied to judicial matters yet. In this study, an attempt was made in order to develop a reliability-based index methodology to allocate the fault.

e) Suggested procedure was applied a selected case study from Turkish lawsuits. Findings are analyzed and discussed in detail.

f) While evaluating case study, responsibility of all involved parties (governmental agencies such as city administrations, chamber of civil engineers, consulting and inspection companies) was researched.

CHAPTER TWO
- THE EXPERTISE IN THE TURKISH LEGAL SYSTEM

2.1 Introduction

Due to the increase in the problems arising in parallel with the development of the construction sector over time, the disputes arising and the resolution of these disputes have become complex. In such cases, the judge, who is obliged to decide the case, has felt the need to apply to persons with special or technical knowledge that he does not have. This situation has created a common working area between engineers and lawyers. In many countries, in order to evaluate the claims of the parties and reach a decision, judges receive technical support from engineers, who we call experts specialised in the subject matter of the case. However, the differences between the written laws and customs of the countries cause different approaches within the scope of expertise.

As in developed countries, it is observed that the problems arising during the project,constructing, inspection and utilisation phases of the building, infrastructure and art structures, the construction of which has accelerated in our country in recent years, and the disputes arising from these problems have increased significantly. The solution of these legal disputes is sought in the judicial jurisdiction since there are no legally authorised and competent experts or institutions to mediate between the parties.

In the Turkish Legal System, in disputes requiring special knowledge and technical expertise, "Expertise" is widely used in order to help the judge to understand the facts related to the subject of the dispute and to make a decision by examining the complex and contradictory points of the case.

Legislative provisions regarding expert witnesses are mainly given between Articles 62 and 73 of the Criminal Procedure Code (CPC) numbered 5271 and between Articles 266 and 287 of the Code of Civil Procedure (CCP) dated 12.01.2011 and numbered 6100. In addition, a special regulation has been made in Article 293 of the CCP, which specifically explains the concept of Party Expertise (Expert Opinion). In addition to this, legal regulations have been introduced in order to solve the problems arising in the judicial system and causing unacceptable results and to place the expert witness institution on a reliable basis. The European Union project carried out within the Ministry of Justice and a commission working within this scope have examined many country examples by seeing them on site and put forward a study explaining their evaluations. As a result of the studies, the Expertise Law No. 6754 published by the Ministry of Justice on 3.11.2016 and the Expertise Regulation published in the official gazette dated 03.08.2017 were put into force.

For a long time, the problems encountered with the expert witness services provided within the scope of the regulations given in the Civil Procedure and Criminal Procedure Laws regarding our expert witness system have been labelled as "the bleeding wound of the judiciary" and "expert witness disgrace", and this unacceptable situation of the expert witness institution has been discussed in scientific platforms (Aşçıoğlu; 2010).

Article 9 of the Constitution vests judicial power in fully independent courts on behalf of the Turkish Nation and states that *"Judicial power is exercised by independent courts on behalf of the Turkish Nation"*.

In our current justice system, members of the judiciary are only equipped with legal education and are not specialised in science, art or technical knowledge. However, in many cases, the subject matter of the lawsuit, which is the cause of the dispute, exhibits a complex structure that includes technical and scientific details. It is impossible for the judge to know the technical and scientific aspects of the material facts on which the dispute he is tasked with resolving is based. Understanding their content depends on a separate knowledge, science, art or special professional knowledge outside the judge's own field of specialisation. Nevertheless, the judge is obliged to resolve the disputes brought before him/her and reach a decision even if he/she does not have sufficient knowledge.

Article 36 of the Constitution states that;

"Everyone has the right to claim and defend himself as a plaintiff or defendant before the judicial authorities and to a fair trial by the use of legitimate means and procedures. No court shall refrain from hearing a case within its jurisdiction" (Article 36, II of the Constitution)

For this reason, judges are obliged to decide on the cases even if they do not have all kinds of special and technical knowledge about the cases before them. What is meant by special knowledge here is the knowledge of the results researched and revealed by a certain branch of science other than the science of law. Technical knowledge refers to knowledge sufficient to apply the data of positive sciences such as physics, chemistry and mathematics (Arslan, 1984; Tanrıver, 2002).

In solving the problems encountered in construction law, the members of the judiciary, due to the complexity and lack of necessary special and technical knowledge on the subject, frequently take into account the decisions of the Court of Cassation, which constitute precedents in this field. This issue is stated in the first article of the Civil Code that the judge may benefit from scientific opinions and judicial decisions when making a decision. Similarly, in the unification of case law decision of the Court of Cassation dated 9.3.1955 and numbered 22/2, it is reiterated that the judge shall benefit from scientific and judicial precedents when making a judgement. In order to meet this need, judges have been obliged to resort to expert witnesses.

In Article 266 of the Code of Civil Procedure, it is explained that an expert may be consulted in matters that require special and technical knowledge, other than legal matters, which cannot be solved by the Court only with its knowledge and experience. The court may decide to obtain the opinion and opinion of an expert upon the request of one of the parties or in accordance with its own decision. The article re-emphasises that an expert cannot be consulted in matters that can be solved with the general and legal knowledge required by the judicial profession.

Article 3 of the Law on Expert Witnesses states that the judge may not apply to an expert in matters that can be resolved by the legal knowledge he/she has within the framework of the education he/she has received and in cases where he/she has general knowledge and experience regarding the subject of the dispute. In the same article, it is stated that legal qualifications and evaluations are only within the authority of the judge, and that experts cannot make explanations in their reports outside the scope of the subjects whose solution involves expertise, special or technical knowledge.

If it is necessary to make a general definition according to the laws and regulations on the subject, it can be stated that an expert is "a person whose knowledge is consulted in disputes that judicial authorities cannot resolve with their generally accepted technical knowledge other than their own legal knowledge, who has technical knowledge and expertise, and who expresses an enlightening verbal or written opinion to the court by applying his knowledge and expertise to the concrete case".

2.2 Binding Nature of The Expert Report

The general provision of Article 198 of the CCP stating that "Except for legal exceptions, the judge shall freely evaluate the evidence" is expressed more precisely in Article 282 as "The judge shall freely evaluate the opinion and opinion of the expert together with the other evidence." What does this mean? There are different opinions among jurists as to how the judge, who appoints an expert because he/she cannot solve the technical and special issues related to the dispute with his/her own knowledge and experience, can evaluate the expert report, which is outside his/her area of expertise, and how he/she can determine the fault rates. Some jurists state that this issue should be interpreted in accordance with Article 281 of the CCP as "The judge may request an additional expert report in order to complete the matters that he deems incomplete, unclear or incomprehensible in the expert report" or "He may appoint a new expert committee and have a new examination". Since the expert opinion is used to supplement the judge's lack of knowledge in the field of scientific knowledge and experience, the judge, whose knowledge in this field is incomplete, cannot make a decision based on his own knowledge, experience and evaluation, by discarding the expert report. In this respect, a new expert report must be obtained in the event that it is found incomplete and incomprehensible, or objected to, or there is a contradiction between two reports (Köroglu, 2001; Pekcanitez, 2001; Deryal, 2001). The general opinion of the Court of Cassation is clearly evident in many of its decisions (Yargıtay 2. HD. 11.9.1975, 6948/6497; Yargıtay KD. 1976-2, sh 144-145; Yargıtay 7. HD. 12.3.1985, 4688/2851; Yargıtay HGK. 04.02.2009, 2008/4-823 E., 2009/50 K.)

In addition, in order to enable the court to audit the expert report, Article 279/2 of the Code of Civil Procedure stipulates that the decision must include the material facts examined in the expert report and the reasons for the conclusions reached.

As a counter-argument, it is argued that in the event that the judge concludes that the special and technical information written in the expert report is such that he/she has the knowledge to conclude that the conclusions given by the experts in their reports are incorrect, he/she should be able to decide contrary to the decision given by the experts, without the need for an additional expert report or a new expert examination, provided that he/she shows his/her justification (Kuru, Arslan, &Yılmaz 2004). In a decision of the Council of State on the subject, it is summarised as follows: "*The institution of expert witness has emerged in order to provide the judge with the special and technical knowledge necessary to resolve a dispute before him. Otherwise, the result of the expert report is not a decision that will end the case. Only the judge has the duty and authority to make the decision that resolves the dispute."* (*Danıştay 9. D. 11.2.1998, 452/3926*).

When we evaluate both views as a Geotechnical Engineer, considering that in most geotechnical project design and application studies, even our colleagues who have undergraduate civil engineering education cannot comprehend the issues sufficiently, it is very difficult for a judge who has only legal education to read and understand a technical and detailed expert report prepared by experts in this field and to make a decision by distinguishing right or wrong in the light of the technical details given in this report. This can only be possible through the establishment of specialised courts, which are composed of lawyers trained in engineering with technical knowledge and equipment. For example, in Swiss law, in specialised courts, it is possible for the court or one of the members of the court to specialise in a certain field and to hear cases related to that field. In such courts, the judges are familiar with the professional relations to which the case is related and the rules and practices related to these relations, and therefore can conclude the case without the need for any other evidence. If the necessary information is not available in these courts or if the researches to be carried out in order to reach this information take too much time, it is accepted to use an expert witness (Alangoya, 1991).

2.3 Expert Opinion

Article 293 titled "Expert opinion" of the Code of Civil Procedure No. 6100 reads as follows: "(1) The parties may obtain a scientific opinion from an expert in relation to the case. (2) The judge may, upon request or ex officio, decide to invite and hear the expert from whom the report is obtained. At the hearing where the expert is called, the judge and the parties may ask the necessary questions. (3) If the expert does not attend the hearing without a valid excuse, the report prepared by the expert shall not be evaluated by the court."

The court is obliged to consider and evaluate the expert opinion submitted by the party, especially in matters requiring special and technical knowledge, if it is relevant to the subject matter of the case. However, the submission of a convincing and accurate expert opinion to the court does not mean that the court cannot resort to an expert witness.

The judge should make a decision by evaluating all the explanations submitted by the party and the documents and opinions relied upon. The judge should also evaluate the expert opinion relied upon and make a decision on the dispute. Since the violation of the right to be heard is also a violation of the right to a fair trial, the failure to evaluate the expert opinion relied upon by the party in the judgement is also a violation of the right to a fair trial.

Another important difference of the expert opinion practice from the expert witness practice is in terms of the subjects that can be referred to this method. The application of this method (unlike the application to the expert) is not limited only to the issues that the judge cannot solve with his/her general knowledge and expertise, but it is also possible to obtain an expert opinion on legal issues.

As stated, the expert opinion may also be related to an expert report/opinion. It is possible to obtain an opinion from the expert to be evaluated in the preparation of the expert report (before the expert report is prepared) and/or after the expert report is issued *(about the expert report).* It is possible that the expert opinion/report and the expert opinion may contain contradictory evaluations and conclusions; in the event of this, the court will try to resolve the contradiction by summoning the persons who gave the aforementioned report and opinion to the hearing, as well as explaining which one of them, on what grounds, is relied upon with the judgement.

As with the expert report/opinion, the expert opinion is not binding on the court. However, in the judgement to be rendered by the court, this opinion must also be discussed and the reasonable grounds underlying it must be explained, whether the opinion is accepted or not. A sample judgement of the Court of Cassation on the subject is given below:

In the decision of the 15th Civil Chamber of the Court of Cassation dated 10.11.2016 and numbered 2015/5127 E. 2016/4635 K., the same points were emphasised; *"...As it is known, the expert opinion regulated in Article 293 of the CCP No. 6100 is regulated as the parties obtaining information on a subject from a special and technical expert determined by the parties in order to clarify and understand the dispute and to prove the claims and defences, and is also called special expert in practice. In order to protect the interests of the parties and in case they are not satisfied with the expert report, they may obtain an expert opinion and submit it to the court in order to ensure that the incident is fully clarified and the correct and fair decision is made. The court is obliged to take into account and evaluate the expert opinion submitted by the party, especially in matters requiring special and technical knowledge, if it is relevant to the subject of the case. In this sense, if one of the parties objected to the expert report based on the expert opinion, and if these objections were never taken into consideration by the court and the objections were not met in a reasoned manner, the party relying on the expert opinion may have violated the right to legal rest, which is the most important element of the right to a fair trial regulated in Article 27 of the CCP No. 6100, Article 36 of the Constitution and Article 6 of the European Convention on Human Rights. In the expert opinion submitted to the file, findings and opinions contrary to the opinions determined by the expert report have been put forward, and the expert report and the expert opinion contain serious contradictions. Instead of referring the file to a new expert committee in order to eliminate the contradiction between the expert report and the expert opinion, it was not correct to make a decision without evaluating and discussing the expert opinion in the decision based on the report that was insufficient and subject to substantial objection, and it required a reversal...."* (Same direction Yargıtay.15.HD. 28.03.2017 T. 2016/1513 E. 2017/1381 K. ; Yargıtay.15.HD. 10.11.2016 T. 2015/5127 E. 2016/4635 K. ; Yargıtay.11.HD. 24.11.2016 T. 2016/7139 E. 2016/9125 K. ;

Yargıtay.11.HD. 01.10.2015 T. 2015/2448 E. 2015/9719 K. ; Yargıtay.11.HD. 04.05.2016 T. 2015/10467 E. 2016/5052 K. ; Yargıtay.11.HD. 31.03.2016 T. 2015/7580 E. 2016/3513 K.).

CHAPTER THREE

- EVALUATIONS WITHIN THE SCOPE OF EXPERT WITNESS LAW AND REGULATION

As a result of the studies and evaluations carried out in order to improve the unacceptable situation of Expert Expertise practices in the judicial system, the Draft Law on Expertise, which was opened for opinion by the Ministry of Justice General Directorate of Laws on 18.05.2015, was submitted to the Grand National Assembly of Turkey. In the "General Justification" section of the Draft Law, the statements that reveal the problems in the current system are given below.

"The increasingly diversified and complex nature of today's legal disputes, which require technical knowledge for resolution, further increases the role and importance of the expert witness institution within judicial activities. A well-functioning expert witness institution is decisive in the effective and rapid functioning of the judicial system, and the contrary situation not only results in prolonged proceedings, but also causes loss of rights of people who expect justice. The expert whose knowledge and opinion is consulted by the judge on matters requiring special or technical knowledge in the judicial process is called an "expert witness". In the judicial procedure, it is pointed out that expert examination should be applied in matters requiring scientific and technical knowledge that cannot be resolved with the general and legal knowledge required by the judicial profession. Expert examination, which is regulated without exception in the laws regulating the judicial procedure, is an evidence evaluation tool that is frequently used in practice.

Expert examination is applied by the judicial authorities in accordance with the Code of Criminal Procedure No. 5271 and the Code of Civil Procedure No. 6100, by the administrative judicial authorities in accordance with the Code of Administrative Procedure No. 2577, and by the military judicial authorities in accordance with the Law No. 353 on the Establishment and Trial Procedure of Military Courts and the Law No. 1602 on the High Military Administrative Court.

According to the current procedural laws, experts are selected from among the independent experts on the lists established by the justice commissions of the courts of *first instance of the judicial jurisdiction, and in the event that there is no expert in the desired field of expertise on these lists, an expert may be appointed from outside the list by stating the reason. However, it is a generally accepted criticism that the current list practice does not fully meet the expectations from the expert witness institution and may be the subject of grievances and complaints that may cause prolongation of the proceedings.*

Among the criticisms expressed in this context are that expert witnesses have become a profession in practice, that experts are frequently appointed even in matters that can be resolved with the legal knowledge required by the profession of judge, and that the expert almost replaces the judge and exercises judicial authority. These criticisms should also be taken into consideration in terms of the establishment of the "right to a fair trial" guaranteed under Article 36 of the Constitution and Article 6 of the European Convention on Human Rights. On the other hand, the problems experienced in the field of expertise and the proposed solutions have been the subject of various reports and documents prepared by different institutions in the past. In the Report titled "Audit of the Activities and Transactions of the Presidency of the Council of Forensic Medicine for the Years 2007, 2008 and 2009 and Ensuring the Effective and Efficient Execution and Development of the Services of the Council of Forensic Medicine" prepared by the State Auditing Board of the Presidency in 2010, the current expert witness system in our country was comprehensively discussed and analysed. In the Report on "Expertise Expertise" prepared by the Ministry of Justice in 2010, the failing aspects of the current expert witness system and suggestions for solutions were put forward. In both reports, it is emphasised that the problems experienced in the field of expert witnesses' stem from the lack of institutional structure on issues such as training, supervision and selection of experts. In the Tenth Development Plan covering the period between 2014-2018, it is aimed to develop the expert witness mechanism in order to accelerate the judicial process and increase accessibility to the judiciary, and to establish an effective functioning system by reviewing the expert witness institution.

As a result of the "Enhanced Expertise System Twinning Project" carried out between the Ministry of Justice and the European Union between 2013 and 2015, it was emphasised that in order to solve the problems experienced in this field, the need *for the establishment of an administrative supreme board equipped with public powers for the certification, training, supervision and performance measurements of experts, and for the determination and implementation of regulatory and supervisory rules for experts. In the Judicial Reform Strategy document announced to the public on 17/04/2015, the review and institutional restructuring of the expert witness institution is included as a target. In achieving this goal, the establishment of a structure that will manage the accreditation and certification process while creating an expert list or registry, establishing an effective audit system, linking the selection of experts to criteria that will ensure professional competence and establishing quality standards have been adopted as important strategies.*

One of the main problems in expert witness practices is that, although it is expressly prohibited by the legislation, legal experts are consulted in matters that can be resolved with the legal knowledge required by the judicial profession, legal evaluations and legal conclusions are included in the reports of the experts, and the experts make definitive legal judgements on the merits of the dispute instead of expressing opinions on matters requiring technical and special knowledge.

On the other hand, appointments made without paying sufficient attention to the basic qualifications and areas of expertise of the experts may lead to unnecessary multiple expert examinations and reports in practice, which causes the reasonable time threshold in the proceedings to be exceeded and the costs of the proceedings to increase. The registration and deletion of experts, which number in the tens of thousands, to and from the relevant lists are carried out by the judicial justice commissions. These commissions remove the expert from the list only in the presence of limited reasons, and otherwise do not assume an institutional role capable of monitoring and supervising expert witness practices. According to the list procedure, any member of the profession with three years of professional seniority is accepted to the expert lists by the justice commissions and lists of thousands of experts in the same field of expertise are formed. However, these lists do not provide the necessary assurance regarding the competence of the experts.

In order to solve the aforementioned problems and to establish an effectively functioning system In order to solve the problems and establish an effectively *functioning system, it has become a necessity to establish an institutional structure that will determine the basic and sub-specialty areas in expert witness services, determine the qualifications that experts should have and the guiding principles to be followed according to these areas of expertise, determine the ethical rules that experts must comply with, regulate the principles and procedures of the trainings and examinations to be given and examinations to be held on issues related to expert competence such as basic procedural provisions and report writing techniques, assume a regulatory role in the entire process from the creation of expert lists to their audits, and operate independently in this field. This Draft Law has been prepared in order to establish an institutional structure to solve the above-mentioned problems in the field of expertise by establishing a Supreme Board of Expertise, which includes representatives of the relevant institutions at the center to set rules and principles, and regional boards of expertise as the implementing unit."*

The purpose of the Law is to determine the procedures and principles regarding the qualifications, training, selection and supervision of experts, and to ensure the establishment of an effective and efficient institutional structure for expertise.

The purpose of the Regulation is described as "to regulate the conditions for application and acceptance as an expert, the qualifications, training, registration and listing of experts, their appointment, the basic and ethical principles they must comply with, their working principles, supervision, registration and removal from the list, and the working procedures and principles of the Expertise Advisory Board, the Department of Expertise and the regional boards of expertise."

Expert Witness is defined as *"A natural or private law legal person who is consulted to give his/her opinion orally or in writing in cases whose solution requires expertise, special or technical knowledge."*

In parallel with the Code of Civil Procedure, it has been regulated that the judge may not apply to the expert on legal issues and matters that can be resolved by the judge's general knowledge and experience, and that the experts should only make evaluations within the scope of special and technical knowledge related to the subject they are assigned and should not make legal explanations and evaluations.

The expert may be appointed by the relevant authority ex officio or upon request. The experts are selected from the lists organised by the regional boards. Depending on the nature of the work, more than one expert may be appointed, provided that the justification is clearly shown.

When appointing the expert, the judge should clearly state in writing and verbally the scope and limits of the subject to be examined, the solution of which requires expertise, special or technical knowledge. The questions to be answered by the expert should be determined precisely.

Although it is essential for the judge to receive a report on the subject matter subject to examination once, it is stated that the judge may receive an additional report in case of deficiencies or uncertainties in the report.

It is essential that the expert fulfils his/her duty independently, impartially and objectively within the framework of the rules of honesty.

The expert should fulfil his/her duties in an effective, timely, efficient and qualified manner with the awareness of serving justice.

While forming his/her vote and opinion, the expert should, to the extent possible, explain the technical terms and expressions of his/her field of expertise in a language that can be understood by the appointing authority and the parties.

The Department of Expertise was established under the General Directorate of Legal Affairs of the Ministry of Justice. Some of the duties of the Department are given below in the Law.

a) To determine the basic and sub-specialty areas related to expert witness services.

b) To determine the qualifications that the experts should have according to their basic and sub-specialty areas.

c) To determine the ethical principles that the experts must comply with while carrying out their duties.

d) To determine the guiding principles to be followed and the standard of the reports to be prepared by the experts according to their basic and sub-specialty areas.

e) To determine the procedures and principles regarding the basic training of expert witnesses, to determine and authorize the qualifications of training and education institutions and other institutions to provide training, to list these institutions and organizations and to publish them electronically.

f) To determine the procedures and principles regarding those who will be exempted from the basic training of expert witnesses or from enrollment in the list by taking into account their expertise and scientific competence in their fields, to create and publish a list of such persons.

g) To determine the procedures and principles regarding the supervision and performance of experts.

h) To determine the qualifications of the private law legal entities that will serve as expert witnesses and the persons who will work as expert witnesses within this legal entity.

i) To determine the basic and sub-specialty areas and the jurisdiction circles of the private law legal entities that will serve as expert witnesses.

j) Establishing scientific commissions or working groups on the subjects falling within its field of duty.

k) Encouraging and supporting publications and scientific studies related to expertise.

l) Organizing or supporting scientific organizations such as national and international congresses, symposiums, and panels on expert witness.

Some of the fundamental principles required to become an expert witness are given below,

a) Except for the special cases specified by law, persons must complete the fundamental training of expert witness.

b) To have worked at least five years in the field of expertise in which he/she will act as an expert, or if more working time is determined, to have worked for this period.

c) To have the conditions required by the legislation in order to be able to work as a professional member and to have a diploma, professional qualification certificate, specialization certificate or similar document showing the area of expertise required to perform the profession.

d) To carry the qualification requirements determined according to the basic and sub-specialty areas of expert witness.

Regional Boards were also established within the Expertise Department of the Ministry of Justice.

The following items are among the audit and examination duties of the Regional Boards.

(1) Expert witnesses shall be audited by the regional boards ex officio or upon application in terms of compliance of their attitudes and behaviors related to their duties or the reports they prepare with the relevant legislation.

(2) In the event that the judge or public prosecutor is of the opinion that the attitude and behavior of the expert appointed by him/her or the report prepared by him/her are not in compliance with the legislation, he/she shall notify this matter to the regional board by attaching the underlying information and documents, if any.

(3) The regional boards shall check whether the expert reports are prepared in accordance with the procedures and principles set out in the laws, by-laws, regulations and circulars, and whether they comply with the guidelines determined by the Department.

(4) Regional boards may not audit expert reports in terms of special or technical knowledge.

(5) No application can be made to the regional boards regarding the content of expert reports in terms of special or technical knowledge; the applications made shall be rejected without examination.

(6) Such applications shall be sent to the appointing authority and to the professional organization to which the expert is affiliated or to the organizations where the expert is employed.

The following principles are given in the evaluation of the expert's vote and opinion.

(1) The expert report shall be freely evaluated by the appointing authority together with other evidence.

(2) The appointing authority may request an additional report from the expert by posing new questions in order to complete or clarify the deficiency or ambiguity in the expert report.

(3) In case there are incomplete or incomprehensible matters in the expert report, a written explanation shall be requested from the expert within the period determined by the authority making the assignment. If necessary, if it is decided that the expert shall explain his/her vote and opinion orally, his/her explanations shall be recorded in the minutes and the signature of the expert shall be obtained. In the case of assignment as a committee, the experts shall be given the opportunity to immediately discuss the matter to which their knowledge is sought among themselves, and the votes and opinions expressed as a result of the discussion shall be recorded in the minutes and signed by the experts.

As a matter of fact, in its decision dated 9 July 2020, the 17th Civil Chamber of the Court of Cassation, after noting that the determination of the fault ratios is a legal issue, points out that the court of first instance does not need to obtain a report on the fault in the concrete case, and that the degree of fault can be determined by the court according to the evidence within the scope of the file (Yargıtay 17. HD, 9.7.2020, 6414/4591)..

In the decision on the appointment of the expert, the subject matter of the examination must be clearly defined with all its limits, and the questions to be answered by the expert must be indicated (Article 273 of the CCP; Article 66/1 of the Criminal Procedure Code). The expert may be appointed in three different subjects:

a) To establish a fact by means of his/her special and technical knowledge,

b) To transfer his/her specialized and technical knowledge to the judge,

c) To evaluate and draw conclusions from the facts by means of his/her special and technical knowledge.

CHAPTER FOUR
- FUNDAMENTAL LEGAL CONCEPTS WITHIN THE SCOPE OF EXPERT WITNESS ASSESSMENTS

4.1 Introduction

The fact that there are no "direct and mandatory" regulations on construction law in the Turkish legal system and that the provisions of the Code of Obligations related to the contract of works (contract of exception), which are taken into account in the solution, are interpretative and complementary, that is, the provisions of the Code of Obligations related to construction law are in the nature of substitute legal rules that are applied only in matters where there is no agreement between the parties to the contrary, reveals a long process and a complex structure in the resolution of disputes. Basically, the Code of Obligations, which adopts the principles of Roman law and common law, is based on the principle of fault liability. Therefore, the condition for liability for damages is fault, and in cases where a causal link is established, the fault is apportioned among the responsible parties. In our country, there is no authorized mediation institution for the resolution of disputes related to construction law. For this reason, the resolution of disputes is usually brought to the judiciary.

Article 9 of the Constitution vests judicial power in fully independent courts on behalf of the Turkish Nation.

"Judicial power is exercised by independent courts on behalf of the Turkish Nation."

In the event of damage to a building for any reason whatsoever, there are two types of liability for all project engineers, contractors, construction site supervisors, building supervision organizations, and the Ministry of Environment, Urbanization and Climate Change and the relevant municipalities that make the necessary legal arrangements for the construction of the building and issue the necessary permits. Firstly, the persons who have suffered damages have the right to claim compensation. In this case, it is possible to face a civil lawsuit. On the other hand, damage to the structure may turn into a criminal offence. For example, as in Article 171 (b) of the Turkish Penal Code, the collapse of the building may cause a criminal offence. Fault liability arising from private law and criminal liability arising from criminal law are subject to different principles. Every act that constitutes a criminal offence is also considered to be negligent under private law; on the other hand, not every act that is considered negligent under private law constitutes a criminal offence under criminal law. The determination of liability arising from private law is within the jurisdiction of the Civil Courts, while the determination of criminal liability is within the jurisdiction of the Criminal Courts. The judicial procedures applied by the Civil and Criminal Courts differ significantly from each other. Although the role of experts in Civil and Criminal Courts is similar, it is handled separately in our legal system. In this part of our study, liability arising from private law and fault relations are emphasized.

4.2 Principles of The Code of Obligations Within the Scope of Fault Liability

In order to examine the concept of liability, the provisions between Articles 49 and 76 of the Turkish Code of Obligations (TCO) numbered 6098, which was published in the official gazette on 4/2/2011, were evaluated. In addition, the Law of Obligations No. 818 (Code of Obligations), which was repealed in order to interpret the differences of opinion that emerged after the earthquakes, was taken into consideration while discussing the concept of statute of limitations.

Between Articles 49 and 59 of the TCO, "Fault Liability" is emphasized. Article 49 of the TCO is regulated as follows*: "Whoever harms another with a faulty and unlawful act is obliged to compensate for this damage...*". However, even if there is no prohibitive law regarding the unlawful act, the compensation that will arise in case of intentional damage to another person must be compensated. When the text of the article is analyzed, the conditions of liability are the realization of an unlawful act, in other words, the occurrence of a fault, the occurrence of a damage for this reason, and the existence of a causal link between the defect and the faulty party.

Liability is defined in the dictionary of the Turkish Language Association as *"the assumption of one's own behavior or the consequences of any event that falls within one's jurisdiction"* and "an obligation that requires being responsible". According to Article 49 of the TCO, "Fault Liability" means causing damage to the property or personal assets of another person through an unlawful and faulty behavior.

In Article 66 of the TCO, the liability of the employee, which we consider as perfect liability, is mentioned. In the event that the employee causes damage to others while performing the work assigned, the employer must pay this damage. The employer may be relieved from liability if he/she proves that the instructions regarding the work to be performed by the employee are correct and sufficient, that he/she has the necessary supervision and that he/she has taken the necessary care to prevent the damage from occurring. In addition, the laborer who pays the damage of his employee has the right of recourse to the damaging employee in proportion to his responsibility.

4.3 The Concept of Fault

The most striking aspect of being a Forensic Engineer in the Turkish Judicial system is that in almost all disputes, the Forensic Engineer is asked to make a detailed study on the allocation of fault between the disputing parties. As a matter of equity, it is necessary to determine the correct allocation between the compensation claimed and the damage. The determination of those responsible for the damage and the technical evaluation of the facts causing the damage and the preparation of an expert report in a way that the judge can understand is a special subject requiring expertise. The fact that the decision is left to the discretion of the civil judge means that the evaluations given in the expert report should be interpreted carefully and correctly. However, in the current situation, there is no recognized systematic approach for allocating fault. The fault allocations made in the expert reports are mostly not objective. Different committees are repeatedly formed for the same dispute and these committees make incompatible allocations of fault between the responsible parties. Forensic engineers are expected to know the basic legal legislation on the subject as well as their engineering knowledge and experience.

In our legal system, fault is generally considered as intent, gross negligence, and slight negligence. Intent can be defined as a person knowingly and willingly committing an unlawful act and causing damage. Gross negligence is the failure to show the attention and care that everyone would show in general, and slight negligence is the failure to show the attention and sensitivity that a careful and cautious person would show (Nomer, 2010; Tahiroğlu, 2008). Article 41 of the Code of Obligations No. 818, which was abrogated with the entry into force of the Turkish Code of

Obligations No. 6098, states that the unlawful act must be committed "intentionally or negligently" in order to require liability. The person who harms another person unlawfully, either intentionally or through negligence and carelessness, is obliged to compensate for this damage. In the Turkish Code of Obligations No. 6098, the degrees of fault are not mentioned. In Turkish Code of Obligations No. 6098, the fact that the types of faults are not listed is the idea that compensation should be awarded in the event of the realization of any kind of fault provided that the fault causes damage. In this case, according to the intensity of the intention or negligence, the judge will determine the amount of compensation within the framework of equity (Oğuz, 2016). However, according to Article 52 of the Turkish Code of Obligations No. 6098, if the indemnity obligor, who caused the damage with slight negligence, will fall into poverty when he pays the compensation and if equity requires it, the judge may reduce the compensation.

In the determination of the fault, the degree of care to be taken by the responsible person is important. For example, the fact that "Auditing" has been made a separate profession and specialty by law increases the degree of care to be taken. Expert auditors who perform their profession professionally will be liable if they do not know the generally known and accepted rules and methods, the unchanging rules of science and technique, the rules of science and art related to the work subject to audit, the standards and regulations and do not follow the changes in standards and regulations (Okan, 2012).

The concept of "Defect" in construction law can also be handled in two ways as "Patent Defect" and "Latent Defect" in accordance with Article 477 of the Turkish Code of Obligations. What is intended to be expressed in the concept of obvious defect is the obvious construction defects that can be noticed at first glance or seen by the eye without being an expert in the subject. For example, it is possible for a citizen who buys a new house to check whether the door handles in the flat are working or not and to report these defects to the seller. Latent defects are defects that cannot be detected observationally and without any technical expert control and without the use of equipment. The detection of these defects will only be revealed by technical examinations and perhaps back analyses to be carried out by expert engineers. Such defects often become apparent over a period. An example of this is the total and differential settlement exceeding the permissible limits due to load transfer to water saturated clay soils.

4.4 Mutual Fault

Mutual fault is regulated in Article 52 of the TCO as follows: "*If the damaged party consented to the act that caused the damage or had an effect on the occurrence or increase of the damage or aggravated the situation of the indemnitee, the judge may reduce or completely remove the compensation.* The *judge may reduce the compensation if the indemnity obligor, who caused the damage with slight fault, will fall into poverty when he pays the compensation and if equity requires it."* In cases where the fault in question is present, the amount of compensation arising from the damage incurred may be reduced or eliminated in accordance with the relevant article of law. In this context, mutual fault may arise from willful intent or negligence. In determining the compensation, it is important to determine whether the action of the injured party is intentional or negligent. In this regard, although Article 52 of the relevant law does not specify the rate of deduction for contributory negligence, it is argued that the rate of deduction is not specifically stated in the law, and that the rate of deduction should be based on the characteristics of the concrete case and the discretion of the judge.

In order to explain the issue, two Court of Cassation Decisions are summarized below.

The decision given by the Court of Cassation 4th law chamber (E. 2019/835, K. 2020/3372, T. 13.10.2020) has been examined and summarized as follows.

In the main and joined case, the plaintiff's attorney stated that during the excavation works of the construction of the defendant contractor on the neighboring parcel on 26/09/2014, the two carpet pitches and the restaurant, which were covered with a steel roof and located zero to the parcel boundary, were damaged, that the determination they made stated that the facility had become unusable and that it should be demolished and rebuilt, and that the cost required to restore the facility and the loss of earnings deprived should be compensated.

The defendant's attorney argued that the lawsuit was time-barred, that there was no static and steel construction project of the building group specified as the carpet field where the plaintiff was the tenant, that the defect belonged to the plaintiff, that the defendant constructed the construction by using the bored pile system even if the ground water and soil structure was bad, that there was no causal link in the incident and that the defendant had no strict liability, and that the lawsuit should be dismissed.

Articles 738 and 737 of the Turkish Civil Code No. 4271 provide a special regulation regarding damage to the neighboring structure due to excavation. According to the article, "The owner is obliged to avoid damaging neighboring immovable properties by shaking or endangering their lands or affecting the facilities on them during excavation and construction. Provisions regarding flood structures shall apply to structures that violate the rules of neighborhood law." If a person damages or exposes his neighbor’s immovable property to damage due to excavation or construction on his own immovable property, there is no need to search whether this damage exceeds the limits of tolerance. It is not required for the defendant to be at fault in lawsuits for the prevention of encroachment, restitution and compensation arising from neighborhood law.

In compensation cases arising from neighborhood law, first of all, after determining whether there is a causal link between the defendant's action and the damage of the plaintiff, the amount of the damage suffered by the plaintiff, if any, should be determined by the expert, and the compensation should be determined and appreciated according to this damage. It should be noted immediately that the amount of compensation can never exceed the damage. While determining the extent of the damage, it should be determined to what extent the parties affect the occurrence of the damage, that is, whether they have mutual (shared) fault, and if the plaintiff has a fault in the increase of the damage, the amount of compensation should be reduced or completely eliminated according to Article 52 of the Turkish Code of Obligations No. 6098. Since the liability arising from Articles 737 and 730 of the Law No. 4271 is not a liability dependent on fault, the defendant's fault cannot affect the reduction of the amount of compensation.

As for the concrete case, while determining the scope of the damage, the court did not investigate whether the plaintiff had a mutual fault in the occurrence of the damage, and no evaluation was made in this regard. The development of the event subject to the lawsuit, the issues arising from the geological structure of the ground where the facility rented by the plaintiff is located, the age of the facility and the share of wear and tear, whether the plaintiff's facility was built in accordance with the engineering rules, etc. It was not correct to decide in writing with incomplete examination, while it was necessary to determine whether the plaintiff was jointly at fault in the occurrence of the damage and to decide according to the result to be reached, and the decision had to be reversed for this reason.

In another Court of Cassation decision, the explanations that can be considered within the scope of the subject matter are summarized below (Yargitay 4. HD. T 15.2.2012, K 14418/2144).

In the concrete case, it is understood that the 3-storey building on the immovable property numbered 113 block 2 parcel belonging to the plaintiffs is an illegal building without a project, without a license and in violation of the building regulations. According to the contents of the survey conducted by the local court and the expert reports obtained by the local court with the determination file dated 27.10.2007 and numbered 2007/20, the ground of the building belonging to the plaintiff slipped, fractures and cracks occurred in the load-bearing structural elements, and the building tilted due to the weight of the building on the side parcel, since adequate precautions were not taken during the construction work carried out by the defendants on the side parcel, and a causal link was established between the construction work carried out without precautions and the damage to the building belonging to the plaintiff. It was also determined that the plaintiffs' failure to construct in accordance with the construction technique and the loose and sandy structure of the regional soil were also effective in the damage. From all these explanations, it should be accepted that the defendants are liable for the damage according to the tort principles.

In the context of determining the amount of damage that the defendants will be responsible for; it is understood that the plaintiffs did not fulfil the obligations imposed on them by the law by building an illegal building without a license, project and in violation of the building regulations, and that they did not exhibit the behavior expected from a law-abiding citizen. Considering the development of the concrete incident, it should be accepted that the plaintiffs have a mutual (shared) fault in the damage. In this case, the work to be done by the local court is to determine the scope of the damage, and to decide according to the result to be formed by making an appropriate discount by taking into account Articles 51-52 of the TCO due to the proportionate fault of the plaintiffs. It is not correct to have decided to reject the claim completely on written grounds contrary to the explained issues. Therefore, the decision should be reversed.

4.5 The Concept of Jointly and Several Liability and an Examination of the Allocating of Fault by Experts in Light of Judicial Decisions

According to Article 61 of the Turkish Code of Obligations, if more than one person causes damage to another person together (with common fault), those responsible for that damage are jointly and severally liable for the compensation. In joint and several liability, more than one person who has a role in the occurrence of the same damage, but for which part of the damage cannot be determined, must be compensated for the entire right to compensation, which is suitable for division by its nature. According to Article 163 of the TCO, the liability of each responsible party to the injured party continues until the entire damage is compensated. With the aforementioned article, it is intended to provide assurance to the creditors in terms of indemnification of the debt in such cases where there is or is deemed to be a unity of interest between the debtors. Article 62 of the TCO stipulates that in determining the amount of compensation to be paid by the responsible parties, all circumstances and conditions that constitute fault shall be analyzed and the gravity of the fault and the intensity of the danger created by each of them shall be taken into consideration. The injured party may file a lawsuit against the actual perpetrator of the damage, or the instigator, or the one who is involved in the incident in the second plan and request the payment of the damage. Even if the fault of one of them is lighter and therefore the compensation is reduced, this situation will not prevent the injured party from applying to one of the jointly liable parties for the entire compensation receivable.

While the relationship between the injured party and the harmed parties is referred to as external relationship, the relationship between the harmed parties themselves is referred to as internal relationship. In a broader sense, an internal relationship is "a *debt relationship that is valid between the damages after one or more of the damages have been compensated by one or more of the damages, and which regulates the rights of the damaging party who has compensated the damages against the other damaging parties, and which basically arises from the law."* (YAĞCIOĞLU, 2014) According to the internal relationship between the jointly liable parties explained in paragraph 2 of Article 62 of the TCO, the responsible party who pays more than his share of the compensation has the right of recourse against the other jointly liable parties for the overpayment he has made.

In our judicial system, the expert reports related to the concrete events that we have dealt with within the scope of our study have been examined and the fault ratios of the responsible parties have been given by the experts in these reports. As a result, joint and several liability relationships have emerged in terms of compensation liability.

The summary of the decision of the 4th Civil Chamber of the Court of Cassation regarding a case filed after the 1999 Kocaeli Earthquake is as follows.

" ... In the case, the Court decided that the defendant contractor was 30% at fault, the defendant technical application supervisor (TUS) was 30% at fault, the project engineer was 20% at fault, and the municipality was 20% at fault, and since the contractor, as the employer, was also responsible for the faults of the technical application supervisor and the project engineer in accordance with Article 51 of the Code of Civil Procedure, a total of 80% responsibility was decided." (Yargıtay 4. HD, 20.11.2008, 2027/14382; Yargıtay Karar Dairesi 2009/7, 1266)

In another judicial decision upheld by the General Assembly of the Council of State, the experts made a fault allocation as summarized below.

In the lawsuit filed by the relatives of the person who lost his life by being trapped under the rubble of the building that collapsed in the earthquake, with the claim that the defendant administrations had service defects, material and moral compensation was requested; Based on the report of the Board of Experts appointed by the court that *the contractor was 30% at fault, the engineering responsible 37% at fault, the defendant administrations were held liable to pay compensation "in proportion to their faults" based on the report that the Municipality was 29% at fault for not fully fulfilling the supervision of the project and implementation, the Ministry of Environment and Urbanization was 2% at fault for not fully fulfilling the supervision of the plans and projects, and the Disaster and Emergency Management Presidency was 2% at fault for not carrying out the necessary studies and inspections related to the disaster situation; This decision of the court of first instance was upheld by the General Assembly after a long judgement process* (Danıştay İDDGK 19.02.2020, E.2019/2428 K.2020/38)

In another decision of the Court of Cassation, although the experts did not explain in their reports how they made an evaluation with what approach while making the fault allocation between the defendants, they made a decision that the earthquake intensity was 10% defective. The summary of the case is as follows.

The plaintiff purchased the house constructed by the defendant V.G.... Arsa Ofisi Koll.Şirketi (C.G.-Z.C. partnership) from the same partnership. Although the court made a defect examination in the case and made a judgement by making a defect reduction according to the expert report stating that the contractor company was 50% responsible, the municipality was 15% responsible, the Static Engineer was 10% responsible, the TUS officer was 15% responsible, and the earthquake intensity was 10% responsible, it is not possible to make a judgement according to the defect responsibility for the plaintiff buyer in the case. Because the defendant, who is deemed to be at fault, is jointly and severally liable to the plaintiff for the entire damage according to the provisions of the seller's warranty against defects. According to the relevant articles of the Code of Obligations, although the defendant contractor-seller is jointly and severally liable for the entire loss of the plaintiff caused by the collapse of the building in the earthquake due to the incomplete and defective construction of the building not in accordance with the technique, the court's decision to accept the case in proportion to the defendant contractor-seller's fault rate is contrary to the procedure and law and requires reversal (Yargıtay 13.HD. 21.10.2008, E.2008/10773 K.2008/12189).

As can be seen from the case examples given above, all responsible parties in the project design, manufacturing and supervision stages have to share the damages in proportion to their faults. It is useful to emphasize two issues here. The first of these is how the experts determine the rate of fault and whether there is a methodology for determining the rate of fault? If we give an example in another similar expert report (the case is still ongoing);

The section written by our expert colleagues assigned within the scope of a case file that is still ongoing in the ……. Court is exactly as follows:

".... Accordingly, the owner was found to be 25% at fault, the contractor 34%, the inspection firm 40%, the geological engineer 0.5% and the civil engineer 0.5%"

Now let us reconsider the question we have asked above. By what method did the experts determine these liability ratios? Well, according to the concept of joint and several liability, will the injured party in the case be able to collect all of its damages from the civil engineer, who is stated to be only 0.5 percent at fault?

This situation was frequently encountered after the 1999 earthquake. In some cases, although it was determined that the civil engineer, who was the project author, was 1% responsible and the contractor of the building was 99% responsible in the expert reports related to a building damaged due to an earthquake, it was observed that the civil engineer, who was 1% responsible, was faced with the obligation to compensate 100% of the damage to the damaged person in accordance with the principle of joint and several liability that we tried to explain. In this way, civil engineers who compensate the damages caused by the defect of another person could not find anyone to recourse (Daylik, 2002).

Apportionment of fault between the responsible parties in the determination of compensation is also a situation encountered in the United States. Below is an example of a court order that has been issued to illustrate the matter:

A Court Decision from USA (Supreme Court of Mississippi, No. 98-CA-00419-SCT (Miss. Feb 22, 2001).

".... The jury further found that negligence on the part of Wilburn Oil and Murphree himself were also proximate causes of Murphree's death. The jury then made an allocation of fault as follows: *Murphree 60%; Wilburn Oil 39%; Mack 3/4%; Cummins 1/4%."*

It should be emphasized here that when determining the fault ratios among the responsible parties, the opinion of expert witnesses should be sought. The following Court of Cassation decision can be given as an example:

"Since the determination of the rate of fault is a single problem requiring expertise, it should be determined by experts" (Yargıtay 3.HD. 31.10.1979-6260/6521).

4.6 Statute of Limitation of Liability

In our legal system, statute of limitations is defined as the impossibility of obtaining compensation for a material or moral damage within a certain period of time through litigation or the impossibility of exercising this right as a result of the expiration of the period stipulated in the law. There are various regulations regarding statute of limitations in our laws. In general, construction law disputes, which are handled within the scope of fault (tort) liability in the law of obligations, are also included in our Code of Obligations under the statute of limitations for defects in immovable structures.

The most prominent discussions on the concept of statute of limitations in construction law were made after the 1999 Gulf Earthquake and regulations were introduced on the subject with the case law of the Court of Cassation. While discussing the concept of statute of limitations in construction disputes, it will be necessary to examine the abrogated Code of Obligations No. 818 and the Turkish Code of Obligations No. 6098, which was adopted on 11.01.2011 and is still in force.

According to Article 60 of the Former Code of Obligations No. 818, the injured party must file a claim within one year from the day he/she learns of the damage and the damaging party, and in any case within ten years from the act that caused the damage to occur, due to the damage caused by an unfair act (negligence, fault or intent). However, according to Article 215/3 of the Law, "in cases arising from the defect of a building and based on security, the time limit expires within 5 years after the transfer of ownership". However, according to this article, it is stated that if there are hidden defects in the building or gross negligence of the seller, this 5-year limitation period cannot be utilized.

Legally, in order for the injured party to claim compensation, the damage must first occur, the injured party must learn about it, and the amount of the damage must be certain or determinable. When both articles are analyzed, it will be necessary to carefully examine the decisions of the Court of Cassation regarding the uncertainties regarding the beginning of the statute of limitations in the lawsuits to be filed due to damages to the buildings. The decision of the Civil General Assembly of the Court of Cassation with the file number 2003/4-603 is important in terms of explaining the issue. In the lawsuit based on the decision, compensation for the damages incurred in a building as a result of the 1999 Gulf Earthquake is requested. The building subject to the lawsuit was completed in 1976 and collapsed due to the earthquake that occurred on 17.08.1999. Based on the reports received from the experts, it is undisputed that the building was not constructed in accordance with the General Technical Specifications for Construction Works and the Regulation on Structures to be built in disaster areas. The fact that the building was not constructed in accordance with the technical specifications and regulations reveals that the defendant has committed a serious defect, and this defect cannot be considered within the scope of negligence or slight negligence. The plaintiff claims the damages incurred due to the building which was built in 1976 but collapsed as a result of the earthquake (Precedential Decision of the Supreme Court of Appeal General Assembly of Civil Chambers dated 22.10.2003 and numbered E.2003/4-603, K., S. 2003/594).

According to the decision, based on the legal arrangement and the available evidence, although the construction of the building was contrary to the regulations and technical specifications, the plaintiff would not have a right to claim on that date, since the damage did not occur at that time. It is also not possible for the defendant to detect such a hidden defect before any apparent building damage occurs. In this context, starting the statute of limitations on a date when the claim for compensation has not arisen will make it difficult or even impossible to claim and obtain the right. On the date of the construction of the building, the defendant's unlawful act has occurred.

However, there is no damage yet. The damage occurred as a result of the earthquake. For these reasons, in the decision, it is deemed appropriate to start the statute of limitations from this date, since the date of the occurrence of the earthquake is the date of the occurrence of the damage and the date when the damages occurred and who the damaging party was learnt, in accordance with Article 60 of the Code of Obligations. This view adopted by the Court of Cassation is supported by many decisions and the decision of the General Assembly of Civil Chambers numbered 2003/4-400-393. However, in a decision of the General Assembly of the Court of Cassation regarding the earthquake, in which the defect also constitutes an offence in addition to civil cases (the decision of the Criminal Board of the Court of Cassation numbered 2002/9-314 and numbered 2003/15), it was unanimously decided that the offence should be deemed to have been committed at the time the building collapsed, based on the above explanations. Another Court of Cassation decision on the subject is summarized below.

Although the unlawful act has been committed, the damage caused by the unlawful act has not yet occurred; if certain factors must occur or a certain period of time must pass after the date of the act for the damage to occur, naturally, it will not be possible for the statute of limitations to begin to run. On the date of the construction of the building, the defendant's unlawful act has occurred. However, there is no damage yet. As mentioned above, not every unlawful act may cause damage. The unlawful act that occurred during the construction of the building caused the damage as a result of the earthquake. The statute of limitations for compensation receivables, like other receivables, shall commence as soon as it becomes claimable and actionable by the creditor. In the concrete case, although the dwelling belonging to the plaintiff was completed and delivered on 06.11.1975 according to the Certificate of Occupancy and the relationship of the building with the defendants was legally severed as of that date, the wrongful act of the defendants should be deemed to have occurred on 17.08.1999, when the damage alleged to have occurred as a result thereof occurred. Therefore, the beginning of the statute of limitations should be based on this date (Yargıtay HGK.04.06.2003, E.2003/4-400 K.2003/393).

This attitude of the Court of Cassation has been criticized by some legal experts, contractors and engineers. In general, the basis of the objections is the possibility of being held liable even for the heirs, let alone the persons themselves, in the event of a building damage that may occur even though many years have passed since the construction date. When the issue is considered from this point of view, in the event of damage to a building that was built many years ago, it often becomes insurmountable to determine objectively who is at fault and the compensation by examining the regulations and technical specifications and the current situation at the time of construction.

Based on this opinion, according to Article 244, paragraph 3 of the new Turkish Code of Obligations No. 6098 adopted on 11.01.2011:

"Actions arising from the defect of a building shall be time-barred after the expiry of (5) years from the transfer of ownership and (20) years if the seller is seriously negligent."

The amendment has been made in the form of a change.

Since the beginning of the statute of limitations is the date of "transfer of ownership", this (20) year period cannot be exceeded; a lawsuit cannot be filed against the seller for damages arising after twenty years.

Article 244, paragraph 3 of the Law No. 6098 on the statute of limitations in the sale of immovable property is reiterated in Article 478 of the Law No. 6098 on the statute of limitations applicable to the liability of the "contractor" in the contract of work, and it is stated as follows*: "If the contractor has created a defective work, the lawsuits to be filed for this reason shall expire after the expiration of two years starting from the date of delivery, for works other than immovable structures, five years for immovable structures, and if the contractor has gross fault, twenty years regardless of the nature of the defective work."* Here, since the beginning of the statute of limitations is "the date of delivery of the building", the liability of the contractor is limited to twenty years.

The concept of statute of limitations in civil lawsuits gains a different dimension if the lawsuit also constitutes a penalty, as stated in Article 72 of the law in accordance with the general provisions of the TCO under the concept of compensation. The relevant article is given below:

"The claim for compensation shall be time-barred after the expiry of two years from the date on which the injured person learnt of the damage and the person liable for compensation, and in any case after the expiry of ten years from the date on which the act was committed. However, if the compensation has arisen from an act that requires a penalty for which a longer statute of limitations is prescribed by criminal law, this statute of limitations shall apply."

4.7 Legal Problems Arising from Damage to Neighboring Properties During Excavation and Construction

A special regulation has been made in the Turkish Civil Code No. 4721 regarding the legal problems that may arise as a result of damaging neighboring immovables during excavation and construction. According to Article 738 of the Turkish Civil Code No. 4721, "*immovable owners must avoid damaging neighboring immovables by shaking or endangering their lands or affecting the facilities on them during excavation and construction"*. In this case, according to Article 730 of the same Law, the person who has suffered damage or is in danger of damage may sue for the restoration of the situation, the elimination of the danger and the damage suffered. The judge may decide to compensate the damages arising from unavoidable excesses in accordance with local custom with an appropriate price. According to Article 737, everyone is obliged to avoid any encroachment that may adversely affect his neighbors while exercising his powers arising from the ownership of immovable property and especially while carrying out business activities. Equalization rights arising from local customary and unavoidable excesses are reserved.

When Articles 730 and 737 are examined, compensation of damages is mentioned. While examining the damages caused by flooding to the neighbors and the dangers posed by the immovable property, it is not intended to consider only the interests of the damaged neighbors; an appropriate and conciliatory solution is envisaged by investigating the conditions under which the flooding is caused, whether there is inevitability and necessity, and by taking into account the degree of lawfulness of the action.

If it is likely that a stability disorder will occur in the neighboring structure during excavation and construction, a lawsuit may be filed to stop the construction and take the necessary measures. A judgement regarding this situation is given below:

"It is not possible to file a lawsuit for the purpose of preventing the situation that constitutes a defect, on the grounds that the damage will occur in the future. As a rule, the damage must have occurred. However, in exceptional cases, although the damage has not yet occurred, if it is very likely or certain that damage will occur in the near future, the plaintiff should be given the right to file a lawsuit for the prevention of the danger of damage, and the damage should not be expected to occur." (Yargıtay 14. HD, 2019/584 E, 2021/3286 K, 18/05/2021 T.)

Within the scope of the subject, the study written by Lawyer İlker Hasan Duman is examined and the reports received from the experts in a sample case are summarized. (Duman, 2015)

Statement of Claim: *"The plaintiff (M.A) is the owner of the independent section in the building located on the land registered in the title deed of Gemlik district (...). The construction started on 30 April 2012 by the defendant Ö.E. on the land registered in the title deed (...), which is an adjacent parcel. Since the defendant (Ö.E.) did not comply with the necessary science and art rules during the construction, the plaintiff's house was damaged to the extent that it could not be used or inhabited. The plaintiff has requested the compensation of pecuniary (... TL damage compensation) + non-pecuniary damages".*

Petition for Response: *"The construction of the construction belonging to the defendant complied with all construction-art-art rules-science-science rules and the conditions specified in the laws-laws and regulations related to zoning-construction. There is no fault of the defendant. The damage and cracks in the plaintiff's house are the result of the earthquake that occurred in 1999-2001 and have nothing to do with excavation. The building belonging to the plaintiffs is 35 years old and has reached* *the end of its economic life. Since there are olive ponds on the ground of the building, in addition to the load these ponds put on the building, due to the intensive use of salt, it has damaged the session and foundations of the building. The house belonging to the plaintiff does not have a certificate of occupancy. The building belonging to the plaintiffs was constructed in violation of the zoning status, project, license and its annexes".*

Detection Report: *"There are cracks on the stair landings, inside the flats, walls and ceilings on all floors except the basement floor of the immovable. The immovable property is very old, it was built according to the earthquake regulations at the time it was built, and it is inevitable that there will be wear and tear on the immovable as a result of the intervening years. However, the foundation excavation made without a shoring system right next to the immovable and the possible movements caused by the ongoing construction on the ground have caused cracks in the walls in general and partially in the columns and beams in the old building on the adjacent parcel. The immovable property seems inconvenient to reside in this state".*

Geological Expert's Report: The *soil structure of the area subject to the lawsuit consists of Palaeozoic aged shale units and the decomposed and decomposed products of these units at the upper levels. In the laboratory studies, the material forming the ground was determined as Clay Gravel and Clay Sand. There is no underground water level in the ground. The plaintiff party stated that cracks did not occur during the construction of the building belonging to the defendant party, and that cracks started to form after the construction of the building, so no damage occurred to the building belonging to the plaintiff party during the foundation excavation of the new building.*

Technical Expert Report: *"The damaged immovable subject to the lawsuit has a main entrance on Güven Street, which is the front façade and has 5 stories, and from the rear façade, there is an entrance door to the basement from İncirli Street and there are 6 olive pools in the basement floor, 5 pieces 2.25 depth and 1 piece 3.75 depth in the basement floor, there are 6 olive pools, the building on the newly built 258 block 11 parcel belonging to the defendant party was built with a 6-storey reinforced concrete carcass building system and raft foundation system, the building was built as a contiguous order, there are no cracks in the basement floor of the damaged building,* *on the ground and normal floors of the building, generally in all rooms, It was determined that there were cross cracks in the wall parts such as earthquake cracks in the bathrooms, there were many cracks between the beam walls, between the column walls, the plasters burst in places, it was determined that it would be risky to sit in the building and therefore it was evacuated, there was no settlement on the floor of the building, when the projects were examined, it was seen that the new building foundation base bottom elevation was lower than the front road elevation (Güven Street) (-4.25 m) below the front road elevation (Güven Street) (-4. 25 m), the new building foundation bottom elevation is above the old building foundation bottom elevation, therefore it is seen that the excavation of the new building foundation does not damage the old building foundation, the damages to the old building are not caused by the fault or defect caused by the excavation, it is seen that the appropriate dilatation gap was not left between the two buildings in the earthquake regulations when the new building was built, the dilatation gap to be left should be 7 cm, The cracks in the old building belonging to the plaintiff were not caused by ground settlement, they were not caused by the excavation of the new building, the cracks were probably caused by the lack of a dilatation gap, the new building and the old building were working together, the settlements that may occur in the new building may also be reflected in the old building, the personal weight and movements in the new building create lateral pressure on the old adjacent building, in the concrete poured in the new building; during the transition of concrete from the fresh state to the setting state, shrinkages called "shrinkage" will occur, and these shrinkages are reflected to the old building due to the lack of dilatation gap".*

12.3.2014 and 9.9.2014 Original and Additional Expert Reports Submitted to the Court of Instruction: *"It is understood from both the reports submitted to the file and the statements of the defendants that the foundation excavation was made due to the construction of a new building on the adjacent parcel belonging to the defendant to the plaintiff's immovable, that no damage occurred to the plaintiff's structure during the foundation excavation, and that the damage occurred at a certain stage of the defendant's construction, During the foundation excavation carried out by the defendant on the adjacent parcel of the defendant's parcel, the excavation should be carried out without machinery and vibration, the excavation should be carried out* *gradually and with shoring, it should be supported by wooden or steel profile struts between the two neighboring buildings, when the photographs submitted to the file were examined, the two buildings adjacent to the defendant's parcel were not supported by wooden or steel profile struts, dilatation was left between the plaintiff's building and the defendant's building and styrofoam material was used, the reason for the damages to the plaintiff's building was that the defendant did not make machine-free and vibration-free excavation in the foundation excavation on the parcel, the excavation was not made gradually and with shoring, and it was not supported by wooden or steel profile struts between the two neighboring buildings, the building belonging to the plaintiffs is approximately 35 years old, when the reinforced concrete projects of the building are examined, the cross-sections of the carrier system are very inadequate according to the new earthquake regulations, therefore, the strengthening of the building subject to the lawsuit belonging to the plaintiff will not benefit the building, the age of the building belonging to the plaintiff, the material used, the value of the plaintiff's building considering the share of wear and tear (....) TL, the plaintiff's right to demand the current rent due to the damage to the building to the extent that the building is uninhabitable (...) TL, the cost of moving the household goods (...) TL, the commission fee given to the real estate agent for hiring new household goods (...) TL was calculated"* (Expert Reports dated 12.3.2014 and 9.9.2014 submitted to the file numbered 2013/376 of Gemlik 1st Civil Court of First Instance).

4.8 Damage In Liability Law

Damage is defined in the Turkish Language Association Dictionary as "*loss of interest or negative, bad result caused by something, an event*". Damage is the main element of compensation. The material damage subject to compensation is defined as the difference between the property of the injured party before the defective event and after the defective event. (Tekinay, 1979; Nomer, 2010; Yargıtay 7.HD, 06.03.2007 Tarih ve 4082/762 Sayılı Karar)

In this context, a sample judgement is given below.

"*As a result of the earthquake, one building collapsed on another. Even if the collapse had not occurred, the building of the injured party would have been damaged* *in the earthquake. Therefore, the damage is determined according to the difference between the current situation and the hypothetical damaged condition of the building*" (Yargıtay 4. HD, T: 31.01.2005, K 6859/515).

4.9 Can Earthquakes be Considered Force Majeure?

Force Majeure is defined in the Turkish Language Association Dictionary as *"Unforeseen events that are impossible to be prevented against the measures to be taken by anyone, preventing the fulfilment of the obligation, unexpected events beyond the will of the debtor."*

Force Majeure is defined by the Supreme Court as *"events that are outside the perpetrator due to their origin, natural, social and legal nature, which cannot be prevented by the perpetrator, and which cannot be appreciated and predicted in advance"*.

The occurrence of force majeure conditions is a situation that prevents the fulfilment of an obligation or a general obligation of behavior.

In the earthquake hazard map prepared by Ministry of Interior Disaster and Emergency Management Presidency in our country, regionally predicted earthquake magnitudes are given. Static and geotechnical projects are made by considering the parameters given in this map. However, after the earthquakes of 6 February, much higher ground accelerations have occurred in the region than predicted. While determining the fault ratios of the responsible parties, the experts should evaluate whether the earthquake can be accepted as force majeure under these conditions. In the reports submitted to the court, technical details should be expressed in plain language in a way that the judge can understand, and an explanation should be provided on whether the liability for compensation will be cancelled or whether there will be a reduction in compensation. Sample court decisions on the subject after the 1999 Gulf earthquake are given below.

In cases where sufficient examination of the existence of a causal link is not made, the decisions rendered by the local courts may be reversed by the Court of Cassation.

The decision of the 13th Civil Chamber of the Court of Cassation dated 06.05.1993 and numbered 1993/2426 E. 1993/3966 K. is as follows.

"As such, the merits of the lawsuit filed by the plaintiffs against the defendant Mustafa should be entered into, evidence and counter-evidence should be collected, the Board of Expert Experts should be examined and it should be determined whether there is a defect in the construction (in the construction of the merger of the ... apartment building to the ... apartment building), when the defect is seen, it should be investigated and revealed whether there is a "proper causal link between it and the damage, and if the existence is determined, this time it should be clarified whether there is a force majeure and whether the earthquake event will cut this link, and if necessary, whether Article 44 of the Code of Civil Procedure should be taken into consideration in the case. Article 44 of the Code should be considered, and a decision should be made within the framework of the appropriate result to be obtained. It should be noted immediately that there must be a "proper causal link" between the damage and the defect in the construction. It should not be overlooked that *if this appropriate causal link does not exist or if the damage is caused by a force majeure that breaks the causal link, the building owner cannot be held liable."* (Yargıtay 13. HD. E. 1993/2426 K. 1993/3966 T. 06.5.1993).

In the decision of the 3rd Civil Chamber of the Court of Cassation dated 11.11.2014 and numbered 2014/10374 E. 2014/14630 K;

According to Article 51/1 of the TCO; "The judge determines the scope and the manner of payment of the compensation, taking into account the necessity of the situation and especially the gravity of the fault." The plaintiff's damage arose as a result of the collapse of the building in which he resided due to the earthquake and his being trapped under the debris. Although it cannot be accepted that the earthquake is a force majeure event and cuts the causal link with the damage, it must also be accepted that it is the biggest natural disaster that affects everyone in the region, which is unpredictable when and at what magnitude it will occur and causes a great destruction when the result occurs. In addition, the fact that the region is located in the first-degree earthquake zone and the magnitude of the earthquake should not be overlooked. In that case, it is also necessary for the court to make an equitable *deduction from the amount of compensation determined by the expert. The fact that no evaluation was made in this regard was not deemed correct, and the judgement had to be reversed for the reasons explained."* (Yargıtay 3. HD. E. 2014/10374 K. 2014/14630 T. 11.11.2014)

In some judicial decisions we have examined, it is stated that although natural events (such as earthquakes, floods, landslides) can be accepted as force majeure because they are irresistible, unpreventable and involuntary, the State's responsibility will not be eliminated if the probability of their occurrence is foreseeable, and the relevant administrations do not carry out the necessary works in order to minimize the damages.

This issue is explained in the decisions of the Council of State as follows "In the event that there is a 'negative action' of the administration in the region located in the earthquake zone, which consists of the negativities in the whole of the administrative activities related to the determination of the areas related to the settlements by taking the earthquake reality as a data, taking, implementing and supervising the decisions regarding the construction in these areas, it is not possible to accept that the earthquake is considered as force majeure and cuts the causal link with the damage. In this case, while the Court should make a decision as a result of the evaluation of whether there is a service defect of the administration in the formation of the alleged damage, the decision to reject the case on the grounds that the causal link between the damage and the administrative activity has disappeared by accepting the earthquake as a force majeure has not been found to be inaccurate." (Danıştay 11. Dairesi, E: 2005/1353, K: 2007/6248, T: 29.06.2007.)

Another Council of State decision on the subject is as follows,

"As it is known, our country is one of the countries that frequently encounter earthquake disasters that cause great loss of life and property due to its geological and topographical structure. To investigate the measures to be taken for the prevention of disasters and mitigation of damages, to determine the basic objectives and policies in this regard, to coordinate scientific, technical and administrative studies within the country, to transfer and supervise the common results to practice through by-laws, regulations, instructions and training, to establish national and international cooperation, projects and programs for the reduction of disaster damages, to transfer the results obtained to practice, Among the duties, powers and responsibilities of the State are to determine and declare the regions that have suffered or may suffer from disasters and the disaster zones prohibited for construction or residence, to determine the rules, construction techniques and project design principles for the buildings to be constructed in disaster zones, to examine earthquakes and their effects, to prepare and develop earthquake catalogues and earthquake maps of the country according to the results obtained, and to carry out studies on the reinforcement and repair methods of structures damaged by earthquakes.

In addition to the fact that the earthquake phenomenon occurs as a natural event, it is possible to prevent or even eliminate the damages that may arise through the practices to be carried out by the administration. In other words, although it is unpredictable where, when and how big the earthquake will occur, it is clear that the negative consequences of the earthquake are foreseeable and measures can be taken in advance to minimize the damages (Danıştay 10. Dairesi 28.05.2007, E.2005/9126 K.2007/3069)

When the judicial decisions we have given above are evaluated, the issue that should be evaluated in terms of the causal link and the reasons requiring a reduction in compensation is the magnitude of the earthquake. In the decisions rendered by the Court of Cassation, the magnitude of the earthquake is generally not considered as an issue that interrupts the causal link, is not accepted as force majeure, but is considered as a reason for a reduction in compensation in accordance with Article 51 of the Turkish Code of Obligations.

As a result of many lawsuits filed after the earthquakes that occurred in our country, the summary of the decisions made by the judiciary can be summarized as follows.

Even if the building destroyed or damaged as a result of the earthquake was built according to the plan and project, zoning regulations and earthquake regulations, it is inevitable that the building will be damaged considering the magnitude of the earthquake. In that case, it is also necessary for the court to make an appropriate equitable deduction from the amount of pecuniary and non-pecuniary compensation in accordance with Article 51 of the TCO (06.03.2013 Tarih, 2012/786 Esas 2013/318 Karar Sayılı Yargıtay Hukuk Genel Kurulu ilamı; Yargıtay HGK. 06.03.2013, E.2012/4-786 K.2013/318; Yargıtay 3. HD. 09.12.2014, E.2014/12359 K.2014/16124; Yargıtay 3.HD. 09.12.2014, E.2014/12359 K.2014/16124)

4.10 Unjust Enrichment

In determining the compensation, the amount of compensation to be paid by the at-fault party is equitable should be only as much as the damage caused by the negligent party. Holding the at-fault party liable for more than the damage caused by the compensation to be paid will lead to an unfair gain in value in the assets of the injured party.

In the following sample judgement of the Court of Cassation, the determination of the amount of compensation is explained.

"The principle here should be as follows; the damage-causing act should cause a decrease in the property of the injured party, the amount of the damages owed by the damaging party should be the same amount. In that case, the amount of the actual damage shall be the amount of the compensation. In other words, the compensation to be paid should be in such an amount so that the same situation can be established with the compensation to be paid, if the damaging act had not taken place, the same situation could be established" (HGK. 5.3.2003, 152/125).

In the determination of compensation arising from earthquakes, the earthquake regulations in force at the time of the construction of the structure should be taken into consideration when it comes to the retrofitting of light and medium damaged structures. To give an example, after the earthquake disaster we experienced on 6 February, many compensation lawsuits have been filed and continue to be filed. In the expert examinations, it is requested to determine the responsible parties and their degrees of fault in order to determine the compensation. Many buildings subject to the lawsuit were built according to the 2007 earthquake regulations. In case of a retrofitting decision in these structures, our current regulation states that the structure should be retrofitted according to the 2018 earthquake regulation. When 2018 earthquake regulations and 2007 earthquake regulations are compared, it is seen that the performance levels of the structures built according to 2018 earthquake regulations are much higher than the structures built according to 2007 earthquake regulations. For this reason, it is much more costly to build and retrofit a building according to the 2018 earthquake code. If the damaged structure is retrofitted according to the 2018 earthquake code, the structure will be more durable and therefore more valuable than before the damage. This will lead to unjust enrichment of the injured party. The indemnity responsible is only obliged to bring it to the condition before the damage. Therefore, the expert should calculate the costs of retrofitting the structure according to the 2007 earthquake regulations and retrofitting according to the 2018 earthquake regulations. The damaging party should be held responsible for the cost of retrofitting according to the 2007 earthquake regulation. For this reason, I am of the opinion that when the structure is strengthened according to the 2018 earthquake regulations, the damaged person should cover the difference. In this context, the following Court of Cassation decision may be an example.

"In the concrete case, in the 2nd expert committee report dated 14.11.2013, it was pointed out that the building was tendered according to the earthquake regulation dated 1998, the final acceptance was made in 2005, despite this, a claim cannot be made according to the earthquake regulation dated 2007, but it is necessary to make a technical examination according to the 1998 Earthquake Regulation, and as a result, a numerical evaluation could not be made. Indeed, in determining the liability of the defendant in the case, it is obligatory to examine whether the building was constructed in accordance with the earthquake regulations in force in the year it was built." **(**Yargıtay 15. HD. E. 2015/3965 K. 2016/1202 T. 24.2.2016)

4.11 Design Criteria Given Within the Scope of Regulations, Specifications and Circulars

When the regulations, specifications and circulars prepared by the state are examined, it is seen that the design criteria given express the minimum conditions. For example;

Türkiye Building Earthquake Regulation (2018) Article 1; *"The purpose of this By-Law is to determine the necessary rules and minimum conditions for the design and construction of all public and private buildings and building-type structures to be rebuilt, altered or enlarged, and for the assessment and retrofitting of the performance of existing buildings under earthquake effect."*

In Soil and Foundation Investigation Application Principles and Report Format General Principles; *"This code of practice and report format determines the procedures and principles to be complied with in soil and foundation investigations of new and/or existing buildings and building type structures. The matters contained in this code of practice and report format define the minimum rules for the performance and supervision of soil and foundation investigations, and soil and foundation investigation reports must be prepared in accordance with the relevant Turkish standards and/or internationally recognized standards (ISO, ASTM, BSI, Eurocode, DIN, etc.)."*

Article 1 Of The Regulation On Excavation Support Structures; *"The purpose of this By-Law is to determine the rules, minimum requirements and principles to be complied with for the design, design and application of excavation support structures under both static loads and earthquake loads in the excavations to be made for the construction of foundations and/or basement floors of all types of buildings to be built in all planned and unplanned areas."*

there are explanations in the form of.

Therefore, even if these criteria are complied with during the design and supervision phase, the responsibility of the engineers will not be eliminated for the negativities that may arise. In this case, there are no explanatory jurisprudence in the existing judicial decisions on the way to be followed in determining the compensation. One of the most fundamental concepts of engineering is that the design should be economical as well as safe. As it is known, designs are made for different performance levels depending on the types of structures. As the performance level for which the building will be designed increases, the cost will increase in parallel. Naturally, the owners want the cost to be as low as possible. This situation will make it difficult for the engineer to decide on the performance level and therefore the economy to be taken into consideration in the design. Engineers design according to the criteria given in regulations, circulars and standards unless otherwise stated. Articles 115 and 116 of the Turkish Code of Obligations No. 6098 explain irresponsibility agreements as we have explained above. Based on these articles, it is null and void for engineers, who are legally accepted as experts, to make a non-liability agreement in advance due to the negativities that may occur even due to slight defects. This imposes all responsibility on the designer. With the studies to be carried out, the way should be paved for the designer to make explanatory agreements with the owners in advance about the performance level and risks to be taken into consideration.

4.12 Responsibilities of Building Inspection Companies in Geotechnical Applications

In the period following the 1999 Marmara Earthquake, building inspection works in our country were taken from the responsibility of municipalities and given to building inspection institutions (Law No. 4708, Official Gazette dated 13.07.2001 and numbered 24461). In Article 1 of the relevant law, the purpose of the law is stated as "To ensure project and building supervision for the construction of quality buildings in accordance with the zoning plan, science, art and health rules and standards in order to ensure the safety of life and property and to regulate the procedures and principles regarding building supervision." Based on this law, "Building Inspection Implementation Regulation" was published in the Official Gazette dated 5 February 2008 and numbered 26678 and the procedures and principles regarding the implementation of the law were determined. Within the framework of this law and regulation, the legal and criminal liability limits of building inspection organisations are clearly defined. In this context, the task of checking the ground survey reports according to the relevant legislation, examining the conformity of the application projects and calculations prepared by the geotechnical project authors with the specifications and standards, and ensuring that the productions and quality control tests are carried out according to the approved projects have been assigned to the building inspection companies. However, despite this control mechanism, many undesirable cases are encountered in matters related to our profession; the determination of the fault rates of those responsible for the damages arising from the damages incurred during the inspection, project design and manufacturing phase is tried to be resolved through the judiciary.

With the relevant law and regulation, the limits of responsibility of the building inspection companies in all phases of the construction are drawn. Within the scope of the law and regulation, the building inspection companies are held responsible in proportion to their defects with the project authors and the contractor when a construction damage occurs. However, it is a big question mark how to apportion the fault between those responsible for causing the damage. Therefore, it is necessary to propose a systematic approach to determine the liability-fault ratio relations of building inspection companies. In this context, the legal basis of the responsibilities of building inspection companies in geotechnical applications and the basic legal issues necessary for a fair apportionment of fault between potential responsible parties in the event of a structural damage are discussed.

According to the relevant law and regulation, construction damage is defined as *"all kinds of damages that prevent the use of the structure or cause loss of value in the structure due to incomplete, faulty and defective construction of the structure contrary to the rules of science and art, except for the damages arising from the use*". The damage referred to here is material damage.

According to article 3 of the Law on Building Inspection and article 3, paragraph d of the Building Inspection Implementation Regulation, construction defect is defined as "Incomplete, faulty and defective construction of the building contrary to the licence and annexes, relevant standards, technical specifications, legislation, science, art and health rules".

The law holds those who have a causal link with the damage responsible in proportion to their faults. According to this law and regulation, the managers, partners, supervisory architects and engineers, project authors, laboratory staff and building contractor of the building supervision organizations are liable to the building owner and the relevant administration for the building damage caused by the implementation of this law, to the extent of their faults. The building contractor and the site supervisor appointed to represent him are jointly and severally liable for the defects in the construction works. In addition, the managing engineers and architects who are partners of the building inspection organization are jointly and severally liable with the inspection personnel for the defects arising from the failure to take measures to ensure that the personnel carrying out the inspection service perform their duties effectively within the framework of the law and regulation. However, according to Articles 115 and 116 of the Turkish Code of Obligations No. 6098 , if a service, profession or art requiring expertise can only be carried out with the permission granted by law or by the competent authorities, it is absolutely null and void for the debtor to make a non-liability agreement even for slight negligence and for the debtor to make an agreement that the debtor will not be liable for the actions of assistants. For this reason, the irresponsibility agreements to be made by the building inspection companies with the project authors and the contractor on the issues of project and implementation supervision, which are under the responsibility of the building inspection companies in accordance with the law and regulations, shall be invalid.

Therefore, in the event of a building damage, the fault ratios of the responsible parties causing the defect should be clearly and precisely determined. However, the law does not explain how and by whom the rate of fault is to be determined. In the current system, the determination of the rate of fault is made on the basis of expert examinations when the problem is brought to the judiciary.

In the dissenting opinion of the 15th Civil Chamber of the Court of Cassation in its Decision No. 2015/2879 and No. 2015/3815, the issue is addressed as follows"*Namely; pursuant to Article 3 of the Building Inspection Law No. 4708, the building inspection bodies, together with the supervising architects and engineers, project authors, laboratory staff and the building contractor, are liable to the building owner and the relevant administration in proportion to their faults due to the damage to the building caused by the construction of the building contrary to the licence and its annexes, science, art and health rules, incomplete, faulty and defective construction. The expert committee, without considering this legal regulation, has only made a calculation regarding the resulting damage, and the fault status of those responsible has not been examined and the amount of damage has not been determined* *accordingly. It was not correct to establish a judgement by relying on the inadequate expert committee report prepared as a result of incomplete examination and research. In that case, the work to be done should consist of obtaining a report from the expert committee to be reconstituted, determining the fault status of both defendant companies (contractor and building inspection company) and the amount of damage incurred, and deciding on the result to be obtained*."

A special statute of limitations has been determined for the liability periods of building inspection companies. According to the relevant article, "The period of responsibility of the building supervision companies is fifteen years for the structural system of the building and two years for other non-carrier parts, starting from the date of obtaining the occupancy permit."

According to the relevant law and regulation, the responsibilities of building inspection companies are regulated against the building owner and the relevant administration. In case of damage to third parties, no explanation is provided on the conditions of liability and the duration of liability.

It is foreseen that administrative sanctions shall be imposed on the building supervision organizations, which are found to have failed to fulfil their supervision duties in accordance with the principles stipulated in the relevant law and legislation, according to the status of the acts and situations detected. In Article 8 of the relevant law, based on paragraphs 2 and 3, it is stated that the construction supervision company will be imposed an administrative fine, banned from taking on a new job for a certain period of time, and even its permit certificate will be cancelled and its collateral will be registered as a deposit, depending on whether the defects of the construction supervision company affect the non-bearing system or the bearing system. In addition, according to the law, if the partners and managers, architects and engineers, and laboratory officers of the building inspection organization pretend to have carried out the inspection they are required to carry out within the framework of the provisions of this law, or if they issue documents falsely despite the fact that they have done so, they will be punished according to the provisions of the Turkish Penal Code regarding the crime of forgery of official documents.

After the 1999 Marmara earthquake, it was revealed that many of the damages occurred in the buildings were caused by geotechnical design and application deficiencies. After this date, a new building inspection mechanism has been established and it has become compulsory to carry out parcel-based ground surveys in accordance with the "Principles Regarding the Preparation of Soil and Foundation Investigation Report" and "General Format of Soil and Foundation Investigation Report for Building and Building Type Structures" prepared by the Ministry of Public Works and Settlement. According to Article 57 of the Planned Areas Zoning Regulation (2017), the ground survey (geotechnical survey) report that will constitute the basis for the static project.

1) By geophysical engineers in terms of studies determining the physical properties of the ground such as dynamic elasticity resistances of the underground and strength of the ground, bearing capacity, presence of groundwater, underground structure, earthquake zoning, movements of ground fractures, settlement, liquefaction and dimensions of landslides,

2) Geological engineers in terms of drilling, field studies, soil and rock mechanics, laboratory tests, which will be used in the analysis of soil-structure interaction, which will be used in the analysis of soil-soil, soil profile and the physical and mechanical properties of the units forming the ground,

3) Civil and geological engineers in terms of soil mechanics, soil dynamics and soil safety stress calculation,

should be prepared. As can be understood from this regulation, no special competence certificate is required from geophysical engineers, geological engineers or civil engineers during the preparation of the ground investigation report.

According to Building Inspection Law and Building Inspection Implementation Regulation, it is among the duties of Building Inspection Companies to examine the soil and foundation reports of the ground or the ground where the building will be constructed and the application projects prepared by the project authors in accordance with the "Principles Regarding the Preparation of the Soil and Foundation Investigation Report" and "General Format of the Soil and Foundation Investigation

Report for Building and Building Type Structures" and to give an opinion of conformity and to have the soil tests performed in laboratories in accordance with the specifications and standards. However, it is emphasized that the provisions stated for the preparation of soil and foundation investigation are the minimum rules for the content of the soil and foundation investigation report, and it is obligatory for the report preparers to take into consideration the required professional knowledge, relevant standards and current scientific studies. Therefore, the building supervision company shall also be liable for incomplete investigations related to the event causing the construction defect in addition to the general format. According to the Building Inspection Implementation Regulation, a special provision has been introduced for the building inspection company to purchase services in cases where the building supervision company does not have sufficient technical staff in order to determine the conformity of the ground investigation report. Despite this, it is obvious that many building inspection companies do not purchase such a service.

In a case heard by the 4th Civil Chamber of the Court of Cassation; "*The defendant ...Ş. worked as a building inspection organization in the construction activity subject to the lawsuit. Pursuant to the Building Inspection Law; building supervision institutions are obliged to control the projects and to supervise the compliance of the building license and its annexes with the legislation. Since the defendant company did not fulfil its obligation in the control of the ground survey report, it is at fault in the occurrence of the damage subject to the lawsuit and is responsible for the damage according to the principles of joint and several liability. It is not correct to decide to dismiss the lawsuit against this defendant on the grounds that its liability is limited to the parcel where the construction was made. As for the defendant ..... Ltd. Şti.; in the expert report taken as basis for the judgement; the said defendant company is liable for the foundation work done by the other defendant contractor ..... A.Ş., the other defendant contractor A.Ş., as a consultant, approved the incomplete and inadequate ground investigation report and failed to carry out adequate control and supervision. However, the liability of the defendant consultant company is not against the third party who suffered damage, but against the defendant .... A.Ş. with which it has a contractual relationship. The court adopted this opinion and decided to dismiss the lawsuit against this defendant. However, there is no doubt that the defendant* *consultant company is liable for the damage caused by the failure of the defendant consultant company to fulfil its obligation arising from the contract with the business owner, in accordance with the provisions of tort against the injured party*" (Yargıtay 4. HD E:2015/9043 K:2016/10942).

Pursuant to Building Inspection Implementation Regulation, there must be a project and application supervisor civil engineer and an application supervisor civil engineer among the minimum personnel to be employed during the establishment phase of building inspection companies. According to the Regulation, a certificate from the relevant institutions and organizations must be obtained for the civil engineer who is the supervisor of the application, stating that he/she has actually worked in his/her profession for at least 5 years. For project and application supervisor civil engineers, it is required to obtain a certificate from the relevant institutions and organizations that they have actually worked in project preparation or examination for at least three years out of 5 years. The Regulation does not provide details on the subjects in which the auditor engineers should be competent. Although there is a special provision in the Regulation regarding the procurement of services for the evaluation of ground investigation reports, there is no provision for the procurement of services for the examination of geotechnical projects and the control of applications. Therefore, supervising civil engineers are responsible for supervising geotechnical projects and applications themselves.

The project supervision duty of the building supervision companies is specified in the law as controlling the application projects and calculations prepared by the project authors and delivered to them. This article has been clarified in the regulation as follows: through the project and application auditor architects and engineers, the project and application auditor controls the conformity of the application projects and calculations prepared by the project authors with the principles of engineering and architectural project regulation, zoning plan, zoning regulations and other legislation, specifications and standards.

According to the regulation, the project author is responsible for making or having made the application projects that are the basis of the building permit and all kinds of survey-based studies, including ground investigation reports, in accordance with the legislation and submitting them to the building supervision institution for examination. The projects annexed to the license must be compatible with each other. The responsibility arising from projects that are not compatible with each other belongs primarily to the project authors, but also to the building supervision organization, the architects and engineers supervising the project and implementation, and the relevant administration. Since the rates of fault according to the Law depend on the rates of responsibility, the rate of fault will be less than the project author, even if the building supervision company has a gross negligence in a building damage caused by a project error in accordance with this article. While determining these rates, the negligence rates of the supervising engineers should also be taken into consideration.

According to the relevant law and regulation, the duty of checking the compliance of the productions with the approved projects, technical specifications and standards and the duty of conducting tests related to the productions are also assigned to the building inspection companies. In a case heard by the 7th Criminal Chamber of the Court of Cassation, based on the expert report, it was stated that the building inspection company did not have any fault until the implementation stage in causing damage to the neighboring building due to an uncontrolled excavation, but they were found to be at fault for not fulfilling their duties sufficiently during the implementation stage (Yargıtay 7. Ceza Dairesi, K 2012/27075, E 2013/17588).

4.13 Sample Expert Reports Prepared After the Earthquake on February 6th

In their assessments, experts should make explanations by knowing the fundamental legal concepts and legal legislation that we have given above. Otherwise, incomplete and erroneous assessments will lead to erroneous fault allocations. In this context, two expert reports prepared by making erroneous assessments are summarized below as examples.

After the 6th of February Earthquakes, two expert reports were obtained and the following evaluations were made.

With reference to the first report examined; In the expert report we have examined, it is stated that there is a data and geotechnical evaluation report of the structure and a ground improvement report with jet grout columns. During the examinations and field observations made within the scope of the report, it could not be determined whether the jet grouting was carried out in accordance with the project. In their reports, the experts did not make evaluations to check the calculations of the improvement project. In addition, they did not make any evaluation about the data report based on the parameters to be taken into consideration in the design within the scope of the report. One of the main causes of the damage to the structure was evaluated as the ground improvement project and its implementation. They decided that the preparation and implementation phases of the ground improvement project are entirely under the responsibility of the designer. In the light of the information we have given above, Building Inspection Organisations and relevant administrations have responsibilities for control and approval in both project design and implementation stages. In the implementation phase, the site supervisor and the contractor have the responsibility of care. However, the experts have stated in their reports that the construction site supervisor and the contractor responsible for the implementation, the building supervision organization and the relevant administration have no responsibility. These assessments were erroneous considering the scope of responsibility given in the relevant laws and circulars.

In the other evaluation made, it was stated that the building was designed according to 0.4g ground acceleration to be taken into consideration in the 1st degree earthquake zone according to the 2007 earthquake regulation valid in the year the building was designed. However, since the ground acceleration value of the earthquake was 0.7g, they stated that damage to the structure is inevitable even if the design is made without error according to the 2007 regulation.

As a result, it is concluded that the magnitude of the earthquake is the most important factor (the main culprit) in the damage. The other defect that contributed to the building damage is the faulty ground improvement project and its implementation.

The relevant Expert Report has been examined and summarized below; Within the scope of the relevant report, the calculations of the project, which was made according to the earthquake regulations valid in the year the building was designed, were recalculated and checked, the evaluation of the on-site inspections and the control works at the license stage were given.

In the content of the report, it is stated that the architect is responsible for the preparation of the architectural project and the structural system in accordance with the Law No. 3194. It has been evaluated that the decision of the structural system is within the scope of the joint responsibility of the civil engineer, the author of the static project, and the architect.

This assessment is completely wrong according to the Planned Areas Zoning Regulation. According to the Regulation, *Static project is all floor plans, including basement floor, roof plans, their sections, details and calculations prepared by civil engineers in accordance with the architectural project and ground survey report, showing the carrier systems of reinforced concrete, masonry, steel and similar structures according to their types, whose scales are determined according to the size and characteristics of the building.*

In the report, it is stated that the architectural and static projects have passed the building supervision control, and their conformity has been certified and submitted to the relevant administration for approval for the license procedures. It is mentioned that the relevant administration should re-analyze the project at the license stage. When the relevant laws and regulations are examined, it is clear that the administration has no responsibility to re-analyze and approve the project. In practice, the engineers who carry out the control and approval process at the license stage in the administrations write on the projects they examine "No liability is accepted for calculation, drawing and application errors. The project author and building supervision are responsible" or "All responsibility arising from field, laboratory and calculation errors belongs to the project author. No liability is accepted". During their examinations, the experts determined that the minimum shear walls required in the design of the load-bearing system according to the relevant earthquake regulation were not met. During the inspections carried out at the license stage, the fact that one of the clear and basic details in the structural system design was overlooked was considered as a serious fault of the control engineer.

As a result of the field inspections, it was determined that the building was constructed in accordance with the project and that there was no intervention that would affect the structural system of the building.

As a result of all these evaluations, it was decided that the defect was caused entirely by the defect in the structural system design. It was stated that the architectural project author, static project author, building supervision company and the civil engineer who carried out the control and approval process on behalf of the administration had different degrees of fault. However, no assessment was made on the degree of fault of those responsible.

CHAPTER FIVE
- FAILURE IN GEOTECHNICAL ENGINEERING

Despite the significant theoretical contributions made by the leaders of the profession and the increasing quality of practice thanks to advancing technology, many failures still occur in geotechnical engineering practice. The term failure in this concept is defined as *"unacceptable difference between expected and observed performance"* (Leonards, 1982). *"Failures are not all catastrophic, such as when a building collapses, but include facilities or parts of facilities that do not perform as intended by the owner, design professional, or constructor"* (ASCE, 2017). The inability of the building to fulfill its expected function may occur in the short or long term. The type of failure can be specified depending on whether the damage caused by the failure is human life or economic loss. The type of failures are (Barrow et. all, 2018);

1. Safety Failures (Ultimate Limit State Failures)

These are the failures that occur as a result of the collapse of all, or part of a structure built as a result of engineering service. As a result of such collapses, loss of life, injuries, and major financial losses occur.

2. Functional Failures (Serviceability Limit State Failures)

As a result of such failures, the serviceability of the structure and its expected intended use are impaired or jeopardized. In addition, deterioration in the appearance of the structure may also occur.

3. Latent Failures

This type of failure occurs as a result of defects that have not yet been revealed but may cause serviceability or collapse in the structure. The detection of such defects can only be made as a result of examinations carried out by specialized engineers. The emergence of such defects usually appears during the progress of construction.

4. Ancillary Failures

Such failures do not cause structural or serviceability problems. Here, construction is delayed due to the resulting inconveniences, often resulting in financial losse

To identify the major shortcomings causing the failures, a sample of about 100 geotechnical failures from Asia, South America, and Europe have been analyzed. According to research, construction errors account for 14% of the technical issues that lead to geotechnical failures, unforeseen ground conditions account for 19%, insufficient field investigation accounts for 21%, and design mistakes account for 46% (Jessep, de Mello, & Rao, 2016). Figure 5.1 illustrates the general categorization of the shortcomings from a selection of analyzed failures.

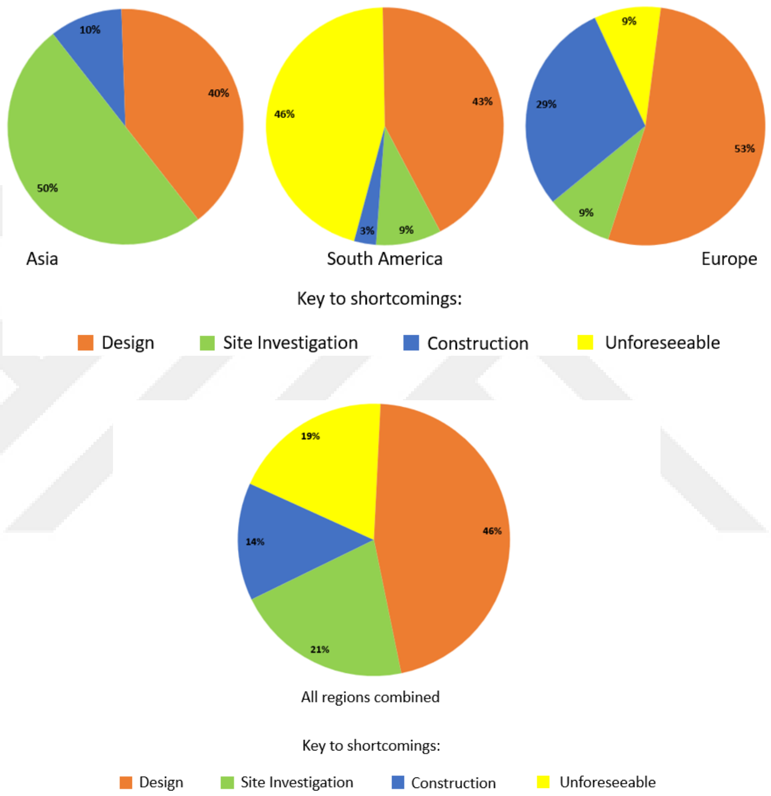

Figure 5.1 The major shortcomings causing the geotechnical failures (Jessep, de Mello, & Rao, 2016)

Sowers (1993), investigated the identification of technical causes and financial liability of failures. The writer's unpublished failure investigations contribute to most of the database. The evaluation of almost 500 failures. Of these, 58% were design origins, 38% were construction origins, and 4% were operation origins. About half of the problems that occurred during construction were caused by design, and the other half by construction. The absence of contemporary technology, ignorance of it, and rejection of it are the three factors. The causes of rejection are 55%, ignorance is 33%, and absence is 12%. 88% of the total indicate human shortcomings that can be improved by admitting professional limitations, continuing education, changing design and construction methods, and resisting the unbalanced pressures that thwart good engineering.

Another research performed by Peter Day (2009) in a study of several published case histories suggests that the most common causes of failures are also given in Table 5.1.

Table 5.1 The most common causes of failures (Day,2009)

Cause	Description
Inadequate geotechnical investigation	Budgetary or program restraints can result in insufficient investigation being undertaken to adequately model the conditions on the site. Alternatively, even the most comprehensive investigations may fail to reveal critical conditions that affect the geotechnical behavior of the profile.
Incorrect parametes	This can occur for many reasons. including: - poor sampling and testing procedures - selection of inappropriate parameters for a particular design situation (e.g., mean values, lower characteristic values, or upper characteristic values) - underestimation of the variability of soil properties
Inappropriate analysis model	Failure to recognize the critical failure mechanism, e.g., drained v. undrained failure of slopes or foundations, internal stability v. external stability of reinforced fills.
Underestimation of actions	Either the magnitude, distribution, or combination of actions (forces or displacements) incorrectly assessed, particular load case or combination not considered, use of structure changed over a lifetime.
Unexpected groundwater regimes or changes in moisture content	Changes in groundwater levels can increase the loading on the structure and decrease the shearing resistance of the soil. Seepage forces can also have an adverse effect on stability. Changes in the moisture content of partially saturated soils can cause softening. heave or collapse settlements.
Sub-standard workmanship or materials	Required construction procedures (including sequence and timing) not followed, specification requirements not met, inappropriate construction techniques employed, and material properties not in accordance with design assumptions.
Abnormal events not catered for in design	Extreme meteorological events (including temperature, precipitation, or wind), accidental impact, errors in construction or use of structure.

The authors (Abdulahad, Jergeas, & Ruwanpura, 2010), evaluated 41 legal cases in Canada related to geotechnical issues. In their study, they investigated the factors contributing to claims related to differing ground conditions in infrastructure and construction projects. The information obtained was categorized according to the causes of geotechnical claims. In Figure 5.2, the cases are categorized and presented according to the reason for the disputed claim. As can be seen in the figure, 23 cases evaluated (56.1% of all cases) are related to the issue of "different soil conditions and recommendations than expected from the geotechnical report". The cause of 6 cases, representing 14.6% of all cases analyzed, was evaluated as "inaccuracies in the design plans and specifications". Five cases (12.2% of the total cases) evaluated fall under the category of "owner's failure to disclose important information." Three cases, accounting for 7.3% of all assessed cases, were classified as "calculation errors in the tender documents of the quantities of material to be excavated." In two cases (4.9% of all cases) " Mistakes in pile design and/or the need for longer piles than recommended in the geotechnical project" were the causes for the claim. The categories of "contractor did not follow the specifications outlined in the agreement" and "different type of rock was used by contractor than rock named in the contract" are each represented by one case, representing 2.4% of the cases investigated.

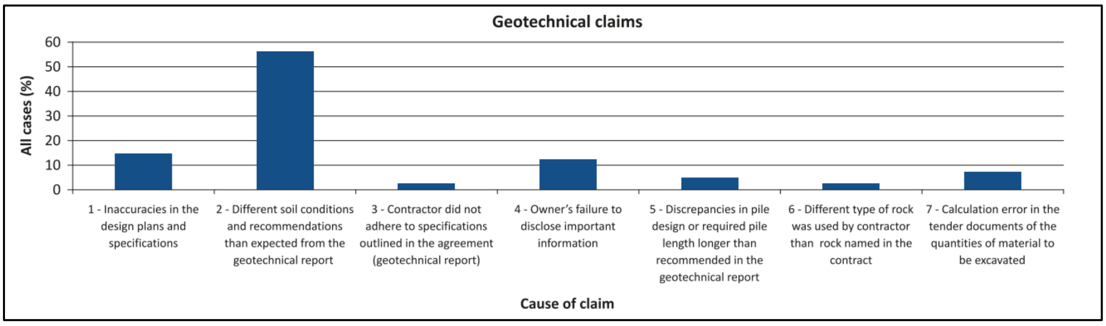

Figure 5.2 Causes of geotechnical disputed claims in Canada (Abdulahad, Jergeas, & Ruwanpura, 2010)

In case of signs of damage in a geotechnical application, the first thing to do is to take the necessary precautions quickly and to eliminate this risk if there is a risk of collapse. After this stage, it is necessary to reveal the mechanism that caused the defect, to find those responsible, and to determine how and by whom the cost of the damage will be compensated (Basile & Saxena. 2008). The answer to all these questions is tried to be found in the discipline of Forensic Geotechnical Engineering.

There are general definitions of Forensic Engineering in the literature. For example, Noon (2000) defines Forensic Engineering as the application of engineering principles, knowledge, skills, and methodologies to answer questions that may have legal ramifications. Carper (1986) states that a forensic engineer is a professional engineer who deals with the engineering aspects of legal issues.

Forensic evaluation is intended to give an opinion on the factors that led to and are ultimately responsible for migration. The US Supreme Court has ruled that the Judge must ensure that any accepted scientific statement or evidence is both relevant and reliable (Lucia, 2012). Admissibility rules are based on four main criteria:

- *When a scientific theory or technique is used to develop an idea, has the theory or opinion been tested?*

- *Has scientific theory or technique been subjected to peer review and publication?*

- *Are there standards to control the application of the scientific theory or technique, and is there a known or potential error rate?*

- *Has the scientific theory or technique gained acceptance within the relevant scientific community?*

However, expert opinion cannot be expected to be 100% accurate. It is necessary to accept that there are uncertainties in science and engineering (Lacasse, 2016). Considering the high uncertainty levels in geotechnical engineering, it can be said that the evaluation will remain within a certain confidence interval.

Since forensic engineers have to work closely with legal regulations, besides engineering knowledge, they should be able to read, think, speak, and analyze like a lawyer. An experienced expert should prepare a well-written, court-convincing report based on a methodology considered reliable. The report should be clearly and legally adequate. It should be prepared simply in non-technical language with explanations that the court and lawyers can understand (Saxena, 2016).

CHAPTER SIX
- RELIABILITY-BASED ANALYSIS IN GEOTECHNICAL ENGINEERING

6.1 Introduction

When it comes to design, planning, construction, and inspection for geotechnical engineering work, the risk is inevitable due to high uncertainties in ground conditions. Therefore, it is necessary to evaluate high uncertainty levels with a correct approach. The issue of uncertainty in geotechnical engineering has been discussed many times in the literature (Ang & Tang, 2007; Baecher & Christian, 2003; Kulhawy, 1992; Lacasse & Nadim, 1996). Empirical relationships and models applied in transforming field and laboratory data into parameters used in the analysis are other sources of uncertainty. In addition to these, factors arising from the nature of the analysis method also contribute to the uncertainty of the result. All of these uncertainty sources mentioned are shown in Figure 6.1. These effects should be adequately reflected in the analysis and conclusions of the Forensic Engineer or Technical Expert.

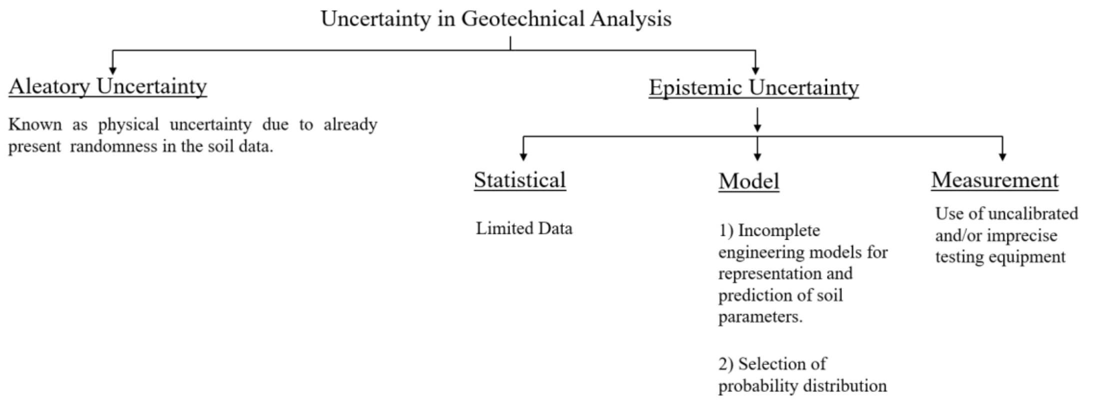

Figure 6.1 Sources of uncertainties in geotechnical analysis.

The use of today's reliability-based engineering approaches is more imperative than ever in accurately reflecting the uncertainties in the geotechnical analysis. The systematic consideration of the uncertainty in soil parameters and models and the use of reliability-based methods in this direction have come to the fore. The fact that the uncertainties in the nature of the ground vary regionally means that the risk level of each project is also different.

In recent years, studies have focused on reliability-based designs so that high uncertainty levels can be taken into account more accurately (Ang & Tang, 2007; Fenton & Griffiths, 2008; Haldar & Mahadevan, 2000; Singh, Jain & Tyagi, 2007). The load-resistance factors (LRFD) approach and the Eurocode 7 used in European Union countries are also based on reliability-based design principles. Reliability is defined as "the probability of an object (item or system) performing its required function adequately for a specified period of time under stated conditions" (Harr, 1996).

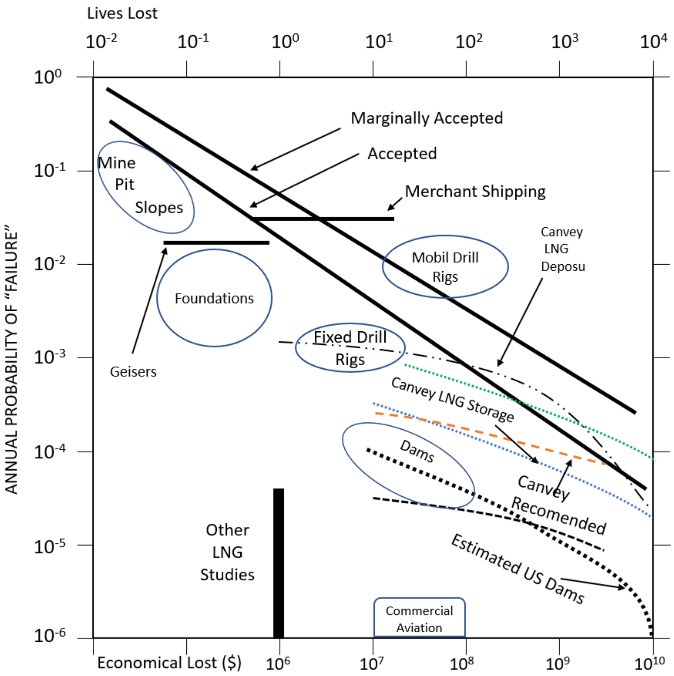

Figure 6.2 F-N Chart showing average annual risks posed by a variety of traditional civil facilities and other large structures or projects, after (Baecher, 1987).

The first step of the reliability-based design is the selection of an appropriate value for the targeted probability of failure (p_f) and the associated reliability index (β). The life and economic losses caused by projects that are inadequate in terms of performance (collapse or exceeding the allowable deformation limits) are collected in the literature and the failure limit ranges and the corresponding losses are plotted. When starting a reliability-based design, the engineer accepts a target probability of failure smaller than the failure limits and a corresponding reliability index and continues the analysis. The curves given in Figure 6.2 are an F-N chart (the relation between frequencies and the number of lives lost, or some other undesired consequence) showing the average annual risks posed by a variety of traditional civil facilities and other large structures or projects (Baecher, 1987). The target probability of failure range should be chosen to be lower than the probability of failure ranges evaluated from case histories, as shown in Figure 6.2. Because failures may occur in construction projects, which may result from uncertainties such as poor construction and human errors that cannot be seen in the design (CIRIA, 1997). For example, the available data show that the failure rate range is between 0.01 and 0.001 for foundations (Figure 6.2). For this reason, the engineer is expected to choose the target failure range between 0.001 and 0.0001 when performing the foundation design. By choosing the upper or lower limit of this failure range, the target reliability index is determined to be 3.1 or 3.7 or between these values, as can be seen in Figure 6.3 (USACE, 1997).

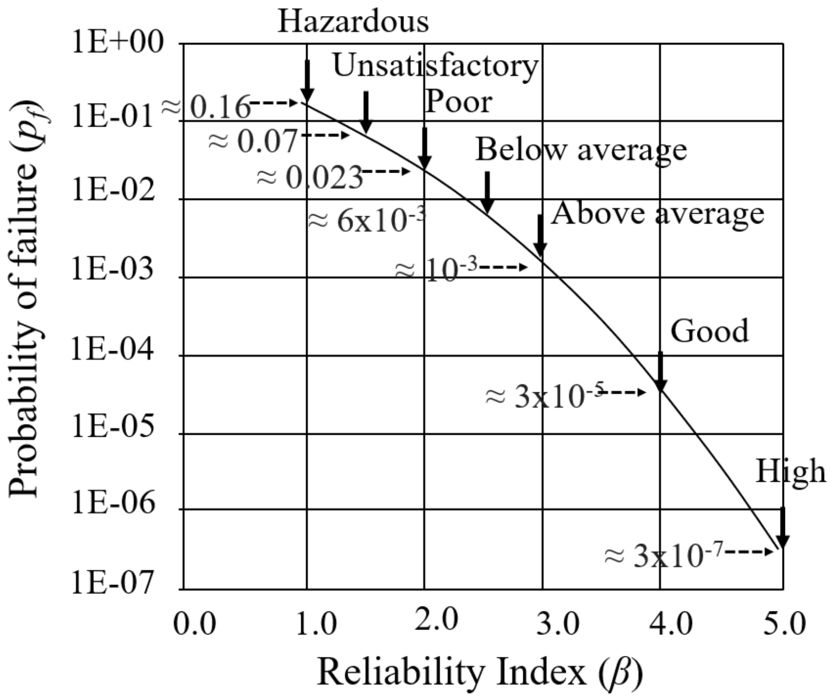

Figure 6.3 Relationship between reliability index (β) and probability of failure (p_f), adapted from (USACE, 1997).

The reliability index, β, can also be determined from different sources. For example, in the European Union Standard EN1990:2002, three different safety classes are defined depending on the result of possible damage (see Table 6.1).

In Table 6.1, the reliability index decreases as the reference period gets longer and increases when the confidence class of the structure increases. While preparing Table 6.1, the shear strength parameters mobilized in case of failure, in other words, the ultimate limit state, were taken into account. In Table 6.2, the reliability indexes determined according to the ultimate limit states in various regulations are given, as well as the values determined according to the serviceability limit states. As expected, the reliability indices for serviceability limit states such as maximum allowable settlement or differential settlement are lower than for the ultimate limit state.

Table 6.1 Recommended minimum reliability index values (ULS) EN 1990:2002.

Reliability Class	Minimum Values for β_T	
	1 Year Reference Period	50 Year Reference Period
RC3	5.2	4.3
RC2	4.7	3.8
RC1	4.2	3.3

Table 6.2 Target reliability index (β_T) values in various reliability-based design codes.

Design Code	ULS (β_T)	SLS (β_T)
Electric Power Research Institute (EPRI) multiple resistance and load factor design (MRFD)	3.2	2.6
Canadian Highway Bridge Design Code (CHBDC 2014)	3.1-3.7	2.3-3.1
Canadian National Building Code (NCBC)	3.5	-
American Association of State Highway and Transportation Official (AASHTO) foundation design code	2.0-3.5	-
Eurocode 7 (RC2)	4.7	2.9

As a basis for the reliability-based geotechnical design, it is sufficient to know the statistical mean (expected value) and standard deviation (or the coefficient of variation) values of the factors affecting the design. To determine the standard deviation (or the coefficient of variation), statistical evaluation of the available parameters, the use of the values given in literature by different researchers, and the use of three-sigma or graphical three-sigma rules are suggested (Abramson, Lee, Sharma & Boyce, 2002; Duncan, 2000; Phoon & Kulhawy, 1999;) summarized the coefficient of variation values suggested by different researchers in the literature in her article on the reliability-based approach in geotechnical engineering.

The most commonly used reliability-based analysis methods in geotechnical engineering design are the Point Estimate (PEM) Method, First Order Second Moment (FOSM) Method (Taylor Series Method), Hassofer and Lind First Order Reliability (FORM) Method, and Monte Carlo Simulation (Beacher & Christian, 2003). FORM and Monte Carlo Simulation approaches were used in the analyzes made within the scope of this study. The basis of Monte Carlo Simulation is the iterative analysis of a defined limit state function with many artificially generated random variables (Thomopoulos, 2013). To apply the method, first of all, the limit state function must be defined. It is necessary to know which distribution function the produced artificial variables fit, the mean value, and the standard deviation (or the coefficient of variation). While generating random variables affecting the limit state function, it should be noted that the parameters included in the analysis are independent or dependent on each other (Abramson, Lee, Sharma & Boyce, 2002; Beacher & Christian, 2003). According to the results of repeated analysis, p_f (probability of failure) and accordingly β (reliability index) can be calculated directly. If N trials are conducted, the probability of failure is given approximately by Equation 6.1.

$$p_f = \frac{N_f}{N} \tag{6.1}$$

where N_f is the number of trials for which the limit state function is violated out of the N experiments conducted.

The FORM approach, the second method followed in our study, was suggested by Hasofer & Lind (1974). Here, too, it is aimed to determine the reliability index. The approach is known as the first-order reliability method. The matrix formulation of the Hasofer & Lind (1974) reliability index is in Equations 6.2.

$$\beta = \sqrt{(x-\mu)^T [C]^{-1} (x-\mu)} \tag{6.2}$$

or, equivalently Equation 6.3,

$$\beta = \sqrt{\left[\frac{x_i - \mu_i}{\sigma_i}\right]^T [R]^{-1} \left[\frac{x_i - \mu_i}{\sigma_i}\right]} \tag{6.3}$$

where x is a vector representing the set of random variables x_i, μ is the vector of mean values μ_i, C is the covariance matrix, R is the correlation matrix, and σ_i is the standard deviation (Ditlevsen, 1981).

6.2 Uncertainties of soil parameters

Uncertainties of soil parameters considered in geotechnical engineering are generally divided into two categories: aleatory and epistemic. (Ang & Tang, 2007; Baecher & Christian, 2003; Lacasse & Nadim, 1996; Lacasse, Nadim, Rahim, & Guttormsen, 2007; Whitman, 1984). Aleatory uncertainty (physical uncertainty) is related to the natural randomness of soil parameters that are unpredictable and occur by chance. For example, uncertainty results from the inherent variability of soil due to unforeseen geological processes, and a quantity's inherent uncertainty, such as the variation in soil strength from place to place within a soil volume. Such uncertainties cannot be eliminated or reduced by additional work. The other category is epistemic uncertainties. Lack of information and errors in measurement and calculation lead to epistemic uncertainty. These uncertainties are related to the quality of field and laboratory tests and the correlations used to determine the parameters to be considered in geotechnical analysis. Such uncertainties can also be expressed as measurement errors, errors arising from statistical analysis, and transformation errors. Measurement errors are due to equipment and operator errors in field and laboratory tests (Jaksa, Brooker, & Kaggwa, 1997) Statistical errors can be expressed as the determination of design soil parameters using inadequate or limited test results (Lacasse & Nadim 1996). The choice of statistical distribution, the parameter used to represent phenomena, and the uncertainty of the chosen distribution are all examples of epistemic uncertainty. The source of transformation uncertainties arises from the use of correlations of design parameters proposed by different researchers in the literature. Since epistemic uncertainties are caused by human error, it is possible to reduce such uncertainties through proper planning and qualified efforts. Increasing the number of tests or enhancing the measurement techniques are two possible ways to decrease this type of uncertainty (Lacasse, Nadim, Rahim, & Guttormsen, 2007).

Kulhawy (1992) has illustrated the uncertainties that are effective in the determination of the geotechnical soil parameters in Figure 6.4.

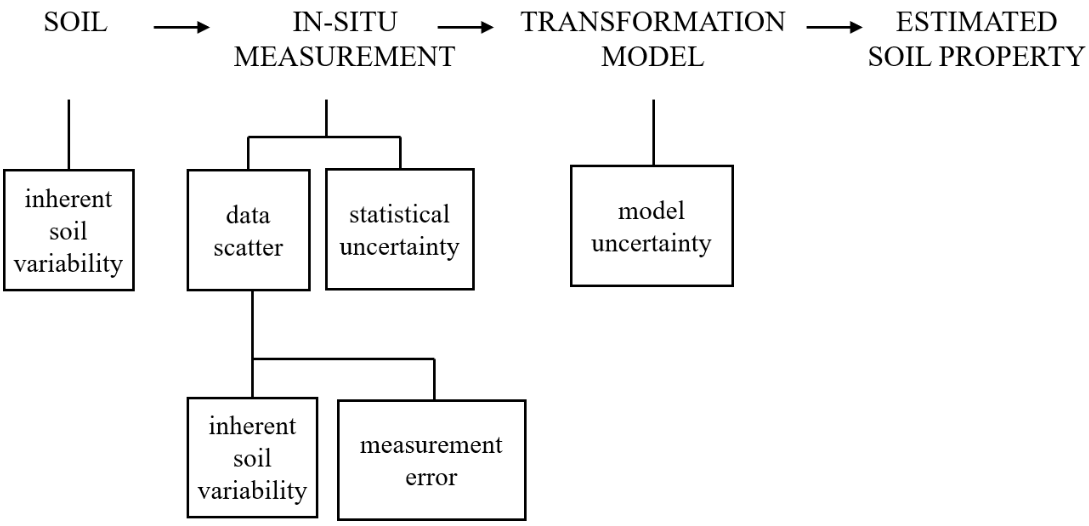

Figure 6.4 Illustration of sources of uncertainties contributing to overall uncertainty in geotechnical design soil parameters (Kulhawy,1992)

There are Approximate guidelines proposed as a result of the studies carried out by different researchers in the literature regarding the uncertainties mentioned above. Tables related to the proposed mean, standard deviation, and the range of coefficient of variations are given below depending on the uncertainty types. Approximate guidelines provided by Phoon & Kulhawy (1999a) and Kulhawy, Phoon, & Prakos, (2000) for inherent soil variability is given in Table 6.3 and 6.4.

Table 6.3 Approximate guidelines for ranges of mean values and COVs of inherent soil variability (Phoon & Kulhawy 1999a).

Test type	Parameter[a]	Soil type	Mean	COV(%)
Lab strength	s_u(UC)	Clay	10-400 kN/m^2	20-55
	s_u(UU)	Clay	10-350 kN/m^2	10-30
	s_u(CIUC)	Clay	150-700 kN/m^2	20-40
	ϕ	Clay and sand	20-40^o	5-15
CPT	q_T	Clay	0.5-2.5 MN/m^2	<20
	q_c	Clay	0.5-2.0 MN/m^2	20-40
		Sand	0.5-30.0 MN/m^2	20-60
VST	*su*(VST)	Clay	5-400 kN/m^2	10-40
SPT	*N*	Clay and sand	10-70 blows/ft	25-50
DMT	A reading	Clay	100-450 kN/m^2	10-35
		Sand	60-1300 kN/m^2	20-50
	B reading	Clay	500-880 kN/m^2	10-35
		Sand	350-2400 kN/m^2	20-50
	I_D	Sand	1-8	20-60
	K_D	Sand	2-30	20-60
	E_D	Sand	10-50 MN/m^2	15-65
PMT	p_L	Clay	400-2800 kN/m^2	10-35
		Sand	1600-3500 kN/m^2	20-50
	E_{PMT}	Sand	5-15 MN/m^2	15-65
Lab index	w_n	Clay and silt	13-100 %	8-30
	w_L	Clay and silt	30-90 %	6-30
	w_P	Clay and silt	15-25 %	6-30
	PI	Clay and silt	10-40 %	b
	LI	Clay and silt	10 %	b
	γ, γ_d	Clay and silt	13-20 kN/m^2	<10
	D_r	Sand	30-70 %	10-40[c]
				50-70[d]

[a]s_u undrained shear strength; *UC* unconfined compression test; *UU* unconsolidated-undrained triaxial compression test; *CIUC* consolidated isotropic undrained triaxial compression test; ϕ effective stress friction angle; q_T corrected cone tip resistance; q_c cone tip resistance; *VST* vane shear test; N standard penetration test blow count; A and B readings, *ID*, *KD* and *ED* = dilatometer A and B readings, material index, horizontal stress index, and modulus; p_L and E_{PMT} pressure meter limit stress and modulus; w_n natural water content; w_L liquid limit; w_P plastic limit; *PI* plasticity index; *LI* liquidity index; γ and γ_d total and dry unit weights; D_r relative density
[b]COV = (3–12 %)/mean
[c]total variability for direct method of determination
[d]total variability for indirect determination using SPT values

Table 6. 4 Inherent soil variability for soil and rock (Kulhawy, Phoon, & Prakos, 2000)

Test type	Parameter	Material type	Coefficient of variation (%)			
			m	Mean	S.D.	Range
Index	γ, γ_d	Fine-grained	14	7.8	5.8	2-20
	w_n	Fine-grained	40	18.1	7.9	7-46
	w_P	Fine-grained	23	15.7	6	6-34
	w_L	Fine-grained	38	18.1	7.1	7-39
	PI—all data	Fine-grained	33	29.5	10.8	9-57
	− ≤20 %	Fine-grained	13	35	11.4	16-57
	− >20 %	Fine-grained	20	26	9	9-40
	γ, γ_d	Rock	42	0.9	0.7	0,1-3
	n	Rock	25	25.9	19.4	3-71
Strength	ϕ, tan ϕ	Sand, clay	48	13.9	10.4	4-50
		Sand	32	9	3	4-15
		Clay	16	23.5	13	10-50
	s_u	Clay	100	31.5	14.2	6-80
	q_u	Rock	184	14.2	11.7	0,3-61
	$q_{t\text{-brazilian}}$	Rock	74	16.6	10.4	2-58
Stiffness	$E_{t\text{-}50}$	Rock	32	30.7	15	7-63
CPT	q_c	Sand, clay	65	36.6	15.5	10-81
		Sand	54	38.2	16.3	10-81
		Clay	11	28.4	6.8	16-40
	q_T	Clay	9	7.9	4.9	2-17
VST	s_u(VST)	Clay	26	25.3	6.5	13-36
SPT	N	Sand, clay	23	38	10.8	19-62
DMT	A, B	Sand, clay	56	27.9	11.9	12-59
		Sand	30	34.8	11.3	13-59
		Clay	26	19.9	6.2	12-38
	I_D—all data	Sand	30	40.7	21.6	8-130
	- w/o outliers		29	37.7	14	8-66
	K_D—all data	Sand	31	41.2	19.2	15-99
	- w/o outliers		29	37.6	13.5	15-67
	E_D—all data	Sand	31	42.7	19.6	7-92
	- w/o outliers		30	41.1	17.6	7-69

A summary of total measurement error is given in Table 6.5 for laboratory tests and in Table 6.6 for field tests.

Table 6.5 Summary of total measurement error of some laboratory tests (Phoon & Kulhawy 1999a).

Parameter[a]	Soil type	No. of data group	No. of tests/group		Property value (units[b])		Property COV (%)	
			Mean	Range	Mean	Range	Mean	Range
s_u(TC)	Clay, silt	11	-	13	7-407	125	8-38	19
s_u(DS)	Clay, silt	2	13-17	15	108-130	119	19-20	20
s_u(LV)	Clay	15	-	-	4-123	29	5-37	13
ϕ(TC)	Clay, silt	4	9-13	10	2-27°	19.1°	7-56	24
ϕ(DS)	Clay, silt	5	9-13	11	24-40°	33.3°	3-29	13
	Sand	2	26	26	30-35°	32.7°	13-14	14
tan ϕ(TC)	Sand, silt	6	-	-	-	-	2-22	8
tan ϕ(DS)	Clay	2	-	-	-	-	6-22	14
w_n	Fine-grained	3	82-88	85	16-21	18	6-12	8
w_L	Fine-grained	26	41-89	64	17-113	36	3-11	7
w_P	Fine-grained	26	41-89	62	12-35	21	7-18	10
PI	Fine-grained	10	41-89	61	4-44	23	5-51	24
γ	Fine-grained	3	82-88	85	16-17	17	1-2	1

[a]s_u undrained shear strength; ϕ effective stress friction angle; *TC* triaxial compression test; *UC* unconfined compression test; *DS* direct shear test; *LV* laboratory vane shear test; w_n natural water content; w_L liquid limit; w_P plastic limit; *PI* plasticity index; γ total unit weight

[b]units of s_u kN/m2 ; units of w_n, w_L, w_P, and *PI* %; units of γ kN/m3

Table 6.6 Summary of measurement error of common in situ tests (Kulhawy & Trautmann, 1996).

Test	Coefficient of variation, COV (%)				
	Equipment	Procedure	Random	Total[a]	Range[b]
Standard penetration test (SPT)	5[c]-75[d]	5[c]-75[d]	12-15	14[c]-100[d]	15-45
Mechanical cone penetration test (MCPT)	5	10[e]-15[f]	10[e]-15[f]	15[e]-22[f]	15-25
Electric cone penetration test (ECPT)	3	5	5[e]-10[f]	7[e]-12[f]	5-15
Vane shear test (VST)	5	8	10	14	10-20
Dilatometer test (DMT)	5	5	8	11	5-15
Pressuremeter test, pre-bored (PMT)	5	12	10	16	10-20[g]
Self-boring pressuremeter test (SBPMT)	8	15	8	19	15-25[g]

[a]COV(Total) = $[\mathrm{COV(Equipment)}^2 + \mathrm{COV(Procedure)}^2 + \mathrm{COV(Random)}^2]^{0.5}$

[b]Because of limited data and judgment involved in estimating COVs, ranges represent probable magnitudes of field test measurement error

[c,d]Best to worst case scenarios, respectively, for SPT

[e,f]Tip and side resistances, respectively, for CPT

[g]It is likely that results may differ for p_o, p_f and p_L, but the data are insufficient to clarify this issue

Phoon & Kulhawy (1999b) have provided useful guidance on typical "total" coefficients of variation of many common design soil strength characteristics, which are included as a reference in Table 6.7. If it hasn't been determined whether the variability associated with testing procedures, site circumstances, and transformation models is substantially comparable to the values found in the literature Tabulated values should not be applied carelessly.

Table 6.7 Approximate guidelines for design soil parameter variability (Phoon & Kulhawy, 1999b).

Design parameter[a]	Test[b]	Soil type	Point COV (%)	Spatian avg. COV[c] (%)	Correlation equation[f]
s_u(UC)	Direct (lab)	Clay	20-55	10-40	-
s_u(UU)	Direct (lab)	Clay	10-35	7-25	-
s_u(CIUC)	Direct (lab)	Clay	20-45	10-30	-
s_u(field)	VST	Clay	15-50	15-50	14
s_u(UU)	q_t	Clay	30-40[e]	30-35[e]	18
s_u(CIUC)	q_t	Clay	35-50[e]	35-40[e]	18
s_u(UU)	N	Clay	40-60	40-55	23
s_u	K_D	Clay	30-55	30-55	29
s_u(field)	PI	Clay	30-55[e]	-	32
ϕ	Direct (lab)	Clay, sand	7-20	6-20	-
ϕ (TC)	q_T	Sand	10-15[e]	10[e]	38
ϕ_{cv}	PI	Clay	15-20[e]	15-20[e]	43
K_o	Direct (SBPMT)	Clay	20-45	15-45	-
K_o	Direct (SBPMT)	Sand	25-55	20-55	-
K_o	K_D	Clay	35-50[e]	35-50[e]	49
K_o	N	Clay	40-75[e]	-	54
E_{PMT}	Direct (PMT)	Sand	20-70	15-70	-
E_D	Direct (DMT)	Sand	15-70	10-70	-
E_{PMT}	N	Clay	85-95	85-95	61
E_D	N	Silt	40-60	35-55	64

[a]s_u undrained shear strength; *UU* unconsolidated-undrained triaxial compression test; *UC* unconfined compression test; *CIUC* consolidated isotropic undrained triaxial compression test; s_u(field) corrected s_u from vane shear test; ϕ effective stress friction angle; *TC* triaxial compression; ϕ_{cv} constant volume ϕ; K_o in situ horizontal stress coefficient; E_{PMT} pressure meter modulus; E_D dilatometer modulus
[b]*VST* vane shear test; q_T corrected cone tip resistance; *N* standard penetration test blow count; K_D dilatometer horizontal stress index; *PI* plasticity index
[c]averaging over 5 m
[d]mixture of s_u from *UU*, *UC* and *VST*
[e]COV is a function of the mean; refer to COV equations in Phoon & Kulhawy, (1999b) for details
[f]Quality of correlation affects the COV of design parameters. The correlation models used are referenced by the equation numbers in Phoon & Kulhawy, (1999b)

6.3 Methods of Estimating Statistical Values of Soil Parameters

One of the most fundamental factors affecting the results of reliability-based analysis is the correct determination of the mean, standard deviation, and therefore the coefficient of variation of the parameters to be considered in the analysis. Compared to many engineering sciences, the determination of parameters to be used in geotechnical engineering analysis is much more difficult due to the inherent variability of the soil. Some standards regulate the field and laboratory tests required for the identification of the soil volume interacting with the structure. However, the criteria given in these standards express the minimum requirements. The planning of field and laboratory tests to be carried out in accordance with our regulations is the responsibility of geotechnical engineers. To begin with, it is crucial to identify the design parameters within a specific confidence interval. To achieve precise outcomes, it is important to enhance the quality and quantity of the planned studies. Nevertheless, the cost will inevitably rise as the investigations and experiments increase. The geotechnical engineer must decide on the economy as well as the reliability of the works due to the nature of the work in the planning phase. In any case, he must determine the design parameters correctly because of the optimum decision he will make in planning. It should be noted that the determination of geotechnical parameters shows high variability due to many uncertainties. Therefore, the parameters obtained because of the evaluation of the data obtained because of the studies will inevitably have a certain variability. As it is known, in conventional safety factor approaches, the design is based only on the average values of the parameters. In addition to the evaluation of field and laboratory test results, the expected value of the soil can be estimated by using tables or correlations related to the average values of the parameters given in the literature depending on the soil types. In addition to these, experienced engineers decide on the design parameters by considering the studies carried out in the past on neighboring parcels. However, designing with average values does not reveal the risk of the system. Reliability-based methods have been developed to analyze the risk of systems, and their importance is increasing day by day. One of the most significant advantages of reliability-based design is the ability to consider the variability of design parameters. The first step at this stage is the statistical evaluation of the parameters. Determining the correct design parameters is the most critical phase of the art of geotechnical engineering. Depending on the amount of data available, various methods have been proposed to estimate the standard deviations of geotechnical parameters. Below, some of the studies in the literature on how to statistically evaluate the parameters for this purpose are summarized.

6.3.1 Estimation of Statistical Values of Soil Parameters for independent soil parameters if enough data are available.

Let the soil parameter *X* and the values of N measurements related to the parameter be considered as $x_1, x_2, ...x_i$. With the assumption that the parameters are independent, the formula definition of σ_x, μ_x and COV_x (Equation 6.4, 6.5 and 6.6) can be used to determine its value if enough data are available:

$$\mu_x = \frac{1}{N}\sum_{i=1}^{N} x_i \tag{6.4}$$

$$\sigma_x = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}(x_i - \mu_x)^2} \tag{6.5}$$

$$COV_x = \frac{\sigma_x}{\mu_x}\ x\ 100\ \% \tag{6.6}$$

in which

σ_x = Standard Deviation.

x_i = i^{th} value of the parameter *X*.

μ_x = average value of the parameter *X*.

N = number of values of *X* (the size of the sample).

6.3.2 Three-Sigma Rule

According to Dai & Wang (1992), this general rule of thumb makes advantage of the fact that 99.73 percent of all values of a normally distributed variable lie between plus or minus three standard deviations of the average. Consequently, these are around three standard deviations above and below the average value if HCV is the parameter's maximum possible value and LCV is its lowest possible value. By first estimating the highest and lowest possible values of the parameter and then dividing the difference between them by six, the standard deviation of the parameters can be estimated by applying the 3σ rule (Equation 6.7) (Duncan, 2000).

$$\sigma_X = \frac{\mathrm{HCV} - \mathrm{LCV}}{6} \tag{6.7}$$

HCV = highest conceivable value of the parameter, and LCV = lowest conceivable value of the parameter.

6.3.3 Parameter estimation for dependent soil parameters

If we express the soil parameter we are considering as Y, we can calculate the standard deviation of the parameter with this approach when we can describe the variation of the measured values of Y with depth with an acceptable linear function.

Considering the measurements (y_i) corresponding to different depths (z_i), the variation of Y with depth can be calculated by the following equation.

$$Y = a_0 + a_i z + \varepsilon \tag{6.8}$$

where

$a_0 + a_i z$ represents the linear mean variation with depth, ε is the natural variability of Y about the mean, and z the depth below the soil surface. The variable Y vs. z is shown in Figure 6.5.

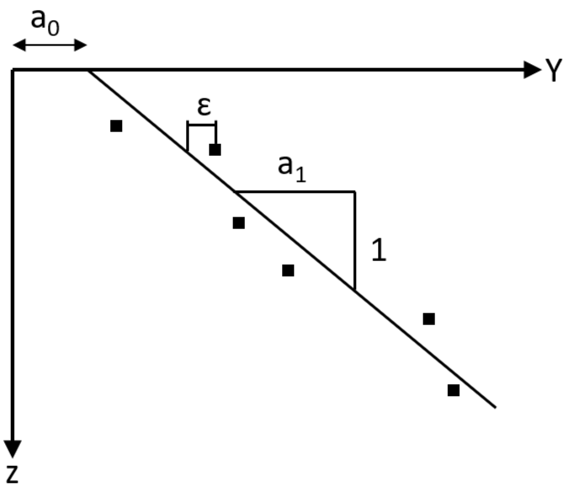

Figure 6.5 Variability of a depth-dependent soil parameter.

$$\widehat{a_\iota} = \frac{\sum_{i=1}^{n}(z_i - \bar{z})(y_i - \bar{y})}{\sum_{i=1}^{n}(z_i - \bar{z})^2} \tag{6.9}$$

and

$$\widehat{a_0} = \bar{x} - \widehat{a_\iota}\bar{z} \tag{6.10}$$

in which

$$\bar{y} = \frac{1}{n}\sum_{i=1}^{n} y_i \tag{6.11}$$

and

$$\bar{z} = \frac{1}{n}\sum_{i=1}^{n} z_i \tag{6.12}$$

The standard deviation (σ) of the natural variability term is estimated by the sample standard deviation:

$$\sigma = \sqrt{\frac{1}{n-2}\sum_{i=1}^{n}\left(y_i - (\widehat{a_0} + \widehat{a_1} z_i)\right)^2} \tag{6.13}$$

The derivation above is valid when the standard deviation or variance of ε is constant with depth.

6.3.4 Graphical Three-Sigma Rule

The approach behind Dai & Wang's (1992) three-sigma rule can be advanced into a graphical technique that applies in many geotechnical engineering cases where the parameter of interest varies with depth.

Duncan (2000), the following is how the graphical three-sigma rule is employed step by step.

1. *Draw a straight line or curve through the data that represents the most likely average variation of the parameter with depth.*
2. *Draw straight lines or curves that represent the highest and lowest conceivable bounds on the data. These should be wide enough to include all valid data and an allowance for the fact that the natural tendency is to estimate such bounds too narrowly.*
3. *Draw straight lines or curves that represent the average plus-one standard deviation and the average minus-one standard deviation. These are one-third of the distance from the average line to the highest and lowest conceivable bounds.*

Examples are shown in Figure 6.6 and 6.7.

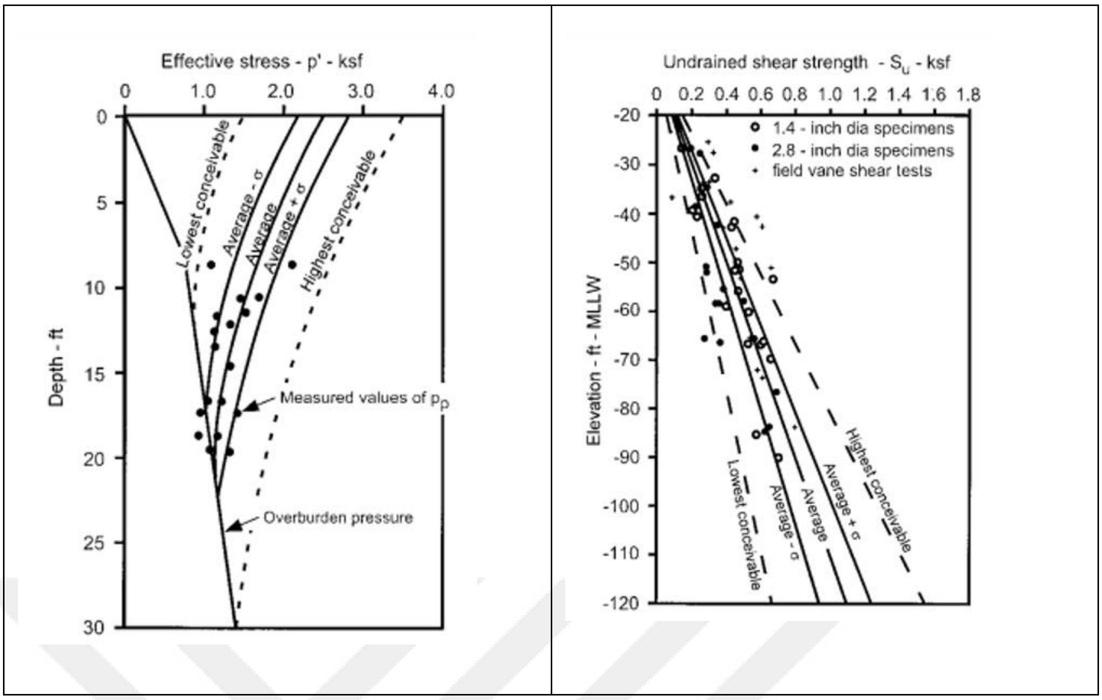

Figure 6.6 Examples of graphical three-six Sigma rule for estimating standart deviation limits for parameters that vary with depth (Duncan, 2000).

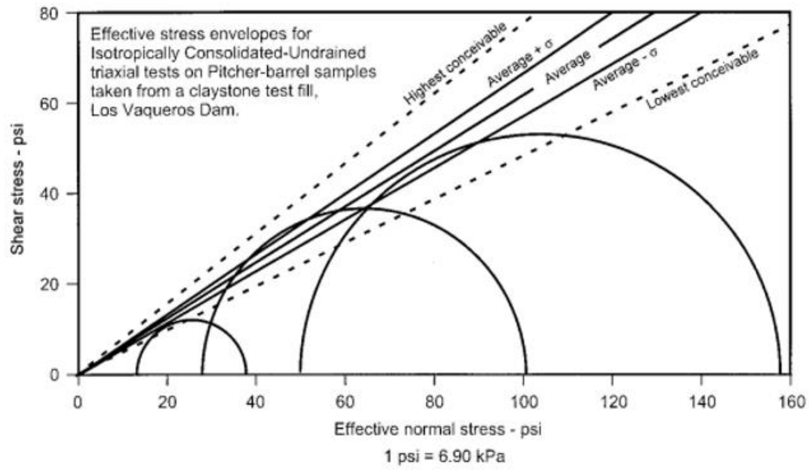

Figure 6.7 Examples of graphical three-six Sigma rule for estimating standard deviation limits for strength envelope (Duncan, 2000).

6.3.5 Parameter Estimation Based on Literature

In addition to the approaches given above, coefficients of variation have been proposed in the literature for different soil parameters. The designer can also use these tables when making his/her evaluations. However, when the values given are examined, it is seen that the coefficients of variation are in a wide range. The designer's direct use of these values may lead to errors. For this reason, he/she should decide on the parameters by making a judgment together with the values obtained from the data report under all circumstances. When the literature is reviewed, it is seen that studies have also been carried out on the probability distribution functions of the parameters. Some related data are given in Table 6.8, 6.9, 6.10 and 6.11.

Table 6.8 Typical values of coefficient of variation (Duncan, 2000; Sivakugan, 2011)

Parameter	Coeff. of variation (%)
Void ratio, e	20-30
Porosity, n	20-30
Relative density, D_r	1040
Specific gravity, G_s	2-3
Unit weight, γ	3-7
Buoyant unit weight, γ'	0-10
Liquid limit, *LL*	10-20
Plastic limit, *PL*	10-20
Plasticity index, *PI*	30-70[a]
Optimum water content, w_{opt}	20-40[b]
Maximum dry density, $\rho_{d(max)}$	5
California bearing ratio, *CBR*	25
Permeability (saturated), k	70-90
Permeability (Unsaturated), k	130-240
Coefficient of consolidation, c_v	25-70
Compression index, C_c	10-40
Preconsolidation pressure, σ'_c	10-35
Friction angle (sands), Φ'	10
Friction angle (clays), Φ'	10-50
Friction angle (mine tailings), Φ'	5-20
Undrained shear strength, c_u	20-40
Standard penetration test blow count, N	20-40
Cone (Electric) resistance, q_c	5-15
Cone (Mechanical) resistance, q_c	15-35
Undrained shear strength from field vane, c_u	10-30

[a]Lower values for clays and higher ones for sandy/gravelly clays.

[b]Lower values for clays and higher ones for granular soils.

Table 6.9 Inherent variability of soil properties (Uzielli, Lacasse, Nadim, & Phoon, 2006).

Test	Property	Type of soil	Mean range	*COV*, %
Triaxial UC	s_u, kPa	Clay	1-40	20-55
UU	s_u, kPa	Clay	1-35	10-30
CIUC	s_u, kPa	Clay	15-70	20-40
CID	ϕ', °	Clay and sand	20-40	5-15
CPT	q_t, MPa	Clay	0.5-2.5	<20
	q_c, MPa	Clay	0.5-2.0	20-40
		Sand	0.5-3.0	20-60
SPT	N, bpf	Clay and sand	10-70	25-50
Index properties	w_n, %	Clay and silt	13-100	8-30
	w_L, %	Clay and silt	30-90	6-30
	w_P, %	Clay and silt	15-25	6-30
	I_P, %	Clay and silt	10-40	-
	I_L, %	Clay and silt	10	-
	γ, kN/m^3	Clay and silt	13-20	<10
	D_R, %	Sand	30-70	10-40
				50-70

Table 6.10 Typical coefficient of variation and distribution of soil properties. (Lacasse & Nadim, 1996).

Soil property	Soil type	Prob. distr. function	COV,%
Cone resistance	Sand	LN	Varies greatly from site to site
	Clay	N/LN	
Undrained shear strength, *s_u	Clay (triax)	LN	5 - 20%
	Clay (index s_u)	LN	10 - 35%
	Clayey silt	N	10 - 30%
Ratio s_u /σ'_{vo}	Clay	N/LN	5 - 15%
Plastic limit	Clay	N	3 - 20%
Liquid limit	Clay	N	3 - 20%
Submerged unit weight	All soils	N	0 - 10%
Friction angle	Sand	N	2 - 5%
Void ratio, porosity, initial void ratio	All soils	N	7 - 30%
Overconsolidation ratio	Clay	N/LN	10 - 35%

N/LN: Normal and lognormal distributions
* s_u estimated from index tests

Table 6.11 Typical coefficient of variation and distribution of soil properties (Mattos & Viviescas, 2015)

Friction angle ϕ’	Cohesion *c*	Unit weight γ	Surcharge *R*	Reference
Normal, log normal, Beta, Gamma and Uniform	x	Normal, lognormal, Beta and Gamma	x	Baecher and Christian (2003)
Normal	Normal	Normal	x	Sivakumar Babu and Srivastava (2007)
Lognormal	x	x	x	Cherubini *et al.* (2007)
Normal	x	Normal	x	Uzielli *et al.* (2007)
Normal y Lognormal	Normal and lognormal	Normal and lognormal	Gamma and Weibull	Phoon (2008)
X	Beta	x	x	Qingnian and Yuzhou (2011)
Normal	Lognormal	Normal	x	Prada *et al.* (2011)
Beta	x	Normal	x	Papaioannou and Straub (2012)
X	Lognormal	Lognormal	Gamma	Fan and Liang (2013)
Normal	Normal	Normal	x	Wu (2013)

6.4 Most Commonly Used Probabilistic Methods in Geotechnical Engineering

6.4.1 Taylor Series Method

It is a method based on the calculation of the performance function depending on Taylor Series expansions of the expected values of random variables (Hahn & Shapiro, 1967). The expected value of the performance function for independent random variables when only the first-order terms of the expansion are considered,

$$E[F] = \mu_F \approx g(E[X_1], E[X_2], \dots, E[X_n]) + e \tag{6.14}$$

Here, the determined mean values of the random variables are used as input parameters to determine the function g(X 1, X2, ...). In some cases, random variables may be dependent on each other (I ρ_{XY} I > 0), in this situation the expected value can be calculated as follows.

$$[F] = \mu_F \approx g(E[X_1], E[X_2], \ldots, E[X_n]) + \sum_{i=1}^{k}\sum_{j=1}^{k} \frac{\partial^2 F}{\partial X_i \partial X_j} Cov(X_i, X_j) + e \tag{6.15}$$

for i < j

where e represents modeling error. The contribution of the summation term is usually relatively small, and being of second-order can be omitted from the calculations. The Taylor series may also be used to estimate the variance of the response of the performance function to the input random variables. The Taylor series might additionally be used to determine the variance of the performance function. Again, if we limit the series to first-order terms only, the variance can be approximated by

$$Var[F] = \sigma_F^2 \approx \sum_{i=1}^{k} \left[\left(\frac{\partial F}{\partial X_i} \right)^2 Var[X_i] \right] + 2\sum_{i=1}^{k}\sum_{j=1}^{k} \left[\left(\frac{\partial F}{\partial X_i}\frac{\partial F}{\partial X_j} \right) Cov[X_i, X_j] \right] + V[e] \quad \text{for } i < j \tag{6.16}$$

where the partial derivative. $\partial F/\partial X_i$; is evaluated for each random variable, based on the selected performance function. If there is no dependence between the random variables, the covariance values will be equal to 0. In this case, the 2nd totalization part in the Equation 6.16 is also equal to 0. The term V*[e]* represents the variance of the unspecified modeling error.

With the expected value and the standard deviation known, the reliability index can be readily calculated using normal or lognormal distributed PDF. The Taylor series has a fundamental advantage in that, in the process of summing the variances of each term, the relative effect of all parameter variations can be observed. This method gives the exact solution for linear equations, but several errors are observed, especially when the performance function is nonlinear. Considering the above equations, partial derivatives cannot be solved directly, therefore it is recommended to use numerical methods to solve partial derivatives. Corps of Engineers (1997) proposed a finite difference approach for numerical solution of the equations.

$$\begin{aligned}\frac{\partial F}{\partial X_1} &= \frac{g(X_1+\sigma_1, X_2, X_3,..., X_n)-g(X_1-\sigma_1, X_2, X_3,..., X_n)}{2\sigma_1}=\frac{\Delta F_1}{2\sigma_1}\\ \frac{\partial F}{\partial X_2} &= \frac{g(X_1, X_2+\sigma_2, X_3,..., X_n)-g(X_1, X_2-\sigma_2, X_2, X_3,..., X_n)}{2\sigma_2}=\frac{\Delta F_2}{2\sigma_2}\\ &\vdots\end{aligned} \tag{6.17}$$

If each of the above derivatives is squared and then multiplied by the variance corresponding to the random variable, the expression simplifies to

$$\begin{aligned}\left(\frac{\partial F}{\partial X_1}\right)^2 Var[X_1] &= \left[\frac{\Delta F}{2\sigma_1}\right]^2 \sigma_1^2\\ &= \frac{1}{4}[\Delta F_1]^2\end{aligned} \tag{6.18}$$

In the above equation X_2, X_3, ..., X_n are the mean values of the component random variables. So for independent random variables, the variance will be given by the simplified expression

$$Var[F]=\sigma_F^2 \approx \frac{1}{4}\sum_{i=1}^{k}[\Delta F_i]^2 + V[e] \tag{6.19}$$

and for dependent variables, substituting $Cov[X_i, X_j] = \rho_{ij}\sigma_i\sigma_j$

$$Var[F]=\sigma_F^2 \approx \frac{1}{4}\sum_{i=1}^{k}[\Delta F_i]^2 + \frac{1}{2}\sum_{i=1}^{k}\sum_{j=1}^{k}[\Delta F_i \Delta F_j \rho_{ij}] + V[e] \tag{6.20}$$

Using the parameters obtained from the equations given above, reliability index values for normal and lognormal distributions can be calculated with the following equations.

$$\beta = \frac{|FS_C - \mu_{FS}|}{\sigma_{FS}} \tag{6.21}$$

$$\beta = \frac{\left|\ln(FS_c) - \ln(\mu_{FS}) - \frac{1}{2}\left(\ln\left(1 + \left(\frac{\sigma_{FS}}{\mu_{FS}}\right)^2\right)\right)\right|}{\sqrt{\ln\left(1 + \left(\frac{\sigma_{FS}}{\mu_{FS}}\right)^2\right)}} \tag{6.22}$$

6.4.2 Rosenblueth's Point Estimate Method

This approach was proposed by Rosenblueth (1975). In the method, when calculating the PDFs of random variables, plus and minus 1 standard deviation values of the mean values are taken into account. This method is direct, gives reasonably accurate results quickly, and has been discussed in detail by McGuffey, Iori, Kyfor, & Athanasiou-Grivas (1981); Harr (1987), & Corps of Engineers (1997). In this section, details for determining the expected value of the FOS, *F*, and it variance will be presented for two and three random variables. For more than three variables, the presentation of the equations gets more complex, but the approach is the same.

In the case where the performance function of the FOS is expressed by two random variables, F can be expressed as follows.

$$F = g(X, Y) \tag{6.23}$$

The uncertainties of the parameters in the performance function are given in terms of standard deviations (σ_x and σ_y) and mean values (μ_x and μ_y). As a generalization, the variables are dependent (with a correlation coefficient of ρ_{XY}) and one can assume that all PDFs are symmetric.

In two random variables, the FOS should be assessed as a first step. F in 4 cases is defined as follows using different combinations of standard deviations and mean values.

$$
\begin{aligned}
F_{++} &= g\left[\left(\mu_X + \sigma_X\right),\left(\mu_Y + \sigma_Y\right)\right] \\
F_{+-} &= g\left[\left(\mu_X + \sigma_X\right),\left(\mu_Y - \sigma_Y\right)\right] \\
F_{-+} &= g\left[\left(\mu_X - \sigma_X\right),\left(\mu_Y + \sigma_Y\right)\right] \\
F_{--} &= g\left[\left(\mu_X - \sigma_X\right),\left(\mu_Y - \sigma_Y\right)\right]
\end{aligned} \tag{6.24}
$$

$$
E[F] = \mu_F = P_{++}F_{++} + P_{+-}F_{+-} + P_{-+}F_{-+} + P_{--}F_{--} \tag{6.25}
$$

where,

$$
\begin{aligned}
P_{++} &= P_{--} = \frac{1}{4}\left(1 + \rho_{XY}\right) \\
P_{+-} &= P_{-+} = \frac{1}{4}\left(1 - \rho_{XY}\right)
\end{aligned} \tag{6.26}
$$

The variance of the FOS will be given by

$$
Var[F] = E\left[F^2\right] - \left(E[F]\right)^2 \tag{6.27}
$$

where

E [F] = expected value of the FOS from 6.25

and

$$
E\left[F^2\right] = P_{++}F^2{}_{++} + P_{+-}F^2{}_{+-} + P_{-+}F^2{}_{-+} + P_{--}F^2{}_{--} \tag{6.28}
$$

So for two variables, the FOS values are evaluated for four conditions using the adopted performance function. The above equations for two variables can be extended to three random variables. X, *Y*, and Z. which will lead to an expected FOS, *E[F]*, given by the summation of eight products:

$$E[F] = \mu_F = P_{+++}F_{+++} + P_{++-}F_{++-} + P_{+-+}F_{+-+} + P_{+--}F_{+--}$$
$$+ P_{---}F_{---} + P_{--+}F_{--+} + P_{-+-}F_{-+-} + P_{-++}F_{-++} \qquad (6.29)$$

where,

$$\begin{aligned} P_{+++} = P_{---} &= \frac{1}{8}(1 + \rho_{XY} + \rho_{YZ} + \rho_{ZX}) \\ P_{++-} = P_{--+} &= \frac{1}{8}(1 + \rho_{XY} - \rho_{YZ} - \rho_{ZX}) \\ P_{+-+} = P_{-+-} &= \frac{1}{8}(1 - \rho_{XY} - \rho_{YZ} + \rho_{ZX}) \\ P_{+--} = P_{-++} &= \frac{1}{8}(1 - \rho_{XY} + \rho_{YZ} - \rho_{ZX}) \end{aligned} \qquad (6.30)$$

and the variance is obtained from the expression.

$$Var[F] = E[F^2] - (E[F])^2 \qquad (6.31)$$

In general, the expected value, *E[F],* is given by the sum of the product of the *P* coefficients and the *F* values, and the variance is computed using Equation 6.31. So, for even more random variables, new *P* coefficients must be derived to follow the sequence presented for two and three random variables. For each case, the numeric coefficient (in Equation 6.26 or 6.30) is the reciprocal of 2", where n is the number of random variables being considered. The signs in front of the correlation coefficients are related to the subscripts of *P,* with + + or - - correlation leading to a positive sign.

The 2^n assessment of the performance function is necessary to determine the expected value and standard deviation in Rosenblueth's procedure.

6.4.3 Monte Carlo Simulation

In the Monte Carlo method, the performance function results of the FOS can be efficiently computed iteratively for random variables. The PDFs of the parameters for different distributions can be used in this method (for example, see Tobutt, 1982, Chandler, 1996).

Monte Carlo simulation can be briefly summarized with the following steps:

a) For each parameter considered in the performance function, random values are first determined in accordance with the chosen distribution.

b) Depending on the random variables determined, the FOS based on the performance function is calculated.

c) Steps 1 and 2 are repeated over and over, and the FOS values determined during the repetition process are kept.

d) Use the large number of FOS values kept in step 3 to determine (a), (b) and (c)

(a) the probability, P(F < Fe), (b) the sample mean and variance, and (c) evaluate the FOS's PDF from the histogram.

The minimum number of repetitions to be performed in the simulation depends on the number of parameters affecting the performance function and the target reliability.

If the results of the Monte Carlo simulation are considered analogous to the binomial distribution, with successes considered as cases where the FOS exceeds a specified critical FOS, we can estimate the required minimum sample size for different confidence levels (Hahn & Shapiro, 1967). Based on this assumption, the number of trial calculations, *n* will be given by

$$n = \left(\frac{100d}{e}\right)^2 \frac{1 - p_F}{p_F} \times m \qquad (6.32)$$

where

n = minimum number of trials for the Monte Carlo simulation

P_F = probability of unsatisfactory performance (or failure)

E = relative percent error in estimating the probability, P_F

m = number of component random variables

d = normal standard deviate according to the following confidence levels (Table 6.12):

Table 6.12 Normal standard deviate according to the confidence levels.

CONFIDENCE LEVEL	NORMAL STANDARD DEVIATE, D
80 %	1.282
90 %	1.645
95 %	1.960
100 %	2.576

So for a simulation that requires a confidence level of 95 percent and a relative error of 20 percent, the minimum number of trials for a preliminary estimate will be 90 (using d = 1.96, P_F = 0.5) for a single random variable. For the same simulation, 384 trials will be required for a relative error of 10 percent.

The FOS is calculated with the performance function, taking into account the random sets of variables of each parameter that affect the function. A comparison is made between stored FOS values and the critical FOS value. All recorded FOS values less than the critical FOS value are counted, and the probability of defeat is expressed as

$$P(F < F_c) = \frac{n_c}{n_{total}} \tag{6.33}$$

where

n_c = number of FOS values less than F_c

n_{total} = total number of trial for the Monte Carlo simulation

6.4.4 Response Surface Methodology

Contemporary methods for risk assessment and reliability analysis of various geotechnical problems often require development of limit state and performance functions since computational costs can be reduced in this manner by avoiding repeated solutions of governing equations. The multiple linear regressions (MLR) and the response surface methods (RSM) are generally utilized in order to achieve such functions. These approaches have been applied to the reliability analysis of laterally loaded piles, retaining systems and differential settlement problems in the past (Tandjiria, Teh, & Low, 2000; Mahedevan & Shi, 2001).

RSM is a collection of statistical and mathematical techniques useful for developing, improving and optimizing process including reduction of variability. In the practical application of RSM, it is necessary to develop an approximating model for the true response surface. Multiple regression is a collection of statistical techniques useful for building the types of empirical models required in RSM. The key ideas in the classical RSM were developed using linear polynomial models, mainly first degree and second degree models, with continuous response variables assumed, for the most part, to be independently and normally distributed with constant error variances. A first order response surface model that might describe the relationship between *Y* and *X1, X2,…, Xp* is formulated as a linear model

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + ... + \beta_p X_p + \varepsilon \qquad (6.34)$$

where β_0, β_1, β_2,....., β_p are constants referred to as the model regression coefficients, *p* is the regressor variable, and ε is a random disturbance or error.

In general, response variable *Y* may be related to *p* regressor variables which model is called a multiple linear regression model (MLR). MLR attempts to model the relationship between two or more independent variables and a response or dependent variable by fitting a linear equation to observed data. Every value of the independent variable *X* is associated with a value of the dependent variable *Y*.

In İmançlı, Kahyaoğlu, & Özden (2009), limit state moment functions for laterally loaded single piles in a local OC clay is proposed. Maximum bending moment data computed using FEM, which better represented three-dimensional nature of the problem upon evaluation of laterally loaded pile analyses results, was used while developing limit state functions via RSM where the pile rigidity is taken into consideration. RSM analyses were examined to find which of the soil and pile properties correlate well with the maximum moment values for both rigid and flexible piles. The undrained shear strength (c_u), which is linearly correlated with elastic modulus of soil (E_u), and the pile diameter (B) were used as independent variables.

The following Limit State Moment Functions have been developed for both rigid (short) and flexible (long) piles (Equation 6.35 and 6.36):

Limit State Moment Function for Rigid Piles

$$(LSMFRP) = 151\ B - 1.66\ c_u - 124 \quad (kNm) \tag{6.35}$$

Limit State Moment Function for Flexible Piles

$$(LSMFFP) = 352\ B - 0.0382\ c_u - 97.2\ (kNm) \tag{6.36}$$

where the pile diameter (B) is in units of meter, and undrained shear strength (c_u) is in units of kN/m^2.

6.5 Discussion on Reliability Based Methods

The developing reliability-based geotechnical design codes and reliability-based analysis methods can take into account the uncertainty levels and probability distribution functions of the soil parameters. However, when the approaches given in the literature are examined, it can be seen that the results vary significantly for the same problem when analyzed using different proposed methods. It is not possible to say with certainty which of the proposed approaches gives a more accurate result when the current studies are analyzed. In order to show the differences in results between the approaches, the analysis of three different geotechnical problems from the literature is summarized and the results of the analysis are tabulated.

A simple example concerning the required area of a spread footing designed against bearing failure is taken into consideration to compare the resistance factors stated in the Canadian Standards Association (CHBDC) (2006) to those specified in other codes from around the world Characteristic soil parameters are assumed as, c =100 kPa and $\varphi = 30^{\circ}$. Embedment depth and surcharge are taken into consideration equal to 0. Characteristic dead and live loads on the foundation are F_D=3700 kN and F_L=1000 kN, respectively. According to the results of the analysis with different design codes considered in Table 6.13, the required footing areas are summarized (Fenton et. all, 2013).

Table 6.13 Values of load and resistance factors (α_D, α_L, ϕ_φ, ϕ_c, ϕ_{gu}) suggested by various sources along with footing area each would require in bearing capacity design example assuming similarly defined characteristic loads. (All factors are applied in a multiplicative fashion.). (Fenton et. all, 2013)

Source	α_D	α_L	ϕ_φ	ϕ_c	ϕ_{gu}	Area (m^2)
CFEM (Canadian Geotechnical Society, 1992)	1.25	1.5	0.8	0.5-0.65		5.22
NCHRP 343 (NCHRP, 1991)	1.3	2.17			0.35-0.6	4.88
NCHRP 12-55 (D'Appolonia and the University of Michigan, 2004)	1.25	1.75			0.45	4.70
DENMARK (Danish Geotechnical Institute, 1985)	1.0	1.3	0.83	0.56		4.13
AASHTO (2012)	1.25	1.75				4.23
AS 5100 (Standards Australia, 2004b)	1.2	1.8				4.14
CHBDC (Canadian Standards Association, 2006)	1.2	1.7			0.5	4.07
AS 4678 (Standards Australia, 2002b)	1.25	1.5	0.75-0.95	0.5-0.9		3.89
EC 7 DA 1 (CEN 2004)	1.0	1.3	0.8	0.8	0.45-0.55	3.06
EC 7 DA 2 (CEN 2004)	1.35	1.5			0.35-0.65	3.04

Reliability analyses were carried out by Sleep & Duncan (2017) for the hypothetical 6.1 m high cantilever retaining wall with silty sand backfill (Figure 6.8). These reliability analyses concluded to demonstrate the results of using several reliability methods.

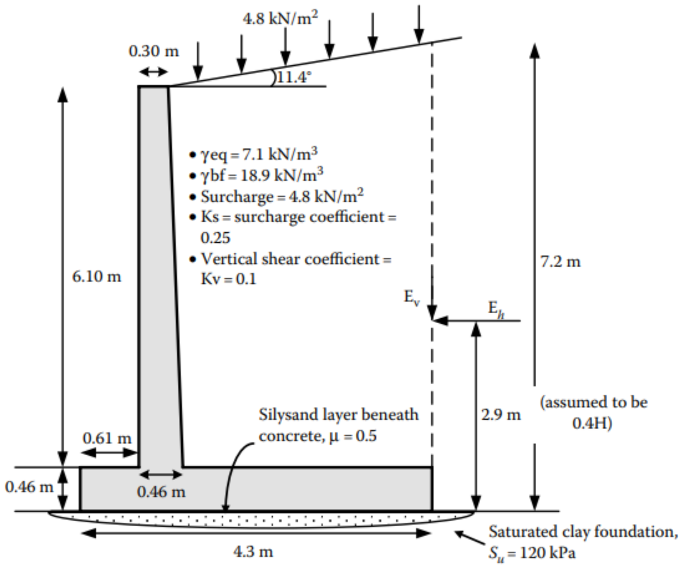

Figure 6.8 Section of analyzed cantilever retaining wall with silty sand backfill

They performed sliding and bearing capacity reliability analyses for silty sand and clay conditions of the soil beneath the wall foundation.

The Monte Carlo approach, the Hasofer Lind method, the Taylor Series method, and the Point Estimate method were all used in reliability assessments. The variables were thought to be normally or lognormally distributed and uncorrelated. There were 24 probabilistic analyses carried out in total. The results of the analysis are summarized in the Table 6.14.

Table 6.14 Factor of Safety and Probability of Failure Results Obtained from the Analysis.

Layer of Soil Beneath the Wall.	Factor of Safety, *FOS*		Probability of Failure, p_f (%)			
	Sliding	Bearing Capacity	Sliding		Bearing Capacity	
			min	max	min	max
Silty Sand	1.4		2.4	5.5		
Clay	2.0	2.0	0.6	5.0	0.2	4.0

Evaluating the results of the analysis, they commented as follows; the results differ by as much as a factor of 20, and there is no justification for choosing one method over the other. Due to the broad variation in outcomes, judgment is required to assess the results and determine which result is the most significant.

Abramson, Lee, Sharma & Boyce (2002) to illustrate the probabilistic analysis the 2H:1V slope of figure given below (Figure 6.9) will be analyzed using Taylor Series Method, Point Estimate Method and Monte Carlo Simulation discussed above. For the three methods that will be used to illustrate the probabilistic analysis, the necessary parameters are summarized in Table 6.15. Results of analysis are also summarized in Table 6.16.

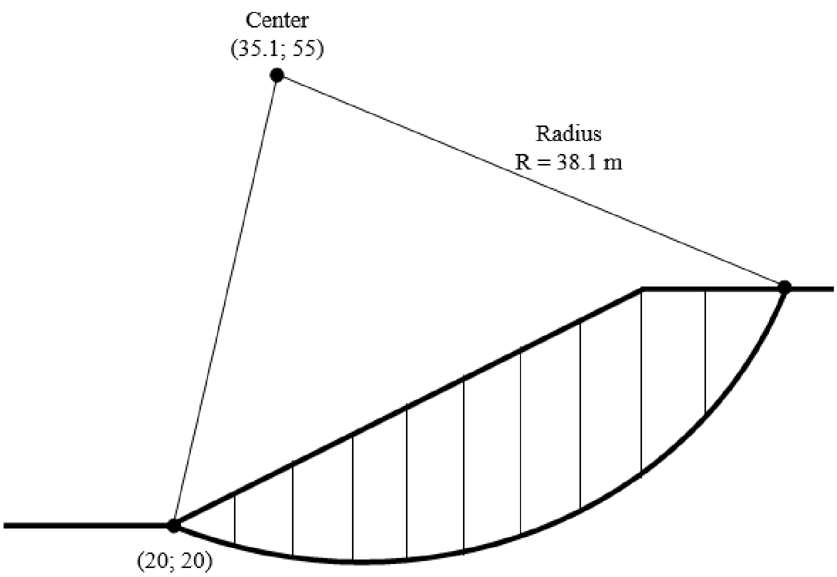

Figure 6.9 Section of slope

Table 6.15 Analysis parameters and statistical values

Parameter	Value	Coefficient of Variation, V_x	Standard Deviation, σ_x	Correlation $\rho_{c, \tan\phi}$
c	20 kPa	25 %	5 kPa	-0.70 and 0.0
$\tan\phi$	0.3640[a]	10 %	0.0364	
γ	16 kPa	Deterministic	Deterministic	

[a] Corresponds to ϕ =20°

Table 6.16 Results of analysis

Reliability Design Method	Stability Analysis Method	Probability Distribution Type	Dependent, ρ $_{c, \tan\phi}$ = -0.7		Independent, ρ $_{c, \tan\phi}$ = 0	
			β	p_f =P (Fc < 1.4)	β	p_f =P (Fc < 1.4)
Taylor Series Method	Simplified Bishop	Lognormal	1.7945	0.0364	0.9509	0.1708
		Normal	1.7340	0.0415	0.9502	0.1710
	Simplified Janbu	Lognormal	0.8326	0.2025	0.4219	0.3365
		Normal	0.8395	0.2006	0.4604	0.3226
Point Estimate Method	Simplified Bishop	Lognormal	1.7848	0.0371	0.9169	0.1769
		Normal	1.7591	0.0393	0.9809	0.1633
	Simplified Janbu	Lognormal	0.8019	0.2113	0.3630	0.3583
		Normal	0.8412	0.2001	0.4610	0.3224
Monte Carlo Method	Simplified Bishop	Normal		0.0362		0.1644
	Simplified Janbu	Normal		0.2016		0.3231

CHAPTER SEVEN
- RECOMMENDED METHODOLOGY FOR FAULT ALLOCATION

7.1 Introduction

The most striking aspect of being a Forensic Engineer in the Turkish Judicial System is that, in almost all disputes, the Forensic Engineer is required to conduct a detailed study on the allocating of faults between the disputed parties. However, a systematic approach to fault allocation is not widely followed at present. The fault allocation made in the expert reports prepared is mostly not objective. Different committees are established over the same subject of dispute, and these committees allocate inconsistent faults among those responsible. The Forensic Engineer is expected to know the relevant legal legislation as well as engineering knowledge and experience. The basis of the method proposed in this study is the identification of geotechnical defects and those responsible according to legal regulations. Failure of the responsible persons to fulfill their obligations in their job descriptions is considered a fault and penalty points are given for each fault. Soil parameters have inherent variability. The engineer is expected to design in a way that takes this variability into account. When a reliability-based design is made, these variations are reflected in the result.

For this reason, when fault allocating is done, whether the design being examined is a failure or exceeding the deformation limits, the approach of using reliability-based methods and understanding whether possible variabilities are taken into account through the target reliability index value has been adopted.

The principles of the Code of Obligations are taken as the basis for the rating of the fault (intent, gross negligence, slight negligence). In our legal system, the fault is generally handled as intent, gross negligence, and slight negligence. It can be defined as intent that a person knowingly and willingly commits an unlawful act and causes harm. Gross negligence is the lack of attention and care that everyone will show in general, and slight negligence is the lack of attention and sensitivity that a careful and cautious person would show (Nomer, 2012; Tahiroğlu, 2008). Article 41 of the Code of Obligations No. 818 (1926), which has been repealed with the entry into force of the Turkish Code of Obligations No. 6098 (2011), states that the unlawful act must be committed " intentionally or negligently" to require liability. Anyone who unlawfully harms another person, either intentionally or through negligence or carelessness, is liable to remedy this damage. In the Code of Obligations numbered 6098 (2011), the rating of the fault is not mentioned.

Here, the idea that compensation should be awarded in case of more or less all kinds of faults, provided that it causes damage, is considered. In this case, the judge will determine the amount of compensation within the framework of equity according to the intensity of intent or negligence (Oğuz, 2016).

However, according to Article 52 of the Turkish Code of Obligations No. 6098 (2011), the indemnity obligor, who caused the damage with slight fault, will fall into poverty when he pays the compensation, and the judge can reduce the compensation if fairness requires it.

In determining the fault, the degree of care expected and required from the responsible person is important. For example, the fact that the "Inspection" job has been made a special profession and area of expertise by law increases the degree of care that should be shown.

Expert inspectors who practice their profession professionally are generally responsible if they do not know the known and accepted rules and methods, the unchangeable rules of science and technology, the rules of science and art related to the subject of the inspection, standards, and regulations and do not follow the changes in the standards and regulations (Okan, 2012).

In construction law, the concept of "Defect" can also be handled in two ways as " Patent Defect" and "Latent Defect", pursuant to Article 477 of the Turkish Code of Obligations. What is meant by the concept of patent defects is obvious construction defects that can be noticed or seen at first glance without an expert on the subject. Latent defects are defects that cannot be detected by observation and without using any technical equipment. The detection of these defects will only be revealed by technical examinations and perhaps back-analysis to be carried out by expert engineers. Such defects usually occur over time. An example of this is the total and differential settlement exceed the allowable limits due to time as a result of load transfer to saturated clays.

In the Building Inspection Law (2001), the job descriptions, in other words, the responsibilities of the parties working at each stage of the project are defined. For this reason, when a building defect occurs, it would be appropriate to start working based on the Inspection Law and Inspection Regulation (2008) on Building Inspection in fault allocation. The explanations regarding the responsibilities in the Law and the Regulation are based on the Turkish Code of Obligations No. 6098. The law holds those who have a causal link with the damage liable in proportion to their faults. While determining the responsibilities, the joint liability between the parties was taken into account. While evaluating joint liability, a ranking should be made between primary (main) and ancillary responsible parties.

For example, according to the Regulation, “The designer must make or have to do the projects and ground investigation reports, which are the basis of the building license. It is responsible for submitting these reports to the building inspection organization for examination. The projects in the license annex must be compatible with each other. Responsibility arising from projects that are not compatible with each other primarily belongs to the designers, respectively, to the building inspection organization, to the project and application inspector architects and engineers, and to the relevant administration. Here, while the designer is primarily responsible, the building inspection organization, the project and application inspector architects and engineers, and the relevant administration are ancillary responsible. The examples given below are presented to shed light on the determination of the rating of the fault.

According to the Turkish Building Inspection Law and Regulation, construction must be controlled by inspecting engineers. The principal responsible for construction defects should be the contractor, and the ancillary responsible should be the building inspection company. In this case, the fault rate of the primarily responsible is expected to be higher than the ancillary responsible. However, the level of neglect of the construction inspection company's duty during the inspection phase will be effective in determining the rating of fault. For example, in an anchored shoring system, it is not possible for the application inspector not to notice such a patent defect if the anchors are constructed in insufficient numbers, or their positions are incorrect. Therefore, the inspector's fault should be treated as intent. In case of such an intention, the defect rate of the building inspection company should be considered equal to the contractor. In case of such an intention, the defect rate of the building inspection company should be considered equal to the contractor.

To give another example, the boring depth is at least 1.5 times the width of the foundation from the base for building foundations, or where the vertical stress increase in the soil ($\Delta\sigma$) due to the net foundation pressure being approximately equal to 10% of the initial effective overburden pressure (σ'_{vo}). Boring depth will be chosen to be more unfavorable. Here, it can be considered as an intention that the construction inspection company does not control the required minimum boring depth in the report.

On the other hand, not noticing that drilling is done shorter in the field than the required boring depth can be accepted as slight negligence.

When the Turkish Building Earthquake Code (2018), Soil Investigation Practice Principles, and Geotechnical Report Format (2019) and Excavation Regulation (2022) are examined, it is seen that the minimum conditions of all evaluations specified in the contents are expressed. For this reason, fulfilling the minimum conditions in case of construction damage will not eliminate the responsibility.

7.2 Recommended Liability Ratios

As mentioned above, it would be appropriate to start allocating responsibilities from the Building Inspection Law and the Implementation Regulation, since the responsible parties and job descriptions are clearly given. While allocating the fault, first of all, it should be decided whether the defect is caused by the construction or the project stage. This is relatively the simplest element of fault allocating. Because in many cases, construction defects can be detected by visual inspection and measurement techniques.

In the next step, details become important. If the situation where the errors are in the project is taken as an example, the parties of a project should be determined first (Table 7.1). As can be followed from the chart, the responsibilities in the improper project are determined according to the number of valid steps for each stage of the project. As can be seen, the primarily responsible for the project is the geotechnical designer with 40%. The responsibility ratios of the other three stages were allocated equally. There is a widespread opinion among the interlocutors of the sector that the Building Inspection Companies responsible for the Inspection stage is responsible for the entire project and implementation. However, Building Inspection Companies are exempt from project analysis by law. Project supervision consists of observing compliance with standards and regulations and compliance with science rules. For this reason, the inspection company has been given a total responsibility of 20%. If some of those who are responsible for the implementation project fulfill their duties completely, the resulting financial compensation is expected to be allocated by the other parties in proportion to their ratios.

Table 7.1 Responsible parties and responsibility ratios at the design stage of a construction.

Stage		Responsible Parties	Responsibility Ratio (%)
Soil Investigation	Planning	Civil and Geological Engineer	5
	Field	Geology and Geophysics Engineer (field)	5
	Laboratory	Accredited Soil/Rock Testing Laboratory and Laboratory Inspector	5
	Report	Geology and Geophysics Engineer (office)	5
Geotechnical Report	Evaluation of Soil Investigation Report	Civil Engineer (Geotechnical M.Sc)	4
	Superstructure Loads	Civil Engineer (Geotechnical M.Sc)	4
	Foundation System Recommendation	Civil Engineer (Geotechnical M.Sc)	4
	Retaining System Suggestion	Civil Engineer (Geotechnical M.Sc)	4
	Soil Improvement Suggestion	Civil Engineer (Geotechnical M.Sc)	4
Geotechnical Design	Analysis Report	Civil Engineer (Geotechnical M.Sc)	30
	Detailed Project Drawings	Civil Engineer (Geotechnical M.Sc)	10
Inspection	Soil Investigation Report	Civil Engineer	5
	Geotechnical Report	Civil Engineer	5
	Geotechnical Design	Civil Engineer	10

If a shortcoming is not identified during the soil investigation and geotechnical report stages, the Geotechnical Design and the Inspection Company are responsible for the defect, and the compensation should be allocated according to the ratio between them. In this case, if there is a 2:1 ratio between the designer and the inspection company, the financial compensation of 100 units should first be divided into three, and then 100x2/3 units should be allocated to the designer and 100x1/3 units to the inspection company. The most important assistant of the Forensic Engineer while investigating the probable responsibility of the project will be the correct determination of the reliability index of the design. Similarly, revealing whether the soil parameters in the "Soil Investigation Report" remains within a certain standard deviation is an important auxiliary element in the evaluation of this stage. The Forensic Engineer should have the authority to change the liability ratios suggested in Table 7.1 and to approve new ratios. As mentioned above, the Forensic Engineer has to resort to methods based on reliability while determining the realization rate of responsibility for each party. Conversely, an approach is more likely to be subjective. For example, if the reliability index of the design is higher than the upper limit of the target reliability index interval, it will mean that the design success rate is 100%, and if it is below the lower limit, it will mean 0%.

In some cases, loss of life or injury may occur as well as financial loss. In the Turkish Judicial system, faults that cause such losses are evaluated as "recklessly causing death or injury" and punishment is given according to the legal dimension of the incident. This issue is outside the scope of our study. However, prosecutors and judges may take into account the fault ratios during the penalty request or discretion. For the designer of a project with a low-reliability index, the penalty that may be appreciated may legally be high.

CHAPTER EIGHT
-A CASE STUDY

In January 2007, during the foundation excavation of a high-rise construction with adjacent buildings on both sides, deformations unexpectedly occurred in adjacent buildings. As a result of the complaints made by the owners of the damaged buildings to the official authorities, the excavation works were stopped and the disputes between the parties were brought to the judiciary. The age of the buildings subject to the lawsuit is around 20-30. The structural system of the buildings is reinforced concrete, and they transfer their loads to the ground with strip footings. The expert committee appointed by the Court consisted of a geotechnical engineer, a geological engineer, and a survey engineer. According to the measurements made during the declaratory action, it was determined that the upper elevation of the building subject to the lawsuit had a displacement of 14 cm in the direction perpendicular to the excavation and 13 cm in the direction parallel to the excavation (Figure 8.1). During the expert investigation conducted under the supervision of the judge, the technical committee was asked to clarify the following issues:

Article 1. Determining the damages caused by excavation in the buildings, determining whether there is any damage to the structural system of the buildings, examining the presence or severity of wall and/or plaster cracks in the apartments in the buildings,

Article 2. Installation of instrumental monitoring devices to observe the evolution of damages over time,

Article 3. Reviewing the projects of the buildings, controlling the excavation project and construction,

Article 4. Analyzing how excavation work can continue safely,

Article 5. Determination of the indemnity caused by the undesirable event and allocation of fault between those responsible

As a result of the analyses made within the scope of Article 4 mentioned above, it was decided to reinforce the shoring system, which originally consisted of cantilever tangent piles, on the north, south, and west sides. While it was relatively easy to provide additional support on the north and south sides using inclined struts, this was critical on the west side due to the need to further restrict displacements.

Since the excavation and foundation on the eastern side had already been completed, the most appropriate measure was to finish the basement floor construction in this location as soon as possible. The buildings to be protected on the west side are adjacent to the excavation pit. In this section, after the construction of three inclinometer wells, the locations of which are shown in Figure 8.2, the steel pipe struts with 3 m plan spacing shown in both Figure 8.2 and Figure 8.3 were placed between the raft foundation and the shoring cap, which were completed in stages. As a result of the examination of the project drawings, it has been determined that the buildings to be protected with a staggered strut system on the west side have generally been constructed by their projects. The technical committee decided to carry out instrumental observations in the field in order to complete the excavation safely. These instrumental observation works are organized as summarized below:

1. Periodic readings were taken from the three inclinometer wells adjacent to the buildings subject to the lawsuit, of the excavation pit. During the excavation process of the part that has not yet been excavated on this side of the excavation area, it is foreseen that inclinometer measurements will be of great benefit in taking additional measures before the deformations in this side shoring structure reach the limits that will damage the structures, and in this way, the works will be completed safely.

2. A sufficient number of inclinometers and crack meters were placed in the buildings in the subject, and it was possible to monitor the movements that may occur in the buildings during the excavation.

Deformation Perpendicular to the Excavation (14 cm) Deformation Parallel to the Excavation (13cm)

Figure 8.1 Upper-Level deformations of the damaged building subject to the lawsuit.

Figure 8.2 View of the subject building and the location of the inclinometers.

Figure 8.3 Steel pipe struts were added to give sufficient capacity to the shoring system and to limit the displacements

When the inclinometer measurements were analyzed, it was determined that the excavation continued after the necessary precautions were taken, when the final excavation level was reached, approximately 15 mm deformation occurred at the pile cap level in the direction perpendicular to the excavation and approximately 12 mm deformation occurred in the direction parallel to the excavation (Figure 8.4). As a result of the measures taken, the deformations could be kept under control and the basement construction was completed.

8.1 Site Inspection of Shoring System Construction Details

The controlled excavation was started after recording the initial deformations with the necessary instrumental measurements and additional support to the shoring system with steel pipe struts. When the existing shoring project was checked, it was seen that the shoring system constructed consisted of cantilever tangent bored piles. The excavation depth is 8 m and the piles with a diameter of 80 cm and a length of 14.5 m are connected with an 80*60 cm cap beam. As a result of the on-site measurements, it was determined that the shoring system construction was in accordance with the project. Therefore, it is concluded that the subcontractor company and the building inspection company responsible for controlling the construction are not at fault under this issue.

8.2 Statistical Evaluation of Soil Parameters for Reliability-Based Analysis

While determining the soil parameters, the soil investigation report of the parcel subject to the investigation was evaluated. There were 8 borings in the site and SPT tests were performed at every 1.5 m in these borings. Laboratory tests were carried out by taking disturbed and undisturbed samples from the boreholes. The parameters taken into account in the analyzes were determined with the help of both laboratory test results and the correlations accepted in the literature based on field tests. In the reliability-based analyses, the unit weight, plasticity index, and Poisson's ratio parameters were taken into account with their mean values, while the internal friction angle, undrained shear strength, and deformation modulus values were taken into account depending on their standard deviations. There is a sand layer with an average internal friction angle of 33.5º up to 9 m from the ground surface. The average undrained shear strength of the saturated clay layer between 9 m and 13.5 m is 100 kPa and the average undrained shear strength of the saturated clay layer between 13.5 m and 16.5 m is 115 kPa. From 16.5 m to 25 m from the surface, there is a sand layer with an average internal friction angle of 39º. The groundwater level is around 2 m. The mean and standard deviations of the soil parameters determined based on the statistical evaluations are given in Table 8.1.

Table 8.1 Mean and Standard Deviation of Soil Parameters Used in the Analysis.

Layer	Depth (m)	Value Type	Drainage Condition	γ_{sat} (kN/m^3)	c_u (kN/m^2)	Φ (°)	E_{50}^{ref} (kN/m^2)	E_{oed}^{ref} (kN/m^2)	E_{ur}^{ref} (kN/m^2)
1	(0-9)	- 1 Std.	Drained	19	-	30.36	19200	19200	57600
1	(0-9)	Avg.	Drained	19	-	33.5	30000	30000	90000
1	(0-9)	+1 Std.	Drained	19	-	36.64	40800	40800	122400
2	(9-13.5)	-1 Std.	Undrained	20	78.01		2241	1793	5379
2	(9-13.5)	Avg.	Undrained	20	100		2598	2078	6234
2	(9-13.5)	+1 Std.	Undrained	20	121.41		3086	2469	7407
3	(13.5-16.5)	-1 Std.	Undrained	20	84.06		2331	1865	5595
3	(13.5-16.5)	Avg.	Undrained	20	115		2841	2273	6820
3	(13.5-16.5)	+1 Std.	Undrained	20	146.74		3657	2926	8778
4	(16.5-24)	-1 Std.	Drained	20	-	35.82	38160	38160	114000
4	(16.5-24)	Avg.	Drained	20	-	39	48000	48000	144000
4	(16.5-24)	+1 Std.	Drained	20	-	42,9	57840	57840	173500

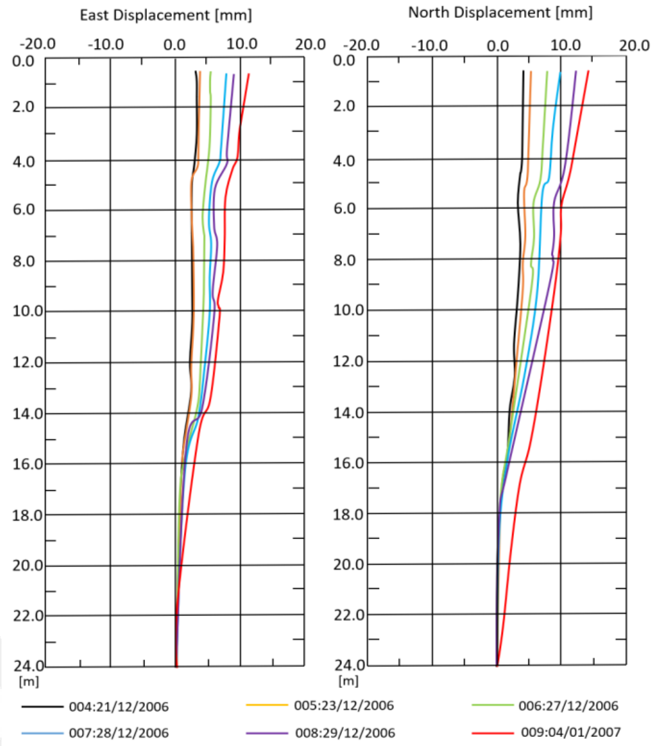

Figure 8.4 No. 2 Inclinometer measurement graphs.

8.3 Reliability-Based Analysis of Shoring System for Ultimate Limit State and Serviceability Limit State Conditions

The planned excavation depth is 8 m in the shoring system of 14.5-meter-long bored piles. When the project was checked, it was determined that only the embedment depth of the shoring system was calculated and the possible deformations that may occur in the shoring system due to excavation were not calculated. The staged excavation to a depth of 4 m resulted in non-structural damage to the adjacent structures. For the analysis of the situation, it was deemed appropriate to make a reliability-based analysis. In the analyses, statistical values of field and laboratory test results were taken into consideration (Table 8.1). Even considering the highest possible conditions of the statistically determined soil strength parameters, it was calculated that 6.5 m embedment depth was insufficient, and collapse would occur in the case of 8 m excavation. In other words, the probability of collapse due to insufficient embedded length is 100%. When the excavation reached around 4 meters, damages occurred due to deformations, and therefore the excavation was continued with additional measures to prevent a possible collapse. In the literature, δh = 0.010H (one percent of the excavation depth) is generally accepted as an upper limit for lateral displacements that will occur in cantilever systems. However, if adjacent structures and facilities are located within the excavation influence area, effects on the stability and serviceability of the structure should be investigated. The designer is responsible for ensuring that the displacements that may occur in neighboring structures do not exceed the deformations that the structure can tolerate without damage. As an upper limit, the angular distortion, in adjacent structures, should not exceed 1/500 in case of static loading and 1/250 in case of an earthquake (Anonim, 2022). If the settlements observed in a structure show different settlement characteristics, negative effects on the superstructure will be more severe. The general approach is to define the damage criteria with angular distortion, ω, (Wahls, 1981; Bjerrum, 1963). In Table 8.2, the limits of angular distortion, ω, developed by Bjerrum (1963) and based on observations are given.

Table 8.2 Limiting Values of Angular Distortion (Bjerrum, 1963).

Angular distortion	Type of damage
1/750 1/600	Dangerous to machinery sensitive to settlement Dangerous to frames with diagonals
1/500	Safe limit to assure no cracking of buildings (factor of safety included)
1/300	First cracking of panel walls (factor of safety not included)
1/300	Difficulties with overhead cranes
1/250	Tilting with high rigid buildings become visible
1/150	Considerable cracking of panel and brick walls
1/150	Danger of structural damage to general buildings
1/150	Safe limit for flexible brick walls (factor of safety not included)

The lateral and vertical deformations that are possible to occur at the pile head and the angular distortion of the foundation were calculated with Plaxis 2D finite element software (Brinkgreve et all., 2016). In the analyses, the hardening small strain soil model (HSS) was used. In the first analyses, even taking into account the probable maximum soil strength parameters, it was calculated that the system would collapse as a result of 8 meters of excavation. In order to analyze the current situation, the probabilities of the horizontal and vertical deformations that may occur in the pile head and the angular distortion of the foundation when the excavation reached 4 m and the associated reliability indexes were calculated with the First Order Reliability (FORM) method and Monte Carlo Simulation approach. Considering the standard deviations of the soil parameters given in Table 8.1, repeated analyses were performed in different combinations and the possible horizontal and vertical pile head displacements, and angular distortions of the foundation as a result of these combinations were calculated. Using the results obtained, performance functions (limit state functions) were obtained with the first order response surface method. The Design ExpertV12 program was used to determine the performance functions. A first-order response surface model is described as a linear mode that can describe the relationship between the dependent variable Y and the independent variables X_1, X_2, ..., X_p as in Equation 8.1 (Myers, Montgomery, & Anderson-Cook, 2016).

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \cdots \ldots \ldots \ldots \ldots \ldots \ldots .. \beta_p X_p + \varepsilon \tag{8.1}$$

where β_0, β_1, β_2, ..., β_p are constants called model regression coefficients, p is the regression variable and ε is a random error.

When the 4 m excavation level is reached, the performance function for the lateral displacement of the pile head is given in Equation 8.2, the performance function for the vertical displacement of the pile head is given in Equation 8.3 and, the performance function for the angular distortion of the foundation is given in Equation 8.4. These equations are presented in the appendices.

$$\begin{aligned} U_x = \quad & 2.3 * 10^2 - 6.97 * 10^{-4} * E_{eod_{L1}} - 4.36 * 10^{-3} * E_{eod_{L2}} + 3.02 * 10^{-4} * E_{eod_{L3}} \\ & + 9.91 * 10^{-7} * E_{eod_{L4}} - 1.11 * 10^{1} * \varphi_{L1} - 4.04 * 10^{-3} * c_{u_{L2}} + 2.15 * 10^{-3} \\ & * c_{u_{L3}} - 7.99 * 10^{-6} * \varphi_{L4} + 1.11 * 10^{-8} * E_{eod_{L1}}^{2} + 6.81 * 10^{-7} * E_{eod_{L2}}^{2} \\ & + 1.46 * 10^{-1} * \varphi_{L1}^2 \end{aligned} \tag{8.2}$$

$$\begin{aligned} U_y = \quad & 1.45 * 10^2 - 1.03 * 10^{-3} * E_{eod_{L1}} - 5.48 * 10^{-3} * E_{eod_{L2}} + 6.40 * 10^{-5} * E_{eod_{L3}} \\ & - 7.23 * 10^{-6} * E_{eod_{L4}} - 5.67 * \varphi_{L1} - 5.97 * 10^{-3} * c_{u_{L2}} + 7.46 * 10^{-4} \\ & * c_{u_{L3}} + 1.77 * 10^{-3} * \varphi_{L4} + 1.63 * 10^{-8} * E_{eod_{L1}}^{2} + 8.30 * 10^{-7} * E_{eod_{L2}}^{2} \\ & + 6.99 * 10^{-2} * \varphi_{L1}^2 \end{aligned} \tag{8.3}$$

$$\omega = 9.76 * 10^{-2} - 4.07 * 10^{-7} * E_{eod_{L1}} - 3.67 * 10^{-6} * E_{eod_{L2}} + 2.63 * 10^{-7} * E_{eod_{L3}} - 7.93 * 10^{-9} * E_{eod_{L4}} - 4.30 * 10^{-3} * \varphi_{L1} - 9.31 * 10^{-7} * c_{u_{L2}} + 3.53 * 10^{-6} * c_{u_{L3}} + 1.49 * 10^{-8} * \varphi_{L4} + 6.14 * 10^{-12} * E_{eod_{L1}}^{2} + 6.31 * 10^{-10} * E_{eod_{L2}}^{2} + 5.42 * 10^{-5} * \varphi_{L1}^{2} \tag{8.4}$$

where, U_x : Pile head lateral displacement limit state function (cm), U_y : Pile head vertical displacement limit state function (cm), ω : angular distortion, E_{eod} : Eodometric modulus of deformation (kN/m^2), φ : internal friction angle (°), c_u: undrained shear strength (kN/m^2), L_i: layer numbers of the variables.

Reliability index values (β) and probability of failures (p_f) calculated for different horizontal and vertical pile head displacements are given in Table 8.3 and Table 8.4 as a result of the analyses performed with the first-order reliability method (FORM) and Monte Carlo Simulation approaches considering the resulted in performance functions. When the reliability index values given in the literature are reviewed, it is stated that if $\beta_{sls} \geq 2.9$ in the serviceability state, the probability of failure is low, and if $\beta_{sls} \leq 1$, is hazardous in terms of failure.

Table 8.3 Pile Head Lateral Displacement Reliability-Based Analysis Results.

Pile Head Lateral Displacement (cm)	FORM, β_{sls}	Monte Carlo Simulation, p_f (100000 Trial)
4	0.85	0.024
8	0.34	0.062

Table 8.4 Pile Head Vertical Displacement Reliability-Based Analysis Results.

Pile Head Vertical Displacement (cm)	FORM, β_{sls}	Monte Carlo Simulation, pf (100000 Trial)
4	5.74	0.00
8	0.95	0.077

the analyses performed for the situation where the angular distortion is greater than 1/500, the β_{sls} calculated based on the FORM method is 1.46 and the p_f is 0.07 based on Monte Carlo Simulation. As can be seen from the analysis results, non-structural damages are expected to occur in the adjacent structure due to angular distortion when the cantilever shoring system, which was constructed in accordance with the project, reaches an excavation depth of 4 meters.

8.4 Determination of Fault Ratios

In general, the liability ratios we have given in Table 7.1 should be revised specifically for the geotechnical case under consideration and should be re-rated based on the engineering knowledge and experience of the expert. The stages and responsibility ratios foreseen for the excavation project with the cantilever shoring system that we considered in our study are given in Table 8.5.

As we have mentioned before, only the project stage was taken into account when allocating the faults since there were no faults of the contractor and the inspection company under the construction stage as a result of the investigations carried out in the field.

Table 8.5 Responsible parties and responsibility ratios at the design stage of construction.

Stage		Responsible Parties	Responsibility Ratio (%)
Soil Investigation	Planning	Civil and Geological Engineer	5
	Field	Geology and Geophysics Engineer (field)	5
	Laboratory	Accredited Soil/Rock Testing Laboratory and Laboratory Inspector	5
	Report	Geology and Geophysics Engineer (office)	5
Geotechnical Report	Evaluation of Soil Investigation Report	Civil Engineer (Geotechnical M.Sc)	15
	Superstructure Loads	Civil Engineer (Geotechnical M.Sc)	-
	Foundation System Recommendation	Civil Engineer (Geotechnical M.Sc)	-
	Retaining System Suggestion	Civil Engineer (Geotechnical M.Sc)	5
	Soil Improvement Suggestion	Civil Engineer (Geotechnical M.Sc)	-
Geotechnical Design	Analysis Report	Civil Engineer (Geotechnical M.Sc)	40
	Detailed Project Drawings	Civil Engineer (Geotechnical M.Sc)	5
Inspection	Soil Investigation Report	Civil Engineer	5
	Geotechnical Report	Civil Engineer	5
	Geotechnical Design	Civil Engineer	5

In light of the assessments given above, if it is necessary to allocate fault for this case within the scope of the responsible parties defined in Table 8.5 and the proposed responsibility ratios, all stages from the ground investigations stage to the construction stage should be carefully evaluated. The ground investigation report, which will be the basis for design and construction, should be considered separately as a ground data report and geotechnical assessment report. Compliance with the relevant regulations and standards should be checked while making the assessments. At this stage, the "Soil and Foundation Investigation Application Principles and Report Format (2019)" and "Excavation Regulation (2022)" prepared by the Republic of Turkiye Ministry of Environment, Urbanization and Climate Change and "Turkiye Building Earthquake Code (2018)" should be taken into consideration. In this context, it has been determined that the required number and depth of borings were performed to design the shoring system in the soil investigation report. However, it was found that the strength parameters for design were given in the report based on the results of the unconfined compression test and triaxial compression tests for clay layers, while for sand layers only correlations based on the SPT test results were used.

According to the relevant report format, these parameters should be given as average, minimum, and maximum values considering both laboratory and field tests. Undisturbed sampling for laboratory tests can be made in accordance with the TS EN ISO 22475-1 (2007) standard for different soil classes. However, it was determined that the Modulus of Elasticity values to be used in deformation analysis were not given in the report. For these reasons, faults of those responsible for the planning, field tests, and preparation of data reports during the ground investigation stage have emerged. In order to minimize the risk, especially in deep excavations where adjacent structures are located, it is of great importance to determine the soil parameters to be used in the analysis correctly.

As we have explained before, in our legal system, the fault is generally considered as intent, gross negligence, and slight negligence. When allocating fault between the primary responsible and the ancillary responsible in the evaluations, the fault ratio of the ancillary responsible to the primary responsible is considered as 25/100 in case of slight negligence, 50/100 in case of gross negligence, and 100/100 in case of intent.

It is a fault that it was not planned at the planning stage that tests should be performed to determine the Modulus of Elasticity and that undisturbed samples should be taken for sandy soils. However, SPT tests were performed in the field according to the report format. Since it is a widely accepted approach that SPT test results can be used to determine the Modulus of Elasticity and angle of internal friction in sandy soils, the fault should be considered as slight negligence at this stage. Therefore, the responsibility was considered (1.25/5) in the planning stage. When the soil investigation report was checked, it was seen that the field tests specified in the planning stage were performed in fulfillment and therefore it was concluded that there was no fault. On the other hand, when the laboratory test results were checked, it was seen that the tests were performed in accordance with the standards and controlled by the inspector. Therefore, it is not possible to mention a fault at this stage. At the stage of preparing the data report, it can be said that there is gross negligence considering the above-mentioned issues and the ratio of responsibility will be accepted as (2.5/5). As a result, the total fault ratio at the ground investigation stage was evaluated as (3.75/20).

In the preparation of the geotechnical report, it would be appropriate to consider the responsibility ratio of the evaluation of the soil investigation report stage as 15 percent and the responsibility ratio of the shoring system suggestion stage as 5 percent. There is an important point to note here. The geotechnical report stages include the stages such as foundation system and soil improvement suggestion in addition to data analysis and shoring system suggestion. However, since there is no causal link in terms of the effect of these stages on the consequences of the event we investigated, these stages should not be included in the total responsibility. In his report, the expert geotechnical engineer summarized the test results obtained from the soil investigation report and the parameters determined with the help of correlations and calculated the Modulus of Elasticity and the internal friction angle of sandy soils, which were not given in the report, using SPT correlations. But, in the determination of any parameter with correlations, he used the equation of only one researcher who suggested the determination of that parameter. What is expected of him at this stage is to use equations proposed by different researchers in the determination of any parameter with correlations and to give the parameters within a certain standard deviation. As it is known, different results are obtained as a result of correlations proposed by expert researchers. Therefore, the fault at this stage can be evaluated as gross negligence and the fault rate will be (7.5/15). In the conclusions section of the geotechnical report stage, it is stated that measures should be taken with an appropriate shoring system considering the soil properties and adjacent buildings. At this stage, when the relevant regulations are examined, it is sufficient to make a suggestion for the excavation stage without making any calculations. Therefore, no fault has occurred in terms of the shoring system suggestion. Accordingly, the total fault ratio at the geotechnical report stage can be evaluated as (7.5/20).

The geotechnical design stage is the stage that causes the greatest impact that may cause failure. It would be appropriate to accept that out of a total of 100% of faults, 40% may arise from the geotechnical analysis report and 5% may arise from the detailed project drawings. As mentioned above, the reliability index values of the design should be greater than the values recommended in the literature both in terms of collapse and serviceability. From the results of the reliability-based analysis, it was calculated that when the excavation reaches 4 meters, the reliability index value falls below the target reliability index value and therefore deformations will occur. In the case of excavation of 8 meters as planned, it was revealed that collapse was inevitable both in terms of insufficient embedded depth and allowable displacements. In this case, a (40/40)% fault occurs at the analysis report stage. At the detailed project drawing stage, it was determined that the drawings prepared were in compliance with the technical drawing rules and therefore no fault occurred at this stage. Therefore, the total fault in the geotechnical project stage was evaluated to be (40/45).

In the inspection stage, since the faults of the building inspection company in the control of the soil investigation data report and the faults in the control of the geotechnical report can be considered gross negligence, it would be appropriate to consider the total fault rate as (5/10) in these two titles. Although it is not appropriate to talk about a responsibility such as making calculation control at the project control stage, the fact that he did not determine that the lateral displacement analysis of the shoring system was not performed in the project can be considered as intent and the defect rate will be (5/5) at this stage. Accordingly, the fault of the building inspection company will be (10/15) in total.

Considering these evaluations, the ratio of the fault that caused the undesired case to the total fault was determined as (61.25/100)%. Of the (61.25/100) total faults, (3.75/61.25) faults were due to shortcomings in the ground investigation stage (6.12%), (7.5/61.25) faults were due to shortcomings in the geotechnical report stage (12.25%), (40/61.25) faults were due to errors in the geotechnical project stage (65.3%) and (10/61.25) faults were due to inspection shortcomings (16.3%). Those responsible may be obliged to pay compensation according to the judge's discretion, taking into account the resulting fault ratios. The plaintiff may demand full compensation for the damages even from only one of the defendants, as there is a relationship of joint and several liability between the defendants. In this case, the jointly liable parties will be able to recourse each other for the compensation they paid according to the allocation of fault between them.

CHAPTER NINE
CONCLUSIONS AND RECOMMENDATIONS

9.1 Conclusions

In this study, a method that takes into account the legal regulations and determines the success of the design with reliability-based analysis is proposed in order to resolve the dispute and allocate the faults in an objective manner. It is expected that the study will be understood by members of the judiciary and adopted as an objective approach to fault allocation.

Once the findings and determinations of the study are evaluated within the frame of the related legislation; the expertise should be comprehensively assessed by handling it within a micro plan and then it should be solved with other related problems. It was stated by all parties that the expertise profession has very crucial problems and it has become one of the problematic fields of the law.

The issues and solution suggestions that have been found significant were respectively stated as follows:

- The most significant point that was determined in the review was the fact that the judges and prosecutors generally do not make the right decision about which field, when and which experts review should be performed; attorneys of the parties do not analyze and supervise the expert reports to protect the rights of their clients.

- In practice, the courts persistently assign the same experts for similar cases; this practice that causes the file stacks for the given expert which also causes certain delays for the settlement phase of the cases.

- It is needed to find an official expertise institution that would perform certain procedures such as issuing certificate at the end of the training to comply with the standards within the period of determination of the experts, maintaining registers indication professional history and to audit the reports.

- The judges and prosecutors to be determined by the Supreme Council of Judges and Public Prosecutors for the field needed to be specialized within the justice system should be motivated to perform academic studies in those fields; the assignation and authorization should be made in the specialized field.

- In the university education related to different science branches, fundamental knowledge regarding the usage of the scientific field within the law cases should be given as additional courses; the awareness of legal and penal liability of this profession should be provided and legal expertise education should be given.

9.2 Recommendations

Professional institutions should also be given authority and liability for the preparation of expert lists as well as the certificate training.

- Securing the judges and prosecutors to be specialized in the needed fields.

The judges should be motivated to be specialized in one of various areas of expertise; their expertise should be taken into consideration during the authorization; thus it should be avoided to assign experts for the cases in which the judge shall already have adequate knowledge.

- Determination of the minimum wage regarding the expert remuneration:

Preparing a report in compliance with the effort made to let competent people take place within expertise profession, the value of the case matter, qualification of the report and the experience of the expert shall greatly remove the injustices of the system.

- Establishing Judicial Expertise Institution :

It is necessary to extend the field of activity of Institution of Forensic Medicine by changing its name as “Institution of Judicial Expertise”; to add chemistry, biology, traffic, narcotic and documentation fields as well as the engineering, informatics and economy in addition to its duties within the field of medicine; in other terms; reorganizing this institution by including expertise as well as the legal experts to be needed for the settlement of any kind of judicial disputes.

- Reuniting and renewing the expertise legislation and founding the academic substructure of expertise:

The entire substructure of the legislation regarding the expertise should be reviewed and the opinion and suggestions of the related organizations as well as the implementers should be requested within the aim of preparing an unqualified legislation; later providing Türkiye Council of Higher Education to receive authorization to found" Judicial Departments" in certain universities via legal studies of the commission to be created. License education and certification service providing regarding the expertise in these departments would be very useful.

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