RESEARCH PAPER / НАУЧНАЯ СТАТЬЯ
UDC 624.131.1
DOI: 10.22227/2305-5502.2025.1.22

Innovation and invention in geotechnical engineering

Gökhan Baykal
Bogazici University; Bebek, Istanbul, Türkiye

ABSTRACT

Introduction. Geotechnical engineering creates a positive environment for innovation due to its multidisciplinary nature and the fact that people have been involved with the soil in every aspect since the establishment of the first civilizations. For invention and innovation, there is a need for ideas that are free from stereotypes, unafraid of making mistakes, inquisitive, productive, diverse and creative. Anatolian civilizations proved their creativity and innovation thousands of years ago with great geotechnical engineering structures.
Materials and methods. Six innovative applications developed at Bogazici University: improvement of pile shaft capacity with lime slurry; rubber added compacted clay liner for underground petroleum tanks; geomaterial production by cold bonding pelletization; compaction of fly ash by using ice; large size large displacement multiple purpose direct shear test apparatus; multiple friction joint pile with adjustable stiffness are presented in this paper. The main objective of the developed methods is to offer environmentaly safe, affordable, sustainable and resillient geotechnical engineering solutions that are accessible to every country in the world and can be easily implemented locally.
Results. The developed methods are practical and have technical advantages over the existing more complicated methods and do not need specialized high cost construction eqipment. Innovative methods can create added value in geotechnical engineering that is compatible with nature, easily accessible and sustainable.
Conclusions. In order to develop creative ideas, during academic education, especially at the doctoral level, instead of stereotyped ideas, ready-made package software and implementation theses, creative projects with strong scientific aspects should be emphasized where new ideas are produced and innovation is encouraged.

KEYWORDS: geotechnical engineering, earth structures from early civlilizations, creativity, inventiveness, innovation

Acknowledgements. The presented studies are completed under by supervision by more than thirty PhD and MSc students and their dedication and hard work is appreciated. One project is supported by TUBITAK Turkish Scientific Research Council, and the others are financially supported as Bogazici University Scientific Research Project grants and the support of TUBITAK and Bogazici BAP office is appreciated.

FOR CITATION: Baykal G. Innovation and invention in geotechnical engineering. *Stroitel'stvo: nauka i obrazovanie* [Construction: Science and Education]. 2025; 15(1):22. URL: http://nso-journal.ru. DOI: 10.22227/2305-5502.2025.1.22

Corresponding author: Gökhan Baykal, baykal@bogazici.edu.tr.

Инновации и изобретения в области инженерной геологии

Гёхан Байкал
Университет Богазичи; Бебек, г. Стамбул, Турция

АННОТАЦИЯ

Введение. Инженерная геология — благоприятная среда для инноваций из-за своей междисциплинарной природы и разных способов взаимодействия с почвой с момента зарождения самых древних цивилизаций. Для изобретений и инноваций необходимы идеи, свободные от стереотипов, не страшащиеся ошибок, любознательные, продуктивные, разнообразные и творческие. Анатолийские цивилизации доказали свою креативность и инновационность тысячи лет назад, создав великие геотехнические инженерные сооружения.
Материалы и методы. В Университете Богазичи разработаны шесть инновационных приложений: повышение несущей способности сваи с помощью известкового раствора; уплотненная глиняная облицовка с добавлением резины для подземных нефтяных резервуаров; производство геоматериалов путем гранулирования; уплотнение золы уноса с помощью льда; многоцелевой аппарат для испытаний на прямой сдвиг; многоцелевая фрикционная свая с регулируемой жесткостью. Основная цель разработок — предложить экологически безопасные, недорогие, устойчивые и жизнеспособные инженерно-геологические решения, доступные в любой стране мира и реализуемые на местах.
Результаты. Предлагаемые методы практичны, они обладают техническими преимуществами перед существующими более сложными методами и не требуют специализированной дорогостоящей строительной техники. Инновационные методы могут создать добавленную стоимость в области инженерной геологии, они совместимы с природой, легкодоступны и устойчивы.
Выводы. Для развития творческих мыслей в классическом образовании, особенно на уровне докторантуры, вместо стандартных идей, готовых программных пакетов и диссертаций по внедрению следует уделять особое внимание творческим проектам с мощной научной составляющей, в которых зарождаются новые идеи и поощряются инновации.

КЛЮЧЕВЫЕ СЛОВА: инженерная геология, земляные сооружения периода ранних цивилизаций, творчество, изобретательство, инновации

Благодарности. Представленные исследования выполнены под руководством свыше тридцати аспирантов и магистрантов, преданность делу и усердная работа которых получила высокую оценку. Один проект поддержан Турецким советом по научным исследованиям TUBITAK, остальные — грантами на научно-исследовательские проекты Университета Богазичи, авторы высоко ценят поддержку TUBITAK и офиса Bogazici BAP.

ДЛЯ ЦИТИРОВАНИЯ: *Байкал Г.* Инновации и изобретения в области инженерной геологии // Строительство: наука и образование. 2025. Т. 15. Вып. 1. Ст. 22. URL: http://nso-journal.ru. DOI: 10.22227/2305-5502.2025.1.22

Автор, ответственный за переписку: Гёхан Байкал, baykal@bogazici.edu.tr.

INTRODUCTION

Geotechnical engineering provides a suitable environment and infrastructure where creativity can flourish due to its multidisciplinary nature. The main subject of geotechnical engineering is soil and rock. Soil has been the main interest of mankind since its existence; mankind has built his house with it, brought his water through canals and conduits formed in soil, built embankments to control floods, built their road using soil, grew their food in soil, cooked their food in earthen pots, buried their loved ones in large earthen temples, and used soil as medicine when necessary. They made great efforts to learn what they were curious about the soil, which was so important to them. From a different perspective, soil is actually the representative of the universe. Dust from the Big Bang thirteen and a half billion years ago led to the formation of planets, and soil was formed as a result of the dynamic processes on our planet. From this point of view, rock and soil have a very deep, mysterious and divine meaning. The rock cycle consists of cooling of magma, solidification and crystallization, weathering, transportation, deposition, lithification, metamorphosis. As geotechnical engineers, we are dealing with the mechanics of such a marvelous and complex material. Unfortunately, geotechnical engineering is actually considered as a low-tech engineering discipline instead of leading all engineering fields. One of the reasons for this is that we are concentrating too much on implementation and getting away from creative ideas. Thousands of years ago, the situation was very different. Earthen structures built 3,000 or even 4,000 years ago were the most important technological wonders of the time. Those times these technologies were the most advanced.

What we know about the development of civilization is completely changed by the new discoveries of today. It is almost as if history needs to be rewritten and all the concepts believed until today need to be reconsidered in connection with this. Anatolia has reinforced its position as the cradle of all civilizations with the discovery of Göbeklitepe. It clearly shows the levels of civilization reached in 10,000 BC. Anatolia has important works in terms of earthen structures. One of the most important of these is the 85 tumuli in Gordion near Ankara, Turkiye. These structures, which were built approximately 3,000 years ago, can be characterized as a geotechnical marvel far beyond being built by trial and error. The construction of a 170 m diameter and 85 m high earthen structure requires serious engineering back ground and design. In particular, although this structure is located right next to the North Anatolian Fault, it has not collapsed in many major earthquakes in the region for thousands of years. The high-tech concepts of these structures come to the fore not only with their height and diameter but also with the fact that they contain a burial chamber. The fact that there is no deflection in the burial chamber under 85 m soil pressure involves some technical challenges even hard to solve for today's geotechnical engineers. Our current theories of earth pressure and deformations may have difficulty in explaining the fact that these structures have survived undamaged until today. One of the tumuli is known as the second largest tumulus in the world. The difference from the pyramids is that the entire structure was built by compacting the soil. We should remember that Proctor's compaction theory dates back to 1936. From this point of view, it is a marvel of geotechnical technology. Pyramids, on the other hand, were built by placing chiseled rocks on top of each other. The transportation and placement of these stones there is a marvel in terms of logistics and engineering. If only one of the tumuli had been built, it might have been thought that they were built by trial and error, but the fact that eighty-five of them were built and almost all of them are still intact after this 3,000-year process shows that this compaction method has some important foundations. The technological level reached by the Phrygian culture is supported not only in the field of geotechnics but also with the precision surgical instruments and other metal tools they have developed. The burial chamber can be reached through an 85 m tunnel excavated in the Midas Tumulus. As a result of erosion, the tumulus has fallen from its original 85 m height to its present 55 m height. The ceiling of the burial chamber is supported by juniper trees. The Gordion Tumuli are not the only examples in Anatolian civilizations. The 35 m high city walls of Hattusa in Hattusa near Çorum, Turkiye are also a geotechnical wonder that has been standing for 3,000 years. The construction method of the 75 m long tunnel under the walls is also a complete innovation. While the earthen wall was being constructed, a rock wall was built on compacted soil in the area where the tunnel was to be built, and after the 35 m height of the earthen wall was built, this rock was excavated and thus the tunnel was obtained. Another interesting earth structure is built on top of 2,150 m high Nemrut mountain in Adıyaman Turkiye. A 55 m high tumulus with 30–35 degree slopes is constructed at the peak point. The tumulus dates back more than 2,000 years. It is possible to increase these examples. In both examples, a comprehensive geotechnical construction technology was used. Both the examples in Anatolia and the foundation systems constructed in Istanbul suggest that it was no coincidence that Karl Terzaghi wrote his book Erdbaumechanic after his work in Istanbul. Between 1918 and 1925 he focused his studies on experimental work at Robert College (Bogazici University) Istanbul. Since he was trained in mechanical engineering, his application of existing knowledge in that field to the soil mechanics discipline with the principles of three-phase mechanics of materials is an example of creativity, inventiveness and innovation.

INNOVATION AND INVENTION

Creativity is a requirement that underpins both inventiveness and innovation. Inventiveness (invention) can be defined as the creation of a method or product that has never been done before. In order for an invention to be patented, it must have industrial implementation. Innovation must provide an advantage in an industrial application by bringing innovation to a pre-existing product or method and must have a commercial side. Innovation cannot be patented. For a technique or process to be Patented inventiveness is a must. In some countries innovation can be protected under Utility Model. All of the intellectual rights are the same with a patent however the duration of protection for Utility Model is 10 years instead of 20 years for patents. In engineering, creativity or creative ideas are very important to bring original solutions to problems. One of the biggest problems in engineering education is the lack of programs that teach creative thinking. Although the increasing specialization in engineering education provides deepening and specialization in a subject, it creates a great narrowing in the vision of the student and prevents him/her from generating various ideas and alternatives. They may graduate without learning not only the knowledge in another engineering field, but even the basic knowledge in different branches of their own engineering field (60). The most important characteristic of creative people is their way of thinking. While the standard way of thinking uses acquired knowledge, creative people have an original productive way of thinking (59). Whatever has been taught in the past in life, education and work, the person uses that knowledge to analytically select the most appropriate solution from the old solutions and prefers to use that solution directly without considering other alternatives. Since he/she is sure that the solution steps he/she has used in the past are correct, he/she is sure that his/her solution is also correct. Creative people, on the contrary, focus on how many different methods they can use to solve the problem by generating original ideas, not on the solutions that have been done and taught in the past. Their scientific, engineering and intellectual back ground is very strong. They do not look at what kind of solution method they have been taught before. They generate many random alternative solutions. They have no fear of making mistakes while generating various ideas. After reaching a diversity of ideas, they choose the most appropriate one among them. Even if they find the most appropriate solution, the desire to try other approaches continues. The classical method of thinking based on acquired knowledge focuses on the rigidity of thinking; when faced with problems that are superficially similar to old problems but have fundamental differences, this way of thinking cannot produce the right solution. The solution method based on acquired knowledge always gives traditional solutions. Old and same results are obtained. It is not possible to produce something new with this way of thinking. Many people may have a large repertoire of interesting ideas and concepts, but if they do not diversify and develop these ideas over time, they lose their validity (59).

The most important problem of engineers in the later stages of their career is that they act with prejudice immediately when faced with a problem. Prejudice is undesirable for an engineer's career. When engineers encounter a problem in every period of their career, they should be able to continue to approach this problem without prejudice. Only in this way can they continue to generate new solutions (60). Creative people have a rich variety of alternative ideas. Instead of solving existing problems, they work on problems they define, are curious about and interested in. They are unprejudiced. In order to generate a large number and variety of ideas, creative people have different characteristics. The first important characteristic is to see what others do not see:

- they know how to approach the problem from different perspectives;
- they can visualize their ideas. They make their thoughts visible by using drawings, graphs, diagrams.

The other important characteristic is to think what others don't think:

- creative people constantly combine ideas and shapes in different combinations. Consciously and subconsciously this combining game is one of the important characteristics of productive and creative people;
- they can reconcile ideas that seem unrelated and unconnected with each other;
- they can think and tolerate even opposite and completely incompatible subjects at the same time. They can continue to work without getting stressed in the face of this dilemma. They can generate very different ideas from this environment;
- they have a perceptive ability to find and evaluate things that they are not looking for randomly outside the subject they are working on and focusing on (60).

In order to generate creative ideas, one must:

- know how to ask questions; ask the right question and be able to express this question in a correct and understandable way;
- to be equipped to classify and label the data collected, and to be able to identify patterns in the data;

• in the light of this data, they should be able to decompose the problem into its small components. They should also be able to create the mechanism to define the relationships between these small components;

• develop a wide range of alternative solution methods by going outside the box;

• identify, elaborate and develop the most appropriate of the alternatives;

• look for solutions from different perspectives and examine the problem from a bigger perspective and not be afraid of making mistakes;

• they should have the will to continue their experiments even if they find the appropriate method among the alternative methods they have developed;

• ethically evaluate the negative effects of the ideas they produce on nature, humanity and life (60).

All of the above ideal situations can be tried to be achieved, especially for academic education and environments. However, it may not be realistic to expect creative and innovative ideas to be developed by construction companies, as commercial applications demand quick solutions that require the completion of day-to-day work. However, since every engineer is trained in an academic institution, undergraduate and postgraduate education should at least include methods of training students in creativity and innovation. When these students start working, they may at least have the potential to produce new ideas when there is a demand. Geotechnical academicians, even if they themselves are only interested in practice, can direct their students, especially at the doctoral level, to theses that focus on developing these characteristics without killing their creative and innovative sides. The situation is different for commercial companies. Since they are practitioners, they can use any method that will provide a quick solution.

INNOVATION AND INVENTION EXAMPLES FROM BOGAZICI UNIVERSITY

Geotechnical engineering provides a fruitful and playful environment for creative ideas due to its practical and effective approach to solve problems related to the behavior of three phase materials. Every material whether it is mud, rock, waste, or any manufactured material the geotechnical engineering may offer a multidisciplinary approach. For mechanical engineers the tolerances are very small and the material properties are well known. For structural engineers if a material has low strength it is not usable. However for geotechnical engineers there is an approach for every material whether weak or strong. Geotechnical engineers can play with the atomic structure, microfabric, micromechanics and provide a solution to the problem. For demonstration a couple of innovative and inventive approaches developed at Bogazici University will be presented.

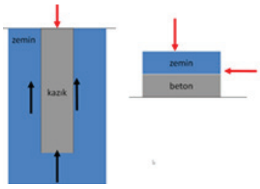
Six of the innovations and inventions completed at Bogazici University will be presented. Increasing the shaft capacity in over-consolidated clays with high plasticity, the use of rubber buffings to prevent groundwater contamination of compacted clay liners, cold pelletization method that will convert silt-sized industrial by-products (fly ash, etc.) to sand, gravel size for safe disposal and utilization as a mineral source, using compaction water in solid phase (ice, snow, etc.) to overcome the water affinity of silt sized material to compaction water content will be discussed in terms of inventiveness and innovation, The development of a universal multiple purpose large-sized large displacement direct shear test apparatus which can be easily built all over the world using locally available off the shelf materials is presented which is essential for testing the techniques emanating from creative ideas. Also, the newly developed and patented concept of multiple friction joint piles will be presented. All these methods have characteristics that can be defined as innovation and invention in geotechnical engineering.

Improving Pile Shaft Capacity with Lime Slurry [1–4]

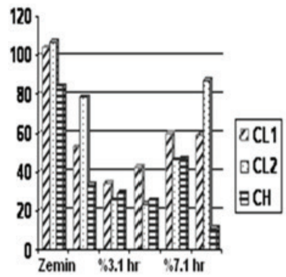
Atomic structure of clays controls the plasticity which dominates their engineering behavior. A very important property affecting the clay behavior is the stress history. Depending on the overconsolidation ratio of the clay, its engineering behavior is different like day and night when compared to that of normally consolidated clay. Under shear the highly overconsolidated clay will suck water in both undrained and drained conditions with different mechanisms resulting an increase in the water content thus decreasing its shear strength. Under undrained condition negative pore pressures will develop leading to suction. Under drained conditions the clay will physically expand and draw water inside leading to shear strength loss. In high plasticity highly overconsolidated clays typical of western part of Istanbul, there is an observed problem related to bored piles. Perched water pockets are typical in the area and under shear at the pile soil interface the water is drawn towards the interface causing a decrease in pile shaft capacity. The affinity of high plasticity clay to water is decreased by application of lime slurry into the pile cavity prior to pouring the concrete.

Definition of the problem: in overconsolidated high plasticity clays, a decrease in shaft capacity may be observed after pile construction. The negative pore water pressure under shear stress causes the water content at the concrete-pile interface to increase over time, reducing the shear strength of high plasticity clays and leading to a reduction in shaft capacity.

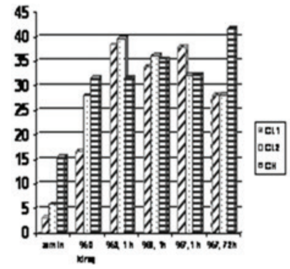
Innovative method: with this innovative technique, the pile cavity is filled with lime slurry. After curing the reinforcement cage is placed and concrete is poured using tremie technique. The lime causes shrinkage in the diffuse double layer of the high plastic clay and decreases the plasticity of the clay making it behave like silt. The clay loses its affinity to water. Fig. 1 provides a summary of the method and details are given in the list of references. The top three figures in Fig. 1 summarize the laboratory test model and the results of the interface direct shear test with lime slurry application. The bottom six figures summarize the results of field tests con-



a) interface direct shear test



b) cohesion and adhesion

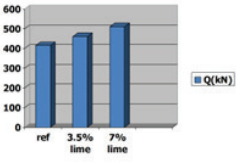


c) internal and interface friction angle

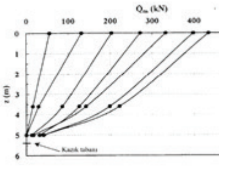
d) pile tests UH NGTS

e) UH NGTS lime slurry application

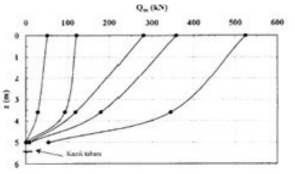
f) U of Houston NGTS



g) pile shaft capacity



h) before lime slurry application



i) after lime slurry application

Fig. 1. Laboratory and field test results showing lime slurry application for pile shaft capacity improvement

Рис. 1. Результаты лабораторных и полевых испытаний, демонстрирующие применение известкового раствора для повышения прочности ствола сваи

ducted at the National Geotechnical Test Site at the University of Houston. The shaft capacity of the tension piles increased by up to twenty percent compared to that of control piles. The last figures show the mobilization of the pile capacity along pile length before and after application of the lime slurry.

Suitable Soil Type: it works well in over-consolidated, high plasticity clays. By affecting the diffuse double layer of the expansive clay in the walls of the pile cavity, it causes the clay to behave like silt and prevents the capacity loss caused by the increase in water content. The negative effects of disturbance during drilling are also eliminated by cementation.

Advantages and Disadvantages: in some projects, the extra mobilization and operating costs of large piling machines can be reduced, as smaller diameter piles will be sufficient due to the increase in shaft capacity. The disadvantage is that contractors may avoid additional step of lime slurry preparation and application in the construction process.

Rubber Added compacted Clay Liner for Underground Petroleum Tanks [5–17]

The plasticity of clay is due to the thickness the diffused double layer. The thickness of the diffused double layer is very important also for low hydraulic conductivity. Thus clays are widely used as liners against effluents. The effluents' properties affect the thickness of the diffused double layer. Low dielectric fluids like hydracarbons is a good example. In the case of leaking underground petroleum tanks, the leaking hydrocarbon alters the clay to silt causing more than an order of magnitude increase in hydraulic conductivity. In the case of leaking underground petroleum tank the effluent affects the diffused double layer of the compacted clay liner and by shrinking the diffused double layer, the hydraulic conductivity of the liner increases. The reason for shrinkage of the diffused double layer is the two orders of smaller dielectric constant of hydrocarbon when compared to that of water. The problem is solved by mixing waste tire buffings (rubber) to the clay. The rubber physically retards the contaminant by absorption and the expansion of rubber provides additional confinement which further helps to decrease the hydraulic conductivity of the silt (clay is altered to silt).

Definition of the problem: hydrocarbon contamination adversely affects the permeability of clay liners. Hydrocarbons, whose dielectric constant is two orders of magnitude lower than that of water, cause the diffuse double layer of clay to shrink, leading to an increase in hy-

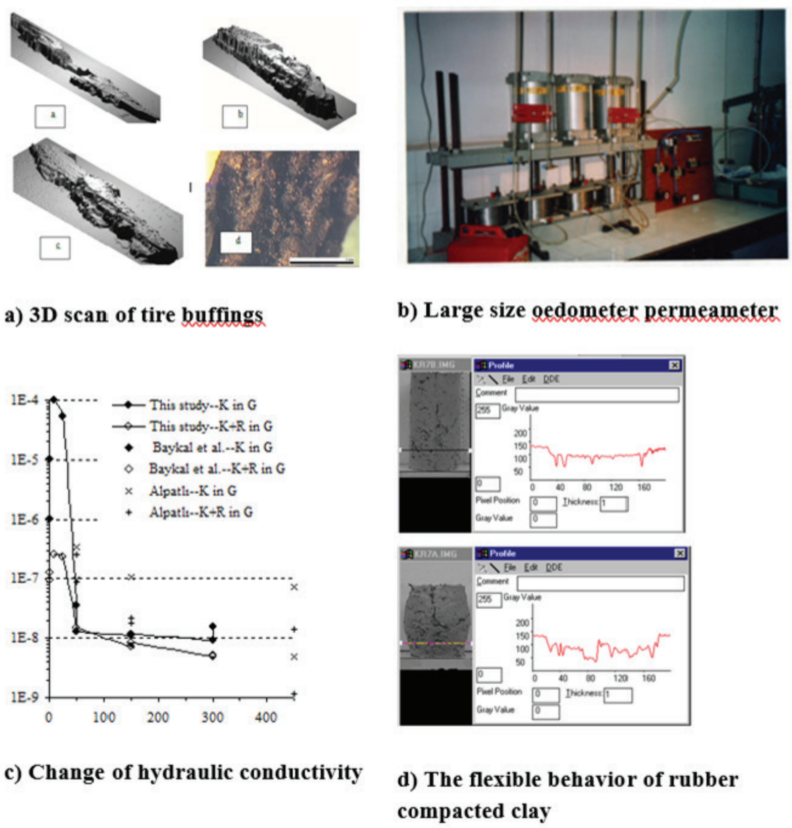


Fig. 2. Tire buffings, large size oedometer permeameter and hydraulic conductivity test results for kaolinite and kaolinite with rubber permeated with gasoline

Рис. 2. Результат шлифовки шин, испытания на проницаемость с применением большого одометра и гидравлическую проводимость каолинита с помощью резины, пропитанной бензином

draulic conductivity by several orders of magnitude. In addition, the progression of cracks in compacted clay liners along the depth also creates problems in terms of hydraulic conductivity. The large number of underground petroleum tanks in residential areas makes the problem more severe in terms of post-earthquake leaks, especially in earthquake zones.

Innovative method: the leaking hydrocarbon shrinks the diffused double layer of clay causing it to turn to silt with an order of magnitude increase in hydraulic conductivity of the clay, Compaction of rubber buffings mixed with the soil directly absorbs the leaking hydrocarbon. In addition, the pressure created by the swelling of the rubber trimmings also leads to a further decrease in conductivity by increasing the confining stress. Another advantage is that it helps to dampen earthquake loads in the tanks. Fig. 2 shows an illustration of the method, the top image is obtained from 3D scans of rubber trimmings. The large-scale consolidation permeameter on the right was developed to verify this method. The addition of rubber to kaolinite caused an order of magnitude decrease in the hydraulic conductivity of the liner subjected to gasoline permeation. The last figure shows how flexible is the rubber added clay.

Suitable Soil Type: although it was developed for compacted clay, it can also be used with sand. Due to its retardation property, it directly retains contaminants even in sand by physical absorption.

Advantages and Disadvantages: tire buffings are byproduct of tire retreading process which is readily available all over the world at a cost. For underground petroleum tank applications the cost of tire buffings can be easily covered due to the reduction in liability insurance fees (Fig. 2).

These two cases demonstrate a unique approach to overcome the problems presented. In pile shaft capacity case the problem due to high plasticity was intentionally altered by lime slurry application to decrease the affinity to water. For the compacted clay liner case the effluent caused an unintentional decrease of the plasticity of the clay which is actually essential for low hydraulic conductivity of the liner. To provide a creative solution waste rubber buffings (fibre size) were added to clay before compaction which retards the effluent by absorption.

Geomaterial Production by Cold Bonding Pelletization [18–28]

The fine size of silts makes it affine to water and when a critical water content is reached the silt fabric collapses. This phenomenon makes the compaction of silt size materials very difficult. The menisci at the contact points of these fine grains pull the grains together. When the water content reaches a critical value, the menisci is lost thus the fabric collapses. Powder sized wastes are present in large volumes and they have to be either utilized or disposed. For both cases adequate compaction is a must. The collapsible behavior of the powder size material makes compaction nearly impossible. Fly ash is an industrial by product with typical silt size. Big failures have occurred at fly ash disposal areas and agricultural land surrounding the disposal area have been contaminated. The same phenomenon that causes collapse of silt size particles is used to solve the problem by using the menisci development to increase the fine size to larger size like gravel. For this purpose, the water is sprayed as droplets on the surface of the fly ash placed in a rotating disc pelletizer. The water droplets form menisci at the grain contact points and cause agglomeration. The agglomerated grains are dropped from the top section of the pelletizing disc to the bottom section causing compaction of these agglomerations. Further spraying of water results in an increase in grain size. This way the same phenomenon that caused collapse of the fabric is used to obtain larger diameter aggregates. Adding small amounts of cement or hydrated lime during the process helps in long term stability and durability of the aggregates.

Definition of the problem: millions of tons of silt-sized industrial powder wastes and by-products are produced every year and their storage creates serious environmental problems and is costly. Due to the fine grain size, air, water and soil pollution risks are high. While this fine grain size is a major problem from environmental pollution point of view, the fine grain size is a big advantage for the pelletizing process. By combining these two concepts, it is possible to convert silt-sized waste and by-products into large volumes of sand and gravel-sized geomaterials.

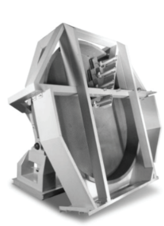
Innovative method: the production of pellets from fly ash by cold palletization using a pelletizing drum is the same as the coal dust pelletizing method used in metallurgical engineering. It is not possible to talk about any innovation here. However, it is an innovative process. That is, to pelletize and store millions of tons of fly ash from thermal power plants and use it as a mineral resource in the future. In this way, huge savings in storage costs can be achieved while minimizing the risks of air, water and soil pollution. Fig. 3 shows an industrial pelletizing drum. Powered by a 200 hp engine, this drum has a pelletizing capacity of 1,200,000 tons of fly ash per year. Much greater wind speed or water velocity is required for the larger size pelletized grains to be eroded decreasing environmental contamination problems. The free draining behavior and high internal friction angle ensures high stability. The manufactured aggregates can be stored for long duration without losing their implementability when needed as mineral source.

Suitable Soil Type: it can be applied to all kinds of silt-sized powder waste and by-products. Although capillarity provides palletization, binding property is required for the pellets to be permanent. This binding can be achieved with additives such as cement, lime, etc.

Advantages and Disadvantages: fly ash pellets have sufficient internal friction angle even without compaction with an equipment. This provides a great advantage during large volume storage. They can also be used in winter conditions due to their ability to compact without needing water. Since they can be produced in the desired size, with the desired crushing strength and the desired surface roughness, a designer geomaterial can be obtained. The disadvantage is that it is not possible to use the waste and by-product far from the region where it is produced due to additional costs (Fig. 3).

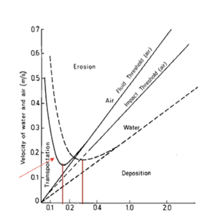
Compaction of Fly Ash Using Ice [29–37]

The focus of the collapse problem during compaction is the small size of the silt and the water in liq-

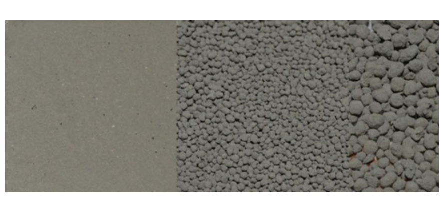


Diameter	7.6 m
Depth	0.8 m
Capacity	200 ton/hour
Power	200 Hp
Annual capacity	1,200,000 ton

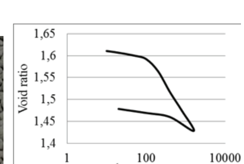
a) pelletization disc



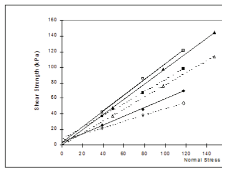
b) hjültorms diagram



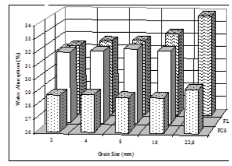
c) fly ash pellet sizes



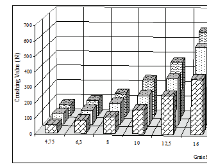
d) fly ash oedometer test results



e) direct shear tests on fly ash pellets



f) water absorption of fly ash pellets



g) crushing strength of fly ash pellets

Fig. 3. A typical pelletization disc; manufactured pellets of various size; and their test results

Рис. 3. Стандартный диск для гранулирования; изготовленные гранулы различного размера и результаты их испытаний

uid phase that first forms menisci at the grain contacts but when saturation is increased, with loss of menisci the fabric collapses. If water is not added in liquid phase but mixed with the silt in solid phase (ice, snow), menisci will not form. The problem of collapse will be solved. Compaction can easily be achieved by adding the water in solid phase. Once the fabric is compacted, the melting of ice or snow from solid phase to liquid phase will not pose any danger for collapse. This solution makes it very practical for construction activities in cold regions. The construction season is very short due to problems with the handling of water in the liquid phase. In cold regions water is plenty in solid phase as snow. The snow can easily be mixed with powder industrial byproduct or waste for embankment construction.

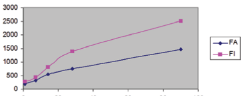
Definition of the problem: compaction of fly ash at optimum water content is problematic due to its silt size. When the optimum value is exceeded even by one percent, liquefaction occurs and compaction cannot be realized. This problem creates serious obstacles in the use of fly ash. The use of industrial by-products and wastes in large volumes in geotechnical projects can only be possible through innovative methods that will eliminate these problems.

Innovative method: in order to compact fly ash, the required compaction water is added to the mixture in the solid phase (ice, snow) with or without compaction water. Thus, compaction can be carried out without any problems. After the ice melts, there is no problem as the material is sufficiently compacted, but the extra water causes a stronger cementation in C-type ashes with cementing properties, resulting in a stronger, lighter filling material. The voids created by melting ice provide thermal insulation. Fig. 4 shows the experiments and results of using the method. The use of ice decreased the dry unit volume weight but increased the water content and void ratio. Adding compaction water in solid phase is an innovative method. However, its main use is in cold climates where it allows fly ash fills in winter conditions by using available snow.

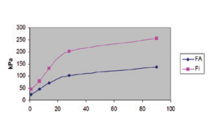
Suitable material: type C fly ashes with self-cementing properties. The same effect is achieved by adding lime or cement to ashes that do not have this property (Fig. 4).

Advantages and Disadvantages: the main advantage of using this method is that in regions with cold climates, all types of embankment construction can be carried out with an extended construction season. The resulting product is stronger, lighter and has thermal insulating properties, which is especially important in permafrost regions. In the formation of cement minerals, Ettringite is formed instead of Thomasite, which reduces gamma radiation by fourty percent due to the presence of 26 moles of water instead of 12 in the atomic structure. As a disadvantage, it may not be economical if the application areas are too far from the thermal power plant.

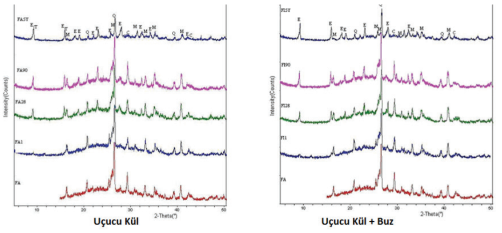
	FA	FA+ICE	% Change
Unit weight, kN/m^3	13.41	11.78	14⬇
Water content, %	19.54	28.89	48⬆
Void ratio, e	0.90	1.17	30⬆

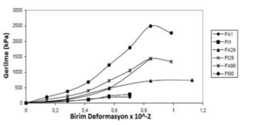


a) unconfined compressive strength of fly ash (FA) and ice compacted fly ash (FI)



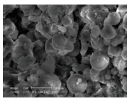
b) split tensile strength of fly ash (FA) and ice compacted fly ash (FI)



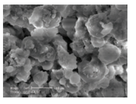


c) stress-strain

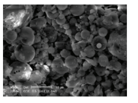
thaumasite ($Ca_3Si(OH)_6(CO_3)(SO_4).12H_2O$) ettringite ($Ca_6Al_2(SO_4)3(OH)_{12}.26H_2O$)



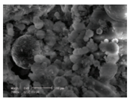
d) one day cured fly ash



e) 90 day cured fly ash



f) one day cured ice compacted fly ash



g) 90 day cured ice compacted fly ash

Fig. 4. Physical changes, Compression and split tension tests, X Ray diffraction anlaysis, stress strain relationship and scanning electron micrographs of ice added and control fly ash

Рис. 4. Физические изменения, испытания на сжатие и растяжение, дифракционный анализ рентгеновских лучей, зависимость напряжения от деформации и сканирующие электронные микрофотографии золы с добавлением льда и контрольной золы

Multiple Purpose Large Size Large Displacement Direct Shear/Model Pile Test Device [38–46]

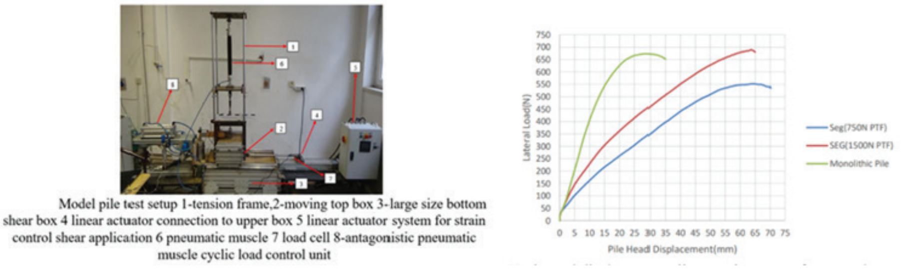
All creative ideas require detailed testing in the laboratory and implementation in the field. There is a need to have an affordable multiple purpose testing equipment that can easily be built all over the world using off the shelf locally available materials and technology for sustainability. Every engineer in the world should have access to experimental tools so that they can test their innovative ideas. Developed countries have many laboratory equipment available but at a very high cost making them unaffordable. Purchasing such equipment is not enough but it is even harder to sustain them due to high maintenance costs. There is a need for one equipment that can test soil in the actual size (large size box), can undergo large displacement (residual tests) can apply both stress and strain control, can apply static and cyclic loads, can aplly tension, can test model piles and model foundations in scaled sizes, can test model pile groups, can do interface tests of actual material sizes etc. The same equipment can conduct inclined plane test, tension test, geosynthetic tests. This is not an easy task. The test equipment presented is very simple and unique and may be a beginning point for further development with international cooperation of geotechnical laboratories worldwide.

Definition of the problem: multiple purpose testing equipment that can easily be built all over the world using off the shelf locally available materials.

Innovative method: the top box is moving instead of the bottom box providing model pile testing. The bottom box is three times larger than the top box to keep the interface area the same throughout the testing. The normal force on the upper box is applied by pnueumatic muscel actuators sliding on rails keeping the angle of appliation of normal force the same. The whole test device can be used as an inclined plane test device by simple elevating one side. A frame is fixed to the upper box to apply tension in the vertical direction. This way a model tension pile can be tested under shear.

Advantages and disadvantages: the whole test equipment can be easily manufactured using sigma profiles which are cheap and are locally available off the shelf all over the world (Fig. 5).

Saidy (57) used the model pile testing apparatus for multi joint piles under tension subjected to shear. Control monolithic concrete piles, and two multi joint piles with 750 and 1,500 N cable tension were tested to displacements up to 50 mm. Strain controlled loading was used in the horizontal direction. The piles were loaded from the pile head and both active and passive loads were applied. The test setup is presented in Fig. 5, *a*. The large size and large displacement direct shear apparatus are capable of applying strain-controlled tests with a linear actuator and a cyclic stress application unit composed of an antagonistic system with pneumatic muscles. The tension is applied to the pile with a pneumatic muscle placed in a frame placed on top of the upper shear box. Typical test results for active loads are presented in Fig. 5, *b*. The results shown are average values of three repetitions. The piles are placed in medium dense sand. The test results show that the multi friction joint piles can undergo much larger displacements when compared to that of monolithic pile. The multi friction joint pile with 1,500 N post tension reached 700 N lateral capacity at 65 mm



a *b*

Fig. 5. The components of the multiple purpose testing apparatus (*a*); model pile test results (*b*)

Рис. 5. Компоненты многоцелевого испытательного устройства (*a*); результаты испытаний образцов свай (*b*)

displacement (pile dimension 50 × 50 mm) which is larger than that of 675 N at 27 mm displacement for the monolithic control pile.

Multiple Friction Joint Piles [47–60]

The examples given till now included atomic structure alteration, fabric collapse and solutions provided for that. The geotechnical engineering approach is not limited to only those soil related issues but offers solutions to multidisciplinary areas of civil engineering and other engineering fields. Mechanics is a fundamental engineering field and it is well established. The mechanics background is a key to successful engineering design. The final contribution that will be presented extends to multidisciplinary engineering fields. The nightmare of engineers is the failure. If the loads, moments, displacements etc. exceed a threshold value the system fails. The inventive step in this last contribution is to use this phenomenon and do reverse engineering beginning with a completely failed system and rebuilt it to a unique functional element. The system is composed of alternating rigid blocks and flexible plates with a large central hole through which an anchor cable is passing to hold the blocks together by applying post tension. The friction on the interfaces with rigid blocks and flexible plates is controlled by the normal force applied by the adjustable post tension force. This summation of these friction forces build up the lateral resistance. This is a completely different approach when compared to that of continuous beams, columns we normally know. Although the continuous systems seem to be strong, they are prone to failure under large displacements and large loads which are likely for civil engineering structures prone to multiple natural disasters. The location of failure planes in continous structuersare not known. The torsional forces and buckling forces also complicate the problem further. The segmental system with many failure planes has the advantage of predetermined failure planes with predefined engineering properties. Exactly where the failure will occur is known. The calculations are very easy because friction is a well understood topic and its dependable. Under torsion each rigid block will simply rotate and torsion forces will not harm the system.

Definition of the problem: as a result of conventional pile manufacturing methods such as driving, pushing, Vibrex, screw pile,bored pile etc. production, the pile is rigid and cannot tolerate horizontal displacements. For this reason, even if its vertical capacity is sufficient, its cross-sections should be enlarged and the amount of reinforcement should be increased in order to tolerate the horizontal forces. This problem occurs especially in the pile cap foundation connection area. Large ground displacements emanate due to multiple disaster loads such as earthquakes, flash floods, slope failures, tornados etc. Due to the rigid structure of monoliithic piles, they transmit the incoming soil thrust directly to the structure. In additon to the negative effects of rigid behavior of monolithic piles, the construction of piles require special heavy construction equipment requiring high initial investment cost, operating cost, high reinforcement requirement and exhaust gas emissions, noise, mobilization costs and lack of easy availability in undeveloped regions. An affordable flexible foundation system is required that can be easly implemented using locally available materials and small construction equipment.

Innovative method: the developed pile system is inspired by the structure and working principles of the human spine. It consists of alternating rigid blocks and flexible plates with a large hole in the center through which an anchor cable is present to apply post tension to the block-plate interfaces. The function of the anchor wire here is to apply normal force to the concrete block interfaces which work as friction joints and to form a system by holding all the blocks together. The horizontal force does not act on the anchor wire until a horizontal displacement equal to the diameter of the hole in the block is reached (except for the component effect of the inclination angle due to pile displacement). At the concrete interfaces, flexible rubber plates help to flex both horizontally and vertically. The normal force acting on the concrete block interfaces is controlled by tensioning and unloading the anchor rope. This allows the pile to be formed with the desired stiffness and to change its stiffness as desired during its service life. The innovative aspect of this pile system is that its stiffness can be adjusted and thus it can be displaced in the lateral direction without breaking in orders of several pile diameter. Due to its modular structure, it can be produced with the desired shape, size and surface texture. Another innovative aspect is that it can be produced without the need

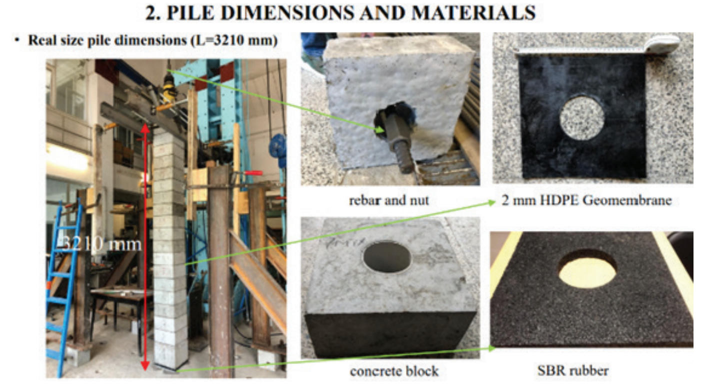


Fig. 6. The multiple friction joint pile components and prototype

Рис. 6. Составные элементы и опытный образец сваи с несколькими фрикционными соединениями

for a piling machine and other support units. A 3–4 m deep excavation pit to be created with a standard backhoe that can be rented anywhere in the world is sufficient for the placement of articulated piles. Concrete blocks can be produced on site or in the factory. The piles are tied together at any desired elevation by squezeing geosynthetics between the blocks. This is an inventive step in production of piles because it allows connection of piles at any elevation along the pile length. The inventive technique leads to construction of frames in trenches which a new terminology in geotechnical engineering emanates as "geoframes".

Advantages and Disadvantages: friction joints are a method used in superstructure to passively control horizontal loads. The interfaces between concrete blocks work on the same principle. Since these joints are formed between each block along the pile, no matter from which level the maximum horizontal force acts, it is met by frictional force in the same plane. In this way, no moment is transmitted.. The torsional moments that may occur along the pile are also compensated by the frictional force at the interface between the concrete blocks and the articulated system rotates against the torsional forces and no damage occurs. The fact that it can be constructed with standard backhoe available all over the world, the availabityanchor wire, anchor plates and tightening nuts are available off the shelf and that it can be manufactured with dywidag screws in places where anchorage tensioning equipment is not available provide great advantages in terms of application.

The disadvantage is that pile lengths are shorter than that of standard piles, which may limit the total settlement in deep alluvial soils. Although the diameter to length ratio is small, short but flexible piles can be obtained by unloading the anchor rope at the desired level. This unique feature can be used to create an ideal foundation system especially for compensating differential settlements. In loose soils, the excavation pit can be problematic. In such cases, piles can be placed by pushing or driving. Good placement of backfill around the pile shaft is important for the formation of pile capacity. Crushed stone type materials can be used as backfill. Flowable backfill with controllable elastic modulus works well with this system.

Soil types used: ın loose sands it can be placed by pushing or hammering, while in solid and hard clays it can be used by placing it in the excavated trench (Fig. 6, 7).

Akbaşak [48] obtained different pile modulus values by using continuous piles made of fire hoses (Fig. 8). The water pressure in the fire hoses provided the rigidity of the pile. This way it was possible to conduct 3 × 3 pile group tests with the target rigidity. The pile/soil modulus ratios were comparable to those studied for segmental

a *b* *c*

Fig. 7. The USPTO patent document cover (*a*); geogrid connection system (*b*); trench excavation for piles (*c*)

Рис. 7. Обложка патентного документа Бюро по патентам и товарным знакам США (*a*); система соединения георешеток (*b*); раскопка траншеи под сваи (*c*)

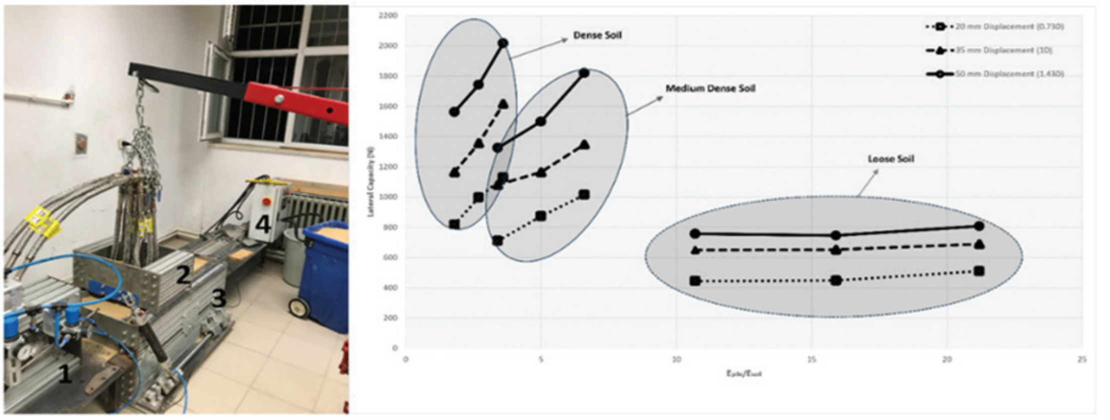
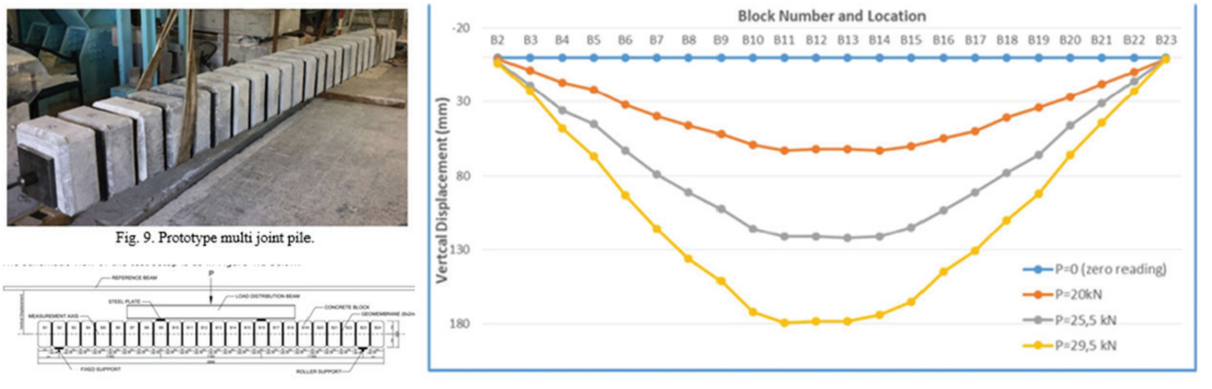


Fig. 8. Model pile test setup and the effect of pile soil modulus ratio on the horizontal capacity of pile groups

Рис. 8. Модельная установка для испытания свай и влияние соотношения модулей упругости грунта свай на предельную горизонтальную нагрузку на группы свай



a *b*

Fig. 9. Prototype multiple friction joint pile (*a*); four point beam test results (*b*)

Рис. 9. Опытный образец сваи с несколькими фрикционными соединениями (*a*); результаты испытания четырехопорной балки (*b*)

piles. The study revealed that at low pile soil modulus values the forces are transferred and carried by the soil resulting in larger horizontal pile capacities.

Dadasbilge [54] conducted four-point bending tests on real size multi joint pile. The block dimensions were 30 × 30 × 15 cm. The thickness of the HDPE flexible layer was 16 mm (8 × 2 mm layers for each interface). Twenty-four blocks were used to form the pile. A 30 mm anchor cable is used to connect the blocks. The cable was tensioned to 150 kN. The prototype pile is shown in Fig. 9. The 4-point flexure beam test set up is given in Fig. 9, *a*. The multijointed pile underwent 180 mm deflection corresponding to 29.5 kN at the midpoint without failure (Fig. 9, *b*).

CONCLUSION AND DISCUSSION

Geotechnical engineering deals with mechanics of three phase materials and uses multidisciplinary approach to provide practical and effective solutions to many civil engineering projects. The background acquired by geotechnical engineers in micro structure, micro fabric and micro mechanics help them to develop many creative ideas. Innovation and invention require newly produced ideas rather than using acquired knowledge or reproduced information. The creative thinking led to construction of several historical earthworks in Anatolia which have survived more than three thousand years. The magnificence of the structures that were built those times confirms their creativity. The creative approach is lost due to problems related to education. Without learning fundamentals of mechanics and materials, specialization created specialists which know only one subject but unaware of the big picture. Use of commercial software for design completely created a group of engineers which cannot think any more. Although artificial intelligence is an impressive tool for the well educated engineer, it will cause disasterous results in the hands of ready made solution seekers. Six innovative applications developed at Bogazici University demonstrate that with a creative approach, problems may be solved with a different perspective. The main goal of all the techniques developed is their simplicity and ease of implement ability all over the world with environmentally safe, economically feasible, sustainable and resilient solutions. When the problem is related to; the atomic structure causing a loss in pile shaft capacity, or increasing the hydraulic conductivity of clay liner; to microfabric involving the collapse behavior of silt sized materials, creative thinking produces innovative solutions. For quantification of innovative solutions there is a need to develop a universal, affordable, multiple purpose testing equipment which can be locally produced all over the world. The developed testing equipment presented may be a good candidate for further improvement. The creative thinking also leads to development of more universal approaches like using reverse engineering to assemble a pile from many existing failure planes which are held together with a post tension cable. The flexible behavior of the multi friction joint pile foundation system will completely change the definition of classical foundation definition. Althoug this technique is developed for geotechnical applications it has a great potential in structural engineering applications also. The main objecitve of providing affordable, easily implementable all over the world with local materials and technologies is satisfied.

REFERENCES / СПИСОК ИСТОЧНИКОВ

1. Ata A., O'Neill M.W., Baykal G., Kalinski M., Stokoe K. Exploratory Study of Lime-Slurry Conditioning for Drilled Shafts. *National Science Foundation Report No: CMS-9615020.* Washington DC, 1998.
2. Ata A., O'Neill M.W., Baykal G. Enhancement of Side Resistance in Bored Piles with Lime. *Proceedings of the Fifteenth Conference on Soil Mechanics and Geotechnical Engineering.* 2001; 2:839-842.
3. Baykal G., Sahtiyanci M., Ata A., O'Neill M.W. Improvement of Bored Pile-Soil Interface by Lime Stabilization. *Seventh National Congress on Soil Mechanics and Foundation Engineering.* 1998.
4. Baykal G., Metehan T. The Effect of Lime Treatment on the Shear Strength Parameters of the Clay-Concrete Interface. *81th TRB Annual Meeting.* Washington DC, 2002.
5. Baykal G. Patent/utility model. *Rubber-Soil Impermeable Liner.* (Examiner: Austrian Patent Office No: TR 182/95. Grantee: Turkish Patent Office, No: 92/0665). 1995.
6. Baykal G. Permeability of Rubber Soil Liners under Confinement. *ASCE Special Technical Publication.* 1995; 46:718-731.
7. Baykal G., Yesiller N., Koprulu K. Rubber-Clay Liners against Petroleum based Contaminants. *Environmental Geotechnology.* Balkema, Rotterdam, 1992; 477-481.
8. Baykal. G., Köprülü K. Rubber Added Fly Ash Base and Subbase in Highway Construction. *10th Fly Ash Utilization Symposium.* 1993.
9. Baykal G., Koprulu K. Rubber Added Fly Ash for Underground Petroleum Tanks. *ACI Special Publication.* 1995; 153:549-560.
10. Baykal G., Kavak A., Alpatli M. *Rubber-Kaolinite and Rubber-Bentonite Liners.* Balkema, Rotterdam, 1995; 399-404.
11. Baykal G., Alpatli M. *Permeability of Rubber-Soil Liners Under Confinement.* ASCE, 2000; 1:718-731.
12. Baykal G., Ozkul Z. The Effect of Stress on the Hydraulic Conductivity of Rubber Soil Liners Permeated with Gasoline. *Proceedings of the Fifteenth Conference on Soil Mechanics and Geotechnical Engineering.* 2001; 3:1955-1958.
13. Baykal G., Yesiller N., Köprülü K. *Rubber-Clay Liners against Petroleum based Contaminants.* Balkema Publishers, Roterdam, 1992.
14. Edinçliler A., Baykal G., Dengili K. Determination of Static and Dynamic Behavior of Recycled Materials for Highways. *Resources, Conservation and Recycling.* 2004; 42.
15. Edinçliler A., Baykal G., Saygili A. Influence of Different Processing Techniques on the Mechanical Properties of Used Tires in Embankment Construction. *Waste Management.* 2010; 30(6):1073-1080.
16. Ozkul Z.H., Baykal G. Shear Behavior of Compacted Fibre-Clay Composite in Drained and Undrained Loading. *ASCE, Journal of Geotechnical and Geoenvironmental Engineering.* 2007; 133:767-781.
17. Ozkul Z.H., Baykal G. Shear Behavior of Clay with Rubber Fibre Inclusions. *Geosynthetics International.* 2006; 13(5).
18. Arslan H., Baykal G. Analyzing the Crushing of Granular Materials by Sound Analysis Technique. *Journal of Testing and Evaluation.* 2006; 34(6):464-470.
19. Arslan H., Baykal G. Utilization of Fly Ash as Engineering Pellet Aggregates. *Environmental Geology.* 2006; 50:761-770.
20. Arslan H., Baykal G., Sture S. Analysis of the Influence of Crushing on the Behavior of Granular Materials under Shear. *Granular Matter.* 2009; 11:87-97.
21. Danyıldız E., Baykal G. Use of Manufactured Pellet Aggregates to Study the Effect of Aggregate Crushing on Strength and Deformation Behavior at the Concrete-Soil Interface. *Characterization and Behavior of Interfaces.* 2008; 139-147.
22. Baykal G., Döven A.G. Utilization of Fly Ash by Pelletization Process; Theory Application Areas and Research Results. *Resources Conservation and Recycling Journal.* 2000; 30:59-77.
23. Baykal G., Danyildiz E. Use of Manufactured Pellet Aggregates to Study the Effect of Aggregate Crushing on Strength and Deformation Behavior at the Con-

crete-Soil Interface. *Transportation Research Board 89 th Annual Meeting.* Washington, USA, 2010.

24. Baykal G., Erdurak M.C. Artificial Sand Production for Geotechnical Uses. *Proceedings of Advances in Ground Technology and Geo Information IS-AGTG.* Singapore, 2011.

25. Baykal G. Pelletizing powder wastes for geotechnical applications; pelletize-dispose-utilize (PDU) strategy. *International Symposium on Testing and Specification of Recycled Materials for Sustainable Geotechnical Construction.* Baltimore, USA, 2011.

26. Baykal G. Mechanics of Manufactured Soil Using Powder Wastes. *Proceedings of 16th International Conference of Soil Mechanics and Geotechnical Engineering.* Paris, 2013.

27. Baykal G. Three techiques for the study of soil structure interface properties; 3D roughness parameter; contact stress mapping; artificially manufactured sand. *Proceedings of Soil Structure Interaction; Underground Structures and Retaining Walls; ISSMGE TC 207 International Conference in Geotechnical Engineering.* St. Petersburg, 2015; 119.

28. Takmaz U., Baykal G. *Evaluation of dynamic properties of artificial sands produced from fly ash.* ZMGM16. Erzurum, 2016.

29. Baykal G. Strength Improvement of Fly Ash Using Ice. *11th International Symposium on Coal Ash Use and Management.* American Coal Association and Energy Production Research Institute, Orlando, 1995; 67-71.

30. Baykal G. Compacted Fly Ash-Ice for Low Cost Housing Projects. *XXIV IAHS World Housing Congress.* Ankara, 1996; 644-651.

31. Baykal G., Mehmetoglu D. Utilization of Fly Ash as Highway Safety Barriers. *Twelfth International Symposium on Management and Use of Coal Combustion Byproducts.* Orlando, 1997.

32. Baykal G., Edincliler A., Saygılı A. Highway Embankment Construction Using Fly Ash in Cold Regions. *Resources, Conservation and Recycling.* 2004; 42(3):209-222.

33. Baykal G., Saygili A. A New Technique to Reduce the Radioactivity of Fly Ash Utilized in The Construction Industry. *Fuel.* 2011; 90:1612-1617.

34. Baykal G., Saygili A. *A New Technique to Improve Freeze Thaw Durability of Fly Ash. Fuel.* 2012; 102:221-226.

35. Baykal G. Compaction of Pozzolanic Material Using Snow to Solve Permafrost Thawing Problems in Highway and Railway Embankment Construction. *The First International Symposium on Transportation Soil Engineering in Cold Regions.* Xining, China, 2013.

36. Baykal G. Use of Fly Ash with no Water Consumption for Cold Regions Transportation Infrastructure. *Sciences in Cold and Arid Regions Journal.* 2015.

37. Saygili A., Baykal G. A new method for improving the thermal insulation properties of fly ash. *Energy and Buildings.* 2011; 3236-3242.

38. Akkol O., Baykal G. A New Test Device and Method: Geotextile-Soil Interface Cylindrical Test (GICT). *Proceedings of the Fifteenth Conference on Soil Mechanics and Geotechnical Engineering.* 2001; 2:1547-1550.

39. Baykal G., Dadasbilge O. Experimental Investigation of Pull-Out Resistance of Uniaxial Geogrids. *Proceedings of the 4th Regional Conference on Geosynthetics in Shanghai.* 2008; 174-178.

40. Baykal G. Pressure Mapping System for Geosynthetic Interfaces. *IGS World conference.* Berlin, 2014.

41. Baykal G. Interface Interaction. *XVII ECSMGE Conference.* Edinburg, 2015.

42. Baykal G. Implementation of Pneumatic Muscles in Geotechnical Laboratory Equipment Deve-= lopment. *4th International Conference on New Developments in Soil Mechanics and Geotechnical Engineering.* Near East University, Nicosia, 2016.

43. Baykal G. *Contact Stress Mapping in Geotechnical 4th International Conference on New Developments in Soil Mechanics and Geotechnical Engineering.* Near East University, Nicosia, 2016.

44. Baykal G. Large Displacement, Constant Contact Area Geosynthetic-Soil Interface Direct Shear Test Device. *6th European Geosynthetics Congress.* Ljubljana, 2016.

45. Baykal G., Keklik A., Elmas B. The Interface Behavior of Smoth and Textured Geomembrane at Low Confinement and Large Displacement. *7th National Geosynthetics Conference.* Istanbul, 2017.

46. Baykal G. Strain and Stress Controlled Geosynthetic Interface Testing. *11th International Conference on Geosynthetics.* Seoul, 2018.

47. Yasser I.O.Y. *An Experimental Study on the Behavior of Segmental Pile with Variable Stifness : PhD Thesis.* Boğaziçi University, Istanbul, 2013.

48. Akbaşak S. *A Study on Pile Group with Adjustable Rigidity Subjected to Large Horizontal Displacement : M.Sc. Thesis.* Boğaziçi University.

49. Baykal G. USPTO Patent, Multiple Friction Joint Pile System. US 11629473 B2. 2023.

50. Baykal G. Development of Soil-Structure Interface Testing System Using Pneumatic Muscles. *BAP 5580 Project.* Boğaziçi University, Istanbul, 2015

51. Baykal G. Development of Segmental Pile. *BAP D6389 Project.* Boğaziçi University, Istanbul, 2015.

52. Baykal G. *Large Displacement-Constant Contact Area Geosynthetic Soil Interface Direct Shear Test Device. Eurogeo6, European Geosynthetics Conference.* Ljubljana, 2016.

53. Baykal G. The Behavior of Segmental Piles with Adjustable Rigidity Subjected to Large Displacements. *BAP 13401 Project.* Bogazici University, 2019.

54. Dadaşbilge O. *Unpublished Thesis Progress Report.* Bogazici University, 2018.

55. Keklik A. *An Experimental Study on the Behavior of Segmental Model Piles Under Static Lateral Loading : M.Sc. Thesis.* Boğaziçi University, 2020.

56. Ozturk B. *Implementation of Stress Mapping Techniques in Geotechnical Applications : M.Sc. Thesis.* Boğaziçi University, 2020.

57. Saidy M.F. *A Study on the Multiple Friction Joint Tension Piles Subjected to Large Horizontal Displacements : M.Sc. Thesis.* Boğaziçi University, 2021.

58. Sengez M. *Lateral Capacity of Segmental Model Piles Under Cyclic Loading : M.Sc. Thesis.* Boğaziçi University, 2019.

59. Michalko M. *Cracking Creativity.* Ten Speed Press, Berkeley, California, 2001.

60. Baykal G. Are Accrediaton Requirements Satisfactory for Civil Engineering Education? *Chamber of Civil Engineers IMO.* Muğla, 2014.

Received August 28, 2024.
Adopted in revised form on September 20, 2024.
Approved for publication on September 25, 2024.

Bionotes: **Gökhan Baykal** — **Bogazici University**; 34342, Bebek, Istanbul, Türkiye; baykal@bogazici.edu.tr.

Поступила в редакцию 28 августа 2024 г.
Принята в доработанном виде 20 сентября 2024 г.
Одобрена для публикации 25 сентября 2024 г.

Об авторе: **Гёхан Байкал** — **Университет Богазичи**; 34342, Бебек, г. Стамбул, Турция; baykal@bogazici.edu.tr.