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Contribution to the knowledge of early geotechnics during the twentieth century: Arthur Casagrande

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Abstract. Arthur Casagrande (1902–1981) is one of the main people responsible for the geotechnics that we know today. Born in Haidenschaft, now Slovenia, he went to the United States in 1926 to participate in major civil engineering projects: he graduated in 1924 from the Technische Hochschule in Vienna, Austria. On this visit to the USA he met Karl Terzaghi (1883–1963), the father of soil mechanics and geotechnology, who taught him the basic concepts of this discipline to which Casagrande dedicated the rest of his life.

In his early years of work with Terzaghi, Casagrande focused on research studies, such as the development on the limits of Atterberg published in 1932, and the development of equipment for soil trials, such as the Casagrande spoon also developed in 1932. Casagrande not only dedicated himself to research in his early years, but he also carried out studies throughout his professional career, such as those carried out on liquefaction, which he began in 1937 and continued throughout his life.

Casagrande not only made important contributions in the field of geotechnology, but also lectured at Harvard University, which he joined in 1932. He also consulted and was involved in several projects for the Army Corps of Engineers of the United States. In addition, Casagrande made an important contribution to the 1st International Conference of Soil Mechanics and Foundations Engineering that took place at Harvard University in 1936.

The aim of this paper is to analyze, through the biography of Casagrande, his contribution to the field of geotechnics, based on his research, teaching, and consulting work. Moreover, Casagrande influenced other important people in the field, such as Terzaghi, Peck, and even the work with his brother Leo, and, of course, the influence of these people on Casagrande's team.

1 Biography

Arthur Casagrande (Haidenschaft[1], 28 August 1902; Boston, Massachusetts, 6 September 1981), born in Austria and a nationalized American, was the eldest of the three children of the marriage between Angelo August Casagrande and Anna Nussbaum. Arthur spent his first school year in Linz (Austria); later the family moved to Trieste and for a year he was educated by his mother, probably because of family finances, but completed this stage of his studies at the German Grammar School in Trieste.

Arthur Casagrande's father served as a cavalry officer in the Austrian army during World War I, but Angelo Casagrande was taken as a prisoner of war in Russia. Due to the capture of his father during the war, from the province of Trieste where his family lived, which became part of Italy, Arthur, along with his mother, his brother Leo[2], and his sister Alix, moved to live in Vienna in the house of his uncle, Guido Casagrande.

When Casagrande was ready to enter high school, he chose to enter the Realschule[3], where he could be trained for the

[1]Haidenschaft, currently Slovenia, a town near Trieste, a cultural center in the German-speaking part of the former Austrian empire.

[2]Leo Casagrande (Haidenschaft, Austria, today Slovenia, 17 September 1903; Cambridge, Massachusetts, 25 October 1990), civil engineer, specialized in structures at the Technical University of Vienna and received a doctorate in 1933 from the same university.

[3]At that time, in Austria, there were three possible options to study for 10 years: the High Academic Way, called the Humanis-

Technical University. This decision was influenced mainly by his maternal family, many of whom were mechanical engineers and chemical engineers.

Casagrande studied engineering at the Technische Hochschule in Vienna (Austria), where he obtained a degree in civil engineering in 1924. During his time as a student Casagrande was an assistant to Professor Schaffernak[4] in the hydraulics laboratory, and after completing his studies he remained an additional year as a full-time assistant.

Years after the war was over, Russia freed the prisoners of war, and Angelo Casagrande returned to his family from Siberia in 1922. The health problems that Angelo Casagrande had since returning from Russia resulted in his death[5] in 1924 (Goodman, 1999). This was the same year in which Arthur graduated as a civil engineer, thus leaving Arthur with the responsibility of maintaining the family. Since an assistant's salary was very low, Casagrande had to supplement his income by tutoring high school students. This was a difficult time for the Casagrande family. By this time, after World War I, the Austro-Hungarian Empire had been dissolved. Austria had shrunk to around 40 % of the size of the empire. Although Casagrande had no political motivation, it was a time of great uncertainty.

All these conditions forced Arthur Casagrande to consider the option of going to the United States against the wishes of the people closest to him, especially his mother and Fitz Schaffernak; none of them could understand why he wanted to leave.

2 From traveling to the USA up to soil mechanics

2.1 Leaving for the United States

Casagrande's enthusiasm for participating in major civil engineering projects, and for providing financial support to his family, mainly led to his departure to the United States, where he arrived on 26 April 1926. At the age of 24 in the USA, he had little money and was without work, but with confidence in his training and skills.

In the United States, Casagrande spent his first few days at a YMCA (Young Men's Christian Association) hostel in New York, although on the tenth day in the USA he was employed as a draftsman at Carnegie Steel, near Newark, New Jersey. As soon as he had the opportunity, Casagrande wrote to Charles M. Spofford[6], director of the department of civil engineering at MIT (Massachusetts Institute of Technology), describing his experience in the hydraulic laboratory in Vienna. Professor Spofford quickly replied and invited him to go to MIT for an interview.

2.2 First works with Karl Terzaghi

It was on this trip to MIT in May 1926 that Casagrande met his "countryman" Karl Terzaghi[7], a pioneer in soil mechanics and geotechnical engineering, who immediately offered Casagrande the opportunity to work as his personal assistant during the summer of 1926 in Washington.

At the end of the summer Casagrande returned to his work at Carnegie Steel, but in December of that same year Terzaghi offered Casagrande a position as an assistant researcher assigned to MIT, through a cooperation agreement between the United States Bureau of Public Roads (BPR) and MIT (Hirschfeld and Poulos, 1974). The cooperation agreement was necessary because the public highway office, being a state agency, required its workers to be American citizens.

From this position of privilege at MIT, Casagrande learned the basic notions of soil mechanics, while attending the course lectures by Terzaghi.

From his collaboration with Terzaghi, Casagrande developed his own "search and do" style quickly that was very useful throughout his life. An example of this is the following story from his first day of work: Terzaghi gave Casagrande handwritten notes to be typed. Casagrande replied that he did not have a typewriter, to which Terzaghi said he should get one. When Casagrande quietly told him that he did not know how to type, Terzaghi ordered him to learn, and he did so (Goodman, 1999).

In 1929, Terzaghi accepted a post at the Vienna Technische Hochschule, the university where Casagrande had obtained his civil engineering degree in 1924. Terzaghi suggested to Casagrande that he should apply for a half-year of leave and accompany him to Vienna to organize a soil mechanics laboratory (Fig. 1) and help him train his new collaborators in Vienna. Arthur Casagrande began his work in Vienna under instructions from Terzaghi in early October 1929.

Taking advantage of the trip to the Technische Hochschule, Casagrande toured all the soil mechanics laboratories in Europe, after which he returned to the United States in 1930 with detailed knowledge of the development

tisches Gymnasium, which taught from classical literature in Latin and Greek; the Middle Academic Way, called the Realgymnasium, with Latin but without Greek; and the Practical Way, called the Realschule, directed towards the military life and engineering.

[4]Fitz Schaffernak, Professor of Hydraulic Engineering I at the Technical University of Vienna from 1918.

[5]According to the statements of Carla María Casagrande, the widow of Leo Casagrande, Arthur and Leo's father committed suicide because of the depression that stemmed from his internment in a concentration camp for prisoners of war in Siberia.

[6]Charles Milton Spofford (Georgetown, Massachusetts, 1871; Newton Center, Massachusetts, 2 July 1963). Civil engineer who graduated from MIT, where he was head of the civil engineering department from 1911 to 1933 and dean of the engineering faculty from 1925 to 1927.

[7]Karl Anton von Terzaghi Edler von Pontenuovo (Prague, Czech Republic, 2 October 1883; Winchester, Massachusetts, 25 October 1963). Graduated with honors in technical engineering from the Technical University of Graz. He is considered the father of soil mechanics.

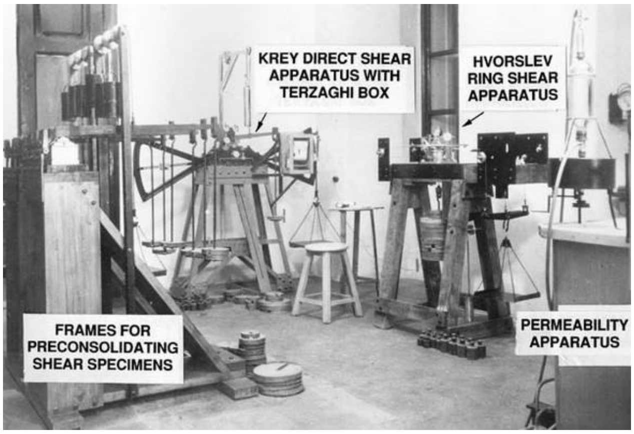

Figure 1. Soil mechanics laboratory installed by Arthur Casagrande and Karl Terzaghi at the University of Vienna. From left to right, equipment to pre-consolidate samples for the cutting test, direct cutting test equipment designed by Terzaghi, direct cutting test equipment designed by Horsley, and permeability measuring equipment.

of soil mechanics in Europe. This trip to Europe reinforced Casagrande's intention to remain in the United States, which was confirmed with his nationalization as an American citizen on 29 December 1931, at the age of 29 years (Hirschfeld and Poulos, 1974).

When Terzaghi and Casagrande began working together, they forged a relationship between them that they maintained and that conditioned them both greatly over the years, mainly in their professional careers. Terzaghi considered Casagrande to be an indefatigable and brilliant worker of great quality, although he always considered him a shy person, obstinately silent with other people, not to mention that he was having difficulties adapting to the American way of life. Arthur himself felt that his self-confidence increased with his closeness to Terzaghi and was always very grateful.

An example of this is the words Casagrande, before returning to Europe to install the laboratory at the Technische Hochschule in Vienna, told Terzaghi: "what I am and what I may become, I owe it to you" (Goodman, 1999).

2.3 First articles, essays, and research

Casagrande collaborated in numerous research projects with Terzaghi, many of them aimed at improving equipment and techniques for soil testing.

In 1927 Terzaghi found that the test to obtain the liquid limit of clays, as proposed by Atterberg[8], did not guarantee the same result if carried out by different operators, and he therefore asked Casagrande to develop a team to eliminate the errors of the test manual (Casagrande, 1958).

[8]Albert Mauritz Atterberg (Hernösand, Sweden, 19 March 1846; 4 April 1916). Graduated in chemistry from Uppsala University in 1871 and attained a doctorate in 1872 from the same university. From 1877 he was the director of the Agricultural Research Station in Kalmar, Sweden (Blackall, 1952).

Figure 2. Casagrande bowl (cup), 1942 model.

The liquid limit (LL) is conceptually defined as the water content at which the behavior of a clayey soil changes from plastic to liquid. However, the transition from plastic to liquid behavior is gradual over a range of water contents, and the shear strength of the soil is not actually zero at the liquid limit. The precise definition of the liquid limit is based on standard test procedures developed by Casagrande described below.

In 1932 and after 5 years of multiple tests, Casagrande finished the design of the instrument that today is known by the name of the Casagrande cup (Fig. 2), which is still used today to determine the liquid limit of clays.

The Casagrande cup consists of a spherical cap fixed at a point on its edge to a device that uses a crank to activate a cam that raises the cap and then lets it fall, always from the same height, producing a controlled shock against its base. Soil is placed in the metal cup portion of the device and a groove is made down its center with a standardized tool of 2 mm (0.079 in) width. The cup is repeatedly dropped 10 mm onto a hard rubber base at a rate of 120 blows per minute, during which the groove closes gradually because of the impact. The number of blows for the groove to close is recorded. The moisture content at which it takes 25 drops of the cup to cause the groove to close over a distance of 12.7 mm (0.50 in) is defined as the liquid limit. The test is normally run at several moisture contents, and the moisture content which requires 25 blows to close the groove is interpolated from the test results. The liquid limit test is defined by ASTM standard test method D 4318.

In addition to the cup, Casagrande also designed numerous pieces of equipment for other tests, such as the hydrometer test, the horizontal capillary test, the consolidation apparatus, and the equipment for the direct cutting test. Apart from

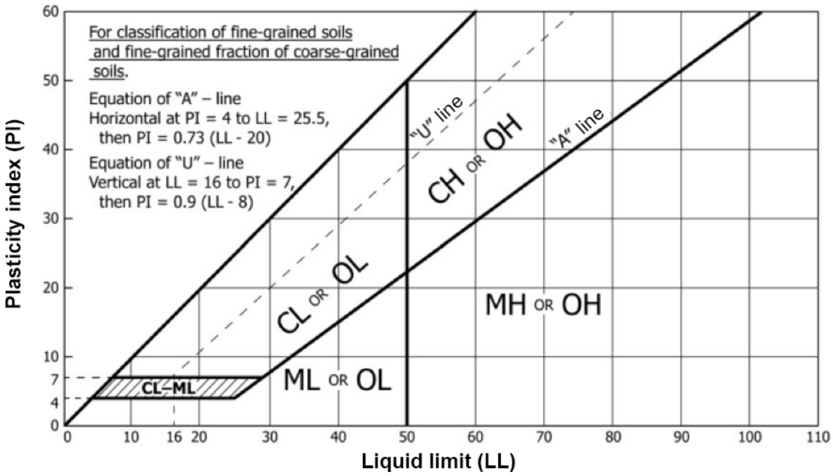

Figure 3. Plasticity chart. CL: lean clay. ML: silt. CH: fat clay. MH: elastic silt. CL-ML: silty clay.

the cup (sometimes called the spoon or the bowl), it is worth mentioning that during the 1930s and in 1932 Casagrande built a triaxial compression cell to measure soil resistance. To do this, Casagrande developed the box of his direct cut test apparatus in which, for the first time, he studied the volume changes that a sample undergoes during the direct cut, which led him to realize that the interstitial pressures are induced during the undrained cut. At the same time, still linked to MIT, Casagrande did the first test in unaltered soil samples that led him to develop his ideas on the pre-consolidation and over-consolidation pressures, presented shortly after 1932. The procedure to identify the pre-consolidation pressure in an over-consolidated soil is due to Casagrande, and is still used today.

Among the research projects Casagrande conducted and carried out field investigations on frost action, for a joint project between the Public Roads Bureau (BPR) and the New Hampshire State Highway Department (New Hampshire State Highway Department). This project led Casagrande to establish a criterion on the susceptibility of soils to frost, a criterion that has been adopted by motorway designers from all over the world.

Also, in 1932 Arthur Casagrande published his celebrated article "Investigation of the boundaries of Atterberg in soils". Regarding his work on the boundaries of Atterberg, it is accepted (by authors in general and by the geotechnical community) that the so-called "Line A" in the plasticity chart is due to Arthur Casagrande (Fig. 3).

The Atterberg limits are a basic measure of the critical water contents of a fine-grained soil: its shrinkage limit (SL), plastic limit (PL), and liquid limit (LL). Depending on its water content, a soil may appear in one of four states: solid, semi-solid, plastic, and liquid. In each state, the consistency and behavior of a soil are different and consequently so are its engineering properties. The plasticity index (PI) is a measure of the plasticity of a soil. The plasticity index is the size of the range of water contents where the soil exhibits plastic properties. The PI is the difference between the liquid limit and the plastic limit ($PI = LL - PL$). Soils with a high PI tend to be clay, those with a lower PI tend to be silt, and those with a PI of 0 (non-plastic) tend to have little or no silt or clay.

In addition to all the publications by Casagrande, he also wrote several important articles that were never published. Among them is an article on direct cutting tests, carried out jointly with his assistant S. G. Albert (Hirschfeld and Poulos, 1974), and another article on the difference between the remodeled clay and the unaltered clay, in which Casagrande points out the different mechanical characteristics between both clays. The latter is among the most significant contributions to the literature on soil mechanics (Casagrande, 1932).

3 Starting as professor and consultant

4 Harvard University

Sometime early in 1931, seeing no future in the position he held at the Public Highway Office (BPR), through his connection with MIT, Arthur Casagrande decided to leave and began to negotiate with universities on the western coast of the United States. During this time his good friends Harry Mohr and J. Stuart Crandall[9] convinced the dean of the Harvard School of Engineering, Harry Ellsworth Clifford[10], and Gordon McKay[11], that soil mechanics should be introduced there, and that Arthur Casagrande was the right person to do it.

Therefore, Casagrande was offered a half-day job that he delightedly accepted. The 1932–1933 academic year was the

[9]James Stuart Crandall, civil engineer, president of Crandall Drydock Engineers, Cambridge, Massachusetts, USA.

[10]Harry Ellsworth Clifford, Dean of the Graduate School of Engineering at Harvard University between 1930 and 1936

[11]Professor of Electrical Engineering since 1909.

beginning of a long relationship between Arthur Casagrande and the Graduate School of Engineering at Harvard University.

During that first academic year at Harvard University, Casagrande organized a two-quarter soil mechanics training program and a case-based foundation engineering training program. In addition, in 1933 he introduced a laboratory testing training program, which was probably the first in the world. The training program that Casagrande developed at Harvard University was of great use to most people working in soil mechanics and brought Harvard worldwide recognition as an exceptional center of teaching and research in the field of the mechanics of soils.

Even in his early years as a lecturer, Casagrande already showed signs of his great dedication as a lecturer and teacher. Casagrande was in the habit of selecting a student at the beginning of the academic year to check whether students had trouble following his lectures. Under the pretext of revising his notes, he secretly watched the student's face to see whether he had understood the previous part of the lesson. If he thought that the student had not understood it, Casagrande began again, trying in a different way, although Casagrande himself recognized that this system did not always work.

In 1933, Karl Terzaghi, while occupying the post of professor of Hydraulic Engineering II at the University of Vienna, realized that the career of Casagrande would be limited by not having a doctorate, so he encouraged him to submit himself to an oral exam. Casagrande was not very convinced by the lack of time to prepare himself and his apprehension of the exam itself, but Terzaghi managed to reassure him after informing him that he would be the president of the committee, and that his supervisor, Fitz Schaffernak, would also be at the exam and that he would commit himself to limiting his questions to matters relating to surface water flows, a matter Arthur knew well. The result was that in June of 1933 Arthur Casagrande became Doctor of Philosophy in Engineering with his thesis in two parts, "Investigation of the limits of Atterberg in soils" and "The hydrometric method", based on the articles he published during the years after arriving in the United States.

Shortly after obtaining the doctorate, in 1934 Casagrande was promoted to the post of Assistant Professor at Harvard University (Goodman, 1999). That same year Casagrande made an important revision of the program for the training of foundations of engineering, incorporating a course on leaks in soils in 1935.

4.1 Franklin Falls Dam

Casagrande's contribution to the Franklin Falls Dam (dam of loose materials 42 m high, built on the Merrimack River to prevent floods) was the first of many consulting jobs that he would do for the Corps of Engineers of the United States Army. A filtration problem at the Franklin Falls Dam (New Hampshire) led Capt. Stratton[12] of the Boston District Corps of Engineers to hire Casagrande as a consultant to investigate the critical foundation density of the dam.

The Franklin Falls Dam had the right abutment and the foundation of the dam on loose sand, of fine to medium granulometry. The analysis carried out by Casagrande showed serious leakage problems that could threaten the integrity of the dam. This led to the design of an upstream tapestry with a deep trench to intercept the leaks due to the danger of particle entrainment caused by the flow. Additionally, to avoid leaks in the sands on which the foundation was supported, these were densified using explosives. The proposed classification test for drainage ditch filters was carried out by G. E. Bertram[13] as part of a general program of filter studies supervised by Casagrande. The success at Franklin Falls Dam marked a milestone in the design and construction of loose material dams on permeable foundations.

4.2 The relationship between Harvard and the Water Experiment Station

From 1933 Spencer Buchanan[14] was the head of the Water Experiment Station (WES, Fig. 4)[15] Mechanics section. Buchanan was a student of Terzaghi at MIT and a colleague of Casagrande during his connection with MIT (Fatherree, 2006). Buchanan and Casagrande developed a fluid correspondence, which was the same between WES and Harvard.

An example of this correspondence is the incorporation of a direct cutting machine, according to the design and subsequent improvements expressly provided by Casagrande, at the new facilities of WES that they inaugurated in 1934 at Vicksburg (Mississippi). Over time, the relation between the WES and Harvard also resulted in a great relationship and collaboration between MIT and Harvard University.

Another result of this collaboration between Harvard University and the Waterways Experiment Station was in 1939,

[12]James H. Stratton (Connecticut 7 June 1898–Washington 16 March 1984). Graduated from West Point Military Academy in 1920 and graduated from the Rensselaer Polytechnic Institute in 1922. He eventually achieved the rank of Brigadier General of the Corps of Engineers in May 1944.

[13]Consulting engineer. He was head of soil mechanics of the engineering division in the office of the chief engineer of the army.

[14]Spencer J. Buchanan Sr. (Yoakum, Texas, 1904; Houston, Texas, 4 February 1982). Graduated in civil engineering in 1926 from the University of Texas. He did postgraduate studies at MIT. During the Second World War he served in the Army Corps of Engineers and participated in the Korean War as a consultant to the Air Force. He reached the rank of Brigadier General in the reserve. In 1946 he joined the University of Texas as Professor of Soil Mechanics and Foundation Engineering, a post he held until his retirement in 1969.

[15]The Water Experiment Station (WES) in Vicksburg (Mississippi) was inaugurated in 1930, and incorporated, from its origin, studies on soil. Later its name was changed to the Waterways Experiment Station.

Figure 4. Aerial view of the new WES facilities, 1936.

when Casagrande persuaded WES to sponsor a triaxial[16] research program, which was carried out between 1940 and 1944 by Harvard University and MIT, with Casagrande and Donald Taylor as representatives, respectively, of each institution. The results of this work were collected in seven progress reports written by Casagrande himself, and in a final report by Philip Rutledge. This is how they started a new era in the knowledge of soil resistance and the tests necessary for it.

5 First International Conference on Soil Mechanics and Foundations Engineering

In 1936 the University of Harvard invited Karl Terzaghi[17] to be a visiting professor during the spring semester, a suggestion proposed by Casagrande. In this way Casagrande succeeded in placing Harvard among the universities with the most advanced knowledge in soil mechanics; however, his intention was much bigger.

Casagrande had the initiative to promote an international congress that would gather the most knowledgeable people on soil mechanics at Harvard. Casagrande succeeded in making this initiative happen in the summer of 1936; initially he was reluctant to go ahead with this initiative, and even Terzaghi had some doubts given the early stage of this science of soil mechanics.

The organizing committee of the First International Congress of Soil Mechanics and Foundations Engineering, held at Pierce Hall at Harvard University, was chaired by Harry E. Clifford[18], which for him represented his last act of international relevance before his retirement. The secretary was Arthur Casagrande, Philip C. Rutledge, the Treasurer, and with the collaboration of John D. Watson[19]. Terzaghi accepted to give the main paper at the conference, a paper that attracted the attention of delegates representing of the 21 countries that attended the congress.

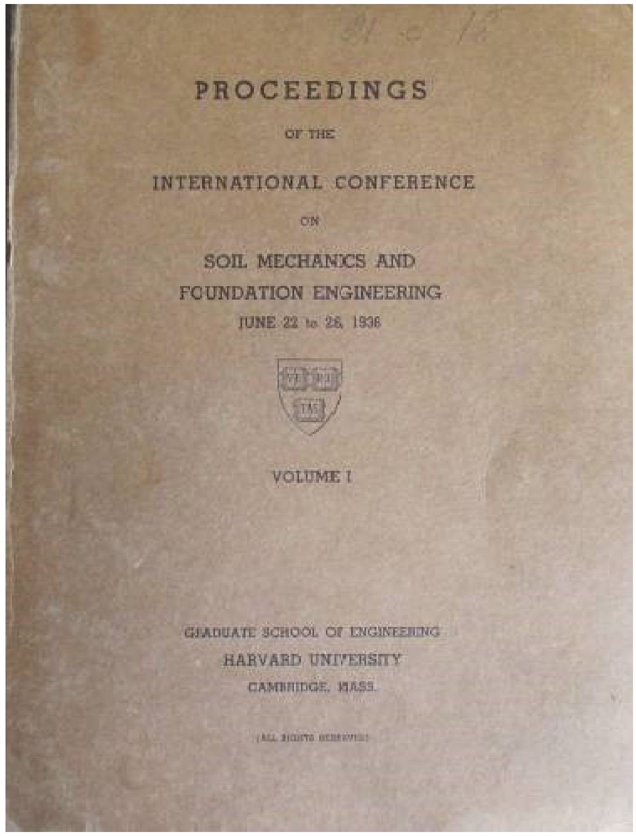

Figure 5. Detail of the cover of Volume I of the proceedings of the First International Conference on Soil Mechanics and Foundations Engineering, Harvard, 1936.

Among the attendees was a large representation of the US Army Corps of Engineers, one of the first organizations to realize the potential value of soil mechanics in their work with dam and levee construction (Peck, 1993).

Taking advantage of this occasion, the International Society of Soil Mechanics and Foundations Engineering was founded, with Karl Terzaghi and Daniel Moran[20] the first president and first vice-president, respectively. The success

[16]Shortly after the International Congress, the Corps of Engineers decided to consolidate its position in the investigation of soils, and by order of its Chief Engineer was ordered to establish at the WES a Research Center for Soil Mechanics.

[17]Terzaghi was in the USA from October 1929 to the summer of 1939, later returning to Europe.

[18]Dean of the Graduate School of Engineering at Harvard University (Casagrande et al., 1936).

[19]Assistant researcher at the Graduate School of Engineering at Harvard University (Casagrande et al., 1936).

[20]Daniel Edward Moran, mining engineer, graduated in 1884 from Columbia University. Consulting Engineer of Moran and Proctor, New York, member of the American delegation to the Harvard Congress.

of the congress helped to establish soil mechanics as a practice in engineering throughout the world.

At the end of the congress, Terzaghi acknowledged that he had incorrectly assessed the situation and appreciated that Casagrande's vision of organizing the congress had been the single most important step taken to bring soil mechanics to the attention of engineers. This acknowledgement by Terzaghi increased the international reputation of Casagrande (Goodman, 1999). As a token of gratitude, Terzaghi addressed the following words to Casagrande: "Our society owes a great debt to Arthur Casagrande for his conviction that it was the right time for the International Congress and for his enormous efforts to organize it" (Ishihara and Jamilokowski, 2011).

After the International Congress, Casagrande was able to resume his work in research. He continued with the development of the triaxial test, now universally used as a basic technique for the investigation of resistance and the characteristic volume change of soils. He also entered into the lifelong study of the phenomenon of liquefaction, or loss of resistance, of saturated soils without cohesion because of a collision or earthquake. Casagrande published an important work on this phenomenon in 1937 (Casagrande, 1937). He was also the first to use the word "liquefaction" in the literature of soil mechanics. Casagrande considered it adequate to describe the effects of the action of an earthquake or the cyclical load in the generation of interstitial pressures and deformations in sands, which is the modern concept of liquefaction.

6 Ralph Peck and Karl Terzaghi at Harvard University

6.1 Ralph Peck, the outstanding late student

In March 1938, an unknown Ralph Peck[21] wrote to Casagrande requesting to join the course of soil mechanics of Harvard University as soon as possible. Casagrande suggested that he wait until the following fall, to coincide with the beginning of the next academic year.

Due to Peck's insistence, Casagrande accepted his request to join his lectures as an observer and thus overcome administrative restrictions. Peck joined the lectures that same April, during the spring trimester of the 1937–1938 program taught by Arthur Casagrande at Harvard University (Hirschfeld and Poulos, 1974).

Once Peck joined the course, he succeeded in impressing Casagrande with his structural skills, hiring him as an assistant under Ralph E. Fadum[22] of the Laboratory of Soil Mechanics at Harvard University and as a field observer of Casagrande for his consulting work in Boston. Peck's attendance during the lectures by Casagrande marked his professional career, eventually becoming an essential scholar in the development of soil mechanics.

6.2 Terzaghi as Harvard professor

In 1938 Karl Terzaghi, who at this time temporarily resided in France, decided to return and settle definitively in the United States. For this reason, Terzaghi consulted with Arthur Casagrande regarding the possibility of finding him a part-time teaching position in the United States that would allow him to continue his consulting activity.

Casagrande took this request by Terzaghi very seriously and provided the necessary guarantees after persuading Dean Westergaard[23] to invite Terzaghi as visiting professor of Harvard University[24]. During the fall semester of 1938/39 Terzaghi taught geological engineering for the first time at the Graduate School of Engineering at Harvard. Sometime later, Terzaghi was promoted to the post of Professor of Civil Engineering Practice.

During the 9 long years of Terzaghi's absence from the United States, Arthur Casagrande had entirely developed a soil mechanics curriculum at Harvard University. Despite this, Terzaghi, with his strong personality, found it perfectly natural to regard himself as the master in a master–disciple relationship with Casagrande. To this situation it is necessary to add the underestimation by Terzaghi of all the academic responsibilities that did not include giving lectures, responsibilities that Casagrande often had to fulfill himself in addition to his own duties, with the corresponding additional time required to do this extra work. Moreover, Casagrande was effectively alone at the mechanics section due to Terzaghi's numerous days away. Many times, Terzaghi was at the University of Illinois collaborating with Ralph Peck, who was also a very close friend. Those who knew both Casagrande and Terzaghi appreciated that Casagrande felt a great respect and

[21]Ralph Brazelton Peck (23 June 1912, Winnipeg, Manitoba, Canada–18 February 2008, Albuquerque, New Mexico, United States) was a civil engineer from the Rensselaer Polytechnic Institute in 1934, and a doctor in 1937, also from the Rensselaer Polytechnic Institute, New York. Trained as a structural engineer, he returned to the university, in this case to Harvard University, to study soil mechanics, a subject in which he became a key expert in the discipline.

[22]Ralph Eigel Fadum (Pittsburgh, Pennsylvania, 19 July 1912; 7 December 2000) was a civil engineer who graduated in 1935 from the University of Illinois. He also obtained a master's degree in science from Harvard University and, later, a doctorate from the same university. He was assistant to Arthur Casagrande from 1935 to 1942 and an active collaborator of the United States Department of Defense.

[23]Harold Malcolm Westergaard (1888 Denmark) was appointed in May 1937 as the new Dean of the Graduate School of Engineering between 1937 and 1946 and Gordon McKay Professor of Civil Engineering in the vacant post left by Harry E. Clifford (News The Harvard Crimson, Harvard University, 11 May 1937).

[24]For the second time, after attending as guest professor in the spring semester of the year 1936.

loyalty towards Terzaghi; for this reason, he was frequently forced to endure with patience some of the demanding circumstances mentioned above.

In 1940, Harvard University granted Casagrande a fixed tenure with the category of "associate professor", and in November of that same year Casagrande married Erna Mass[25]. His first daughter, Vivien[26], was born almost 2 years later on 7 June 1942.

7 Collaborations with the Corps of Engineers of the United States Army

In addition to the previous collaboration on the Franklin Falls Dam that Casagrande performed with the Army Corps of Engineers, there were numerous collaborations over the years, both in consulting and research and teaching.

7.1 Fort Peck Dam

In September 1939, after the great landslide during the construction of the Fort Peck Dam, Arthur Casagrande was again called by the Army Corps of Engineers to join the council of consultants investigating the incident. His work on liquefaction, published 2 years earlier, and the probable role of liquefaction in the failure of the dam, made the expertise of Casagrande invaluable to the Corps of Engineers.

During the construction of the Fort Peck Dam in 1938, a weakening in the underlying "Bearpaw slates" layer resulted in increased stresses in the upper layer of sand on which the foundation was supported and in the deposits of sand upstream from the dam. Although not supported by the advisory board, Casagrande was convinced that the massive failure was a combination of shear and rupture in the bentonite layers within the "Bearpaw slates" layer and liquefaction of the sand above them. For this reason, Casagrande kept insisting on a new evaluation of the slip.

7.2 Collaboration in the California bearing ratio test adaptation

In addition to consulting, Casagrande was also involved in research processes, such as the Californian bearing ratio (CBR).

In 1940 the Nazis were invading France and threatened to invade England as well, so the United States decided to develop new, heavier planes. In the first test of the XB-19, the prototype of the first long-range bomber, it burst the taxiway and damaged the main takeoff runway of the Clover[27] airfield in California. This generated a "complex and urgent technical problem" (Fatherree, 2006). Army engineers realized that the main problem of pavement was concentrated in the failure of the bases and subbases of the ground, which were not able to withstand the applied load, which was about 160 000 pounds (72 575 kg). In addition, they considered it essential that the tracks be constructed in rigid pavement, but since the use of concrete during wartime was prohibitive because of the high cost, the use of asphalt pavements was considered a priority, thus requiring the base and subbase for greater pavement flexibility.

Thomas A. Middlebrooks[28] of the Office of the Chief Engineer of the Army contacted O. James Porter[29] of the Highway Division who had developed a simple, easy-to-use field test to measure the breaking strength of a base material and the subbase. Basically, the procedure consisted of forcing a 3 in square circular piston into the ground and measuring the resistance of the soil to penetration. California Highway engineers expressed the results of that test as the ratio of the bearing capacity obtained compared to the penetration resistance of a high load bearing reference material. This relationship was known as the "CBR" and provided a quantitative expression of soil resistance.

Since at that time the pavement thickness of aerodromes was obtained by a simple extrapolation of the highway designs, which proved to be an invalid method due to the great difference between applied loads, it was necessary to adapt the CBR to the construction of aerodromes, a process in which Casagrande participated.

In February 1942 Casagrande was summoned to a meeting at the Office of the Chief Engineer in Washington DC, with Middlebrooks, Porter, and the then[30] Lieutenant Colonel Stratton[31]. Under the recommendations of Casagrande, Porter, Middlebrooks and Casagrande himself, carried out independent and coordinated studies to establish conclusively the safest thickness of the base and subbase layers, while at the same time recommend a field program

[25] Erna Mass Casagrande (Germany, 5 September 1909; Belmont, Middlesex County, Massachusetts, 27 September 2009) emigrated to the United States shortly before the start of World War II. She died at 100 years of age.

[26] Vivien Casagrande graduated in psychology in 1964 from the University of Colorado and in 1973 as a doctor in physiological psychology from Duke University. She is currently a professor in the Department of Cell and Biological Development at the Vanderbilt University Medical Center (Casagrande, 2014).

[27] The Clover airfield in Santa Monica was the test base of the Douglas Aircraft Company.

[28] Thomas A. Middlebrooks, civil engineer. He was a student of Terzaghi at MIT. He died in 1955. Upon his death, the ASCE established the Thomas A. Middlebrooks Prize for articles on soil mechanics.

[29] Omer James Porter (Mt. Pleasant, Utah, 28 November 1901–December 1967) graduated in science in 1924 from the University of Alberta. Between 1927 and 1930 he developed the concept of the California bearing ratio (CBR).

[30] Lieutenant Colonel Stratton, who was previously the head of the Boston Engineers District, was the one who, as captain, first contacted Casagrande as a consultant for the leaks of the Franklin Falls Dam in 1936.

[31] Lieutenant Colonel Stratton was responsible for the Engineering Section.

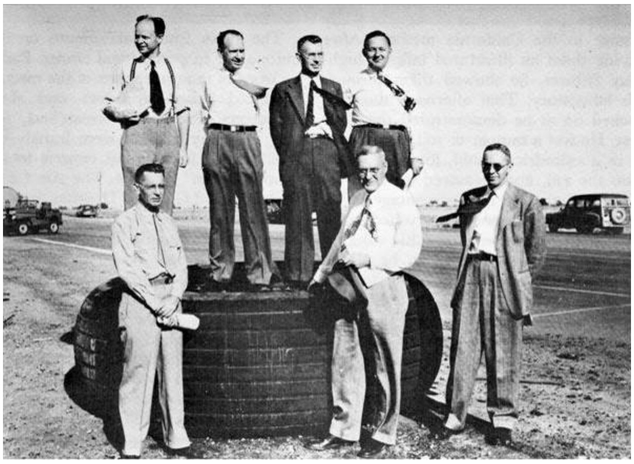

Figure 6. CBR meeting at Stockton, California, Test Track. Front row (left to right): Colonel Henry C. Wolfe, Harold M. Westergaard, and Philip C. Rutledge. In the second row, on the wheel of an XB-19 bomber, (from left to right), Arthur Casagrande, Thomas A. Middlebrooks, James L. Land, and O. James Porter.

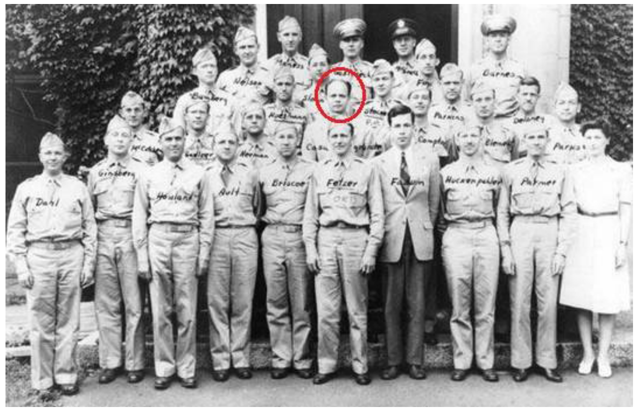

Figure 7. Casagrande (in the center with a red circle) with his students of the first course in the School of Soil Control of the American army, in 1942.

and laboratory tests of existing aerodromes before using their findings for new constructions. This resulted in the WES, at the end of 1942, a section dedicated exclusively to pavements to disseminate this new knowledge and applications of the CBR.

On the work carried out by Casagrande, Lieutenant Colonel Stratton[32] stated that "I would not have endorsed any concept unless I was reasonably certain of its foundations" (Fatherree, 2006), reflecting the requirement of the work done in the process of adaptation of the CBR to aerodromes.

7.3 Professor of the army

In 1942, Casagrande volunteered to the Chief of the Corps of Engineers to deliver a 6-week course in soil mechanics for army officers, focusing on aerodrome paving. The Army School of Soil Control accepted the offer of these courses, and on 3 July 1942, 24 lieutenants attended the Pierce Hall facility at Harvard.

The course began with an intensive review of the concepts of soil mechanics, a subject that was little known to most of the attending officers, whose knowledge base was mostly agricultural (Montès, 2011). At the end, the course developed by Casagrande was a success, which led to the Army Corps of Engineers of the United States requesting Casagrande to train their officers in soil mechanics. During the years 1942 and 1944, in the middle of World War II, Casagrande instructed about 400 officers in soil mechanics. In these intensive courses, Casagrande taught officers who later had the responsibility of building aerodromes, mainly in the Pacific campaign, during World War II.

Knowing the importance of the course and being aware of the difficult decisions that the officers will have to make without the help of a laboratory, Casagrande scheduled a two-hour field identification and soil classification session every Tuesday afternoon. This tutorial, which has never been satisfactorily repeated by anyone, consisted of visual and manual identification of a seemingly endless variety of soils from Harvard University labs.

Hour after hour and with great dedication, Casagrande sat amongst his students and with his hands examining the soils. He made cylinders from the soil and rolled them in the palms of his hands, tasted them, bit them, and rubbed them with his fingernails. He then estimated the resistance of the sample and concluded with a detailed description of its probable origin, permeability, potential problems, susceptibility to frost and estimated the limits of Atterberg, which his assistant invariably found that they were almost as accurate as those determined at the laboratory. Casagrande was able to develop in these students the ability to estimate the numerical values of physical properties by means of manual and visual examination, highlighting their validity for the construction of aerodromes and roads under different conditions. He showed how much can be deduced by "staining his hands" while criticizing engineers who accepted the results of sophisticated analysis without having performed the tests themselves and not knowing how the experience of analysts could alter the results of soil properties (Peck, 1984).

For all the courses given to the members of the army, Casagrande developed a system of classification of soils as supporting documentation, thus improving the existing classification of soils. Thus, in 1942, Casagrande, aged 40, designed the Airfield Classification (AC) which he later incorporated into his courses at Harvard University.

[32]The correspondence between Stratton and Casagrande relating to the sessions held in the Office of the Chief Engineer (OCE) are archived in the Casagrande Room, in the Casagrande Laboratory of the WES.

On 11 February of 1945 was born the second daughter of Casagrande, Sandra [33].

7.4 Panama Canal and Oahe Dam

In 1946 the Corps of Engineers of the Army initiated studies of the level of the sea in the Panama Canal. These studies were motivated after World War II, due to the great concern regarding the stability of the levees of the channel given the possibility of an atomic bomb explosion.

After the end of World War II, Casagrande was particularly busy with his teaching. The number of students taking his courses increased from 12 students when he started lecturing in 1932 to an average of 80–90 students per year after the war. Despite this and in the line of work of the investigations of the Panama Canal, Casagrande began the investigation on the resistance of the ground against dynamic efforts, with the results published in 1948 (Casagrande and Shannon, 1948). In later years he continued with similar investigations, also financed by the Corps of Engineers of the Army. The effect of the load time on the strain – deformation relationship was one of them.

Apart from the studies funded by the Army Corps of Engineers, the Corps also supervised large dams. After his collaboration on the study of the Fort Peck damn, Casagrande was involved in the monitoring of large dams on the Missouri River, the Oahe Dam. At this time soil mechanics was undergoing development in the understanding of soil mechanics and techniques to make this monitoring of dams possible.

8 Leo Casagrande

In 1948 Casagrande began working with his brother Leo, when he returned to the United States. Leo Casagrande was a civil engineer at the Vienna Technical University and, although he initially followed his brother Arthur to work with Terzaghi at MIT, he had returned to Austria. Like his brother, Leo participated in the First International Congress of Soil Mechanics and Foundations Engineering, held at Harvard, but as a member of the German delegation, as Dr. Engineer delegate of the "General-Inspektor[34] fuer das Deutsche Strassenwesen", Berlin (Hirschfeld and Poulos, 1974).

With the German occupation of Austria, Leo worked on the development of the German autobahns under the orders of General-Inspektor Frizt Todt. The German success in motorway development (Autobahn) was largely due to Leo Casagrande. Throughout World War II, Leo was on the side of the Germans and his brother Arthur on the Allied side. After the war, Leo was captured by the British and, after arriving in the UK, he spent 2 years working at the Building Research Station, where he continued his work on electro-osmosis. During this period, he had the opportunity to know, among others, Alec Skempton[35].

Figure 8. Arthur Casagrande (first left) on a visit to the Panama Canal, in 1969.

In those years Leo worked with his brother Arthur mainly on dam projects and, years later, both brothers formed a consultancy which they called Casagrande Consultants Inc.

9 Other consulting work

In addition to working with the Army Corps of Engineers, Casagrande's prestige as a consultant engineer and as a recognized professor opened the door to other consulting work beyond the Corps of Engineers.

[33]Sandra Casagrande graduated from Duke University Medical School in 1974.

[34]General-Inspektor was Fritz Todt, engineer responsible for the German motorway network. Todt became minister of arms and ammunition in the government of Adolf Hitler.

[35]Sir Alec Westley Skempton (Northampton, England, 1914; London, England, 2001) was an English civil engineer, internationally recognized as one of the founding fathers of soil mechanics.

9.1 Consultant in Canada

Such was the recognition that Casagrande had gained that his status extended to Canada. Therefore, Casagrande spent 50 years collaborating as a soil mechanic consultant on many of the major civil engineering projects throughout Canada. Some of these projects in Canada included the Mica Dam, the tallest dam in North America at 244 m high, the Manicouagan III Dam, 135 m high in concrete, and the Gardiner Dam, Canada's largest loose materials dam at 64 m high and 5000 m in coronation length in the southern Saskatchewan River, which is notable for the major problems associated with it during construction.

The foundation of the Gardiner Dam was built into the "Bearpaw slates" with a significant presence of bentonite like the "Pierre slates" in the Missouri River basin.

These foundation conditions presented unusual stability problems in the construction phase that required extensive instrumentation and major project modifications during construction. Casagrande participated in the construction of the Gardiner Dam as chairman of the council of consulting engineers, and in addition to providing advice and guidance throughout design and construction (during the years 1940–1968), he was directly involved in the phase of service after the construction, receiving monthly reports with the data of the instrumentation. Casagrande was only able to review and comment on these data when he could physically do so.

9.2 Embankment across the Great Salt Lake

In 1955 the Southern Pacific Company railway company decided to replace its wooden structures across the Great Salt Lake with an embankment. The Great Salt Lake is the largest lake in the USA outside the region of the great lakes. It is an endorheic lake, with a very high salinity. Casagrande's role in this project was, as he himself often expressed it, to "stretch the imagination to its elastic limit". This embankment was supported, in a great part of its length, by a layer of crystalline salt on a very soft clay. Despite much theoretical research and analysis, there were many failures in performing tests and in the prototype of the embankment. Casagrande thought that, apart from living organic material, many of those colloidal clays that had been found were the most complex materials that nature had made on Earth.

In his classic paper entitled "An unsolved problem of embankment stability on soft ground" Casagrande began by saying that "It is disheartening to conclude that we do not know, with any reasonable degree of precision, the magnitude of the principal force involved, the ground pressure acting on the embankment, nor the effective shear strength in the clay foundation" (Casagrande, 1960), thus highlighting the great difficulty of working with these types of materials.

However, Casagrande considered it reasonable to design and construct the structure with a safety factor practically equal to unity to obtain an adequate level of cost in construction, and that if the embankment was completed without a single failure, it was because of its oversize, even though this was not the philosophy applied to earth dams.

Figure 9. Casagrande, circa 1955.

In 1959, before the end of the project, a big break occurred. Typically, large-scale breakages were repaired slowly, but doing so at that time would have delayed the project by at least 6 months. Despite the objection of the other members of the council of consultants, Casagrande approved the quick fill in of this break with concrete, without stating the reasons for his decision. To the satisfaction of the owners and the astonishment of their associates, the solution worked.

10 Great recognition as professor

In addition to his research work, Arthur Casagrande maintained his relationship with Harvard University and in 1946 was promoted to the post of Gordon McKay Professor of Soil Mechanics and Foundations Engineering[36]. During the

[36]Gordon McKay (Pittsfield, Massachusetts, 1821; Newport, Rhode Island, 1903) was an engineer and entrepreneur who revolutionized the American footwear industry at the end of the nineteenth

2 decades after World War II, Casagrande continued with his active program of lectures and tutoring of several doctoral students. Throughout his career he was director of more than 20 doctoral theses at the University of Harvard and was professor of nearly 1400 students in the field of soil mechanics. Many of the most outstanding professors, researchers, and geotechnical engineers from around the world received valuable teaching from Arthur Casagrande.

10.1 Several anecdotes from his period as a lecturer

Few people have influenced the development of an engineering branch as much as Arthur Casagrande, thanks to his own teaching and to the teaching by those who were his students. Casagrande was an extraordinary teacher, always thoroughly prepared, without drama, and knowing every detail. His students noted his personal interest in their notes and his passion for teaching, and his genuine concern for their future and his good humor were the hallmarks of his personality, which is perfectly reflected in the following anecdotes and notes of interest about Casagrande himself.

- In 1960, Harvard University asked Casagrande to teach a geological engineering course, including a part of the syllabus that dealt with the study of leaks. In the 1960 course there were 13 students already graduated, but not all of them had English as their first language, which certainly made it difficult for the students to follow the lectures. On one occasion Casagrande[37] arrived at the classroom to give his next lecture of the course and said the following: "*You are 13 in this class. Since after my previous lesson 6 of you have come to ask me questions about the lesson, I do not think I gave the lesson very well. I propose repeating it today*". And so, he did. Such humility is a mark of greatness.

- In 1962 Arthur conceived the idea of starting a new program at Harvard University to upgrade the faculty and practicing engineers in all aspects of soil mechanics and foundation engineering. This intensive one-semester program included soil mechanics, laboratory testing, filtration, and foundation engineering. The result of this project was an important contribution to the development of the profession and of the professionals who attended the course during the 6 years that Casagrande spent developing and carrying it out. Harvey Brooks[38], then dean of the Division of Engineering and Applied Physics at Harvard University, recalls that Casagrande gave him his first introduction to that subtle blend of practical experience, pure common sense, and deep theoretical visions that represented the tradition of soil mechanics such as Casagrande and Terzaghi developed at Harvard University.

Casagrande became friends with his students and that friendship lasted through the years. In turn, the students always showed great respect for Arthur Casagrande thanks to his great attitude in teaching. An example of this is the following anecdote.

- In May 1939 a group of graduates in soil mechanics at Harvard University gave a dinner to Casagrande, at the end of which he said a few words, according to Wilson Binger, student of Casagrande during the course in 1938–1939 at Harvard University. Casagrande used to say that the loyalty of students to their most beloved lecturers could lead to concepts and theories they had been taught even when later experiences might suggest that they should be modified or even abandoned. As an example of this, Casagrande noted that many engineers persisted in calculating the thrust of the land by the classical method of Coulomb, although they could see with their own eyes that the foremen did not put the sturdier strut of the shoring at the bottom of a ditch. Faced with this situation, Casagrande said that "*If what you have learned from your own experience after leaving here (from university) differs from what I have taught you, then what I have taught you is wrong, and you should not hesitate to discard it*" (Wilson et al., 1982). Only a great teacher could have made such a statement to his students.

11 Development of the Harvard campus

The period between the 1960s and early 1970s was a period of construction of many buildings at Harvard University as well as the physical transformation of the campus. Casagrande served as a consultant, without remuneration, in everything concerning the foundations of almost all buildings of Harvard University. In the correspondence between Casagrande and several Harvard University officials, in relation to the planning of the new buildings, he clearly and sometimes sarcastically (and always impatiently) expressed his opinions against stupidity and waste. Casagrande could not tolerate incompetence, and his assistants were aware of this.

Arthur Casagrande was always loyal to Harvard University and the Division of Engineering and Applied Physics, even when he strongly disagreed with any of the decisions

century. Upon his death he donated most of his fortune to Harvard University to promote applied sciences. In his honor several disciplines precede his name to that of the chair itself.

[37] A story related by Golder, HQ (London, 14 September 1911, Vancouver, British Columbia, Canada, 15 January 1990), civil engineer who graduated from the University of Liverpool in 1932, master from the same university and doctoral engineer in 1950 from the University of Liverpool.

[38] Harvey Brooks. Physical doctor and dean of engineering at Harvard University between 1957 and 1975.

that were made. On many occasions, and in many areas, he stood firm but in loyal opposition in the most constructive and most beneficial sense; Casagrande saved the University many costly mistakes, although many times they asked for his advice too late.

12 Arrival on the Moon

Below is a short reference regarding Casagrande's comments on the landing of man on the Moon in 1969 that also reflect his personality.

Arthur always kept his feet firmly on the Earth, though at times he gave vent to his imagination. He was excited about the landings on the moon and deeply interested in the likely conditions on the moon ground. In accepting the Army's award for "distinguished civil services", Casagrande commented: "*In the future, however, the only soils that will be of interest to some physicists are the soils of the moon. Soon we will learn more about them. Of course, we will find them totally different from our earth soils, perhaps 'crisp' as I have read in some newspaper predictions; Although I cannot quite believe that without an atmosphere that transmits the sound, anything can be crunchy on the moon. I hope that we will find the properties of the soils on the moon somewhat simple and eventually quite boring. I also predict that diverting the orbit of the moon will someday lead physicists to discover just how interesting the soil materials on Earth are and the exciting research opportunities they have to offer*". His irony and sarcasm served to rivet his sayings in terrestrial reality.

13 His final years

Despite his age, Casagrande collaborated in the foundations of unique buildings such as the Liberty Mutual and John Hancock buildings, both in Boston, and in the construction of Logan Airport, also in Boston, built on a soft clay cladding or the dredging of the port of Boston itself.

It was already in 1970 when Casagrande joined his brother Leo and his nephew Dirk to form a consulting group in geotechnics under the name Casagrande Consultants Inc. with offices in Arlington, Massachusetts. In addition to his activities as a consultant, Casagrande remained active as a teacher, speaker and author of articles.

13.1 End of his teaching career at Harvard

In 1969 Arthur Casagrande half retired, giving only half a day to university matters. For this reason, several hundred of his past students gave his family and him a dinner in his honor. They also gave him a bound book with the testimonies of friends and associates. His old friend and associate H. Mohr, who was always a man of few words, wrote a testimonial sentence: "You taught me everything I know about soil mechanics." The same could have been said by many others.

Four years later, in 1973, Arthur Casagrande retired entirely from Harvard University and became Professor Emeritus, retiring from daily active teaching.

13.2 Liquefaction, its great challenge

Despite completely withdrawing from teaching and despite his age of 71 years, Casagrande continued his research on the behavior of non-cohesive sands and, on this subject, continued with lessons and consultancy even though he was physically frail.

Casagrande was unable to restrain himself against this challenge. One of the main reasons that conditioned Casagrande to continue his studies in the face of liquefaction is that he felt that the term liquefaction itself, used to describe the effect that cyclic loads or charges produced by an earthquake produced on interstitial pressure and its subsequent deformations in sands, was not appropriate and gave rise to unjustified concern on the part of engineers unfamiliar with this terminology. The result was that in 1976 Casagrande published an article entitled "Liquefaction and cyclic deformation in sands – a critical review", in which he emphasizes his great opposition to the behavior of cyclical loads and the importance of the term liquefaction in its original definition: loss of resistance of saturated soils without cohesion, because of a shock or an earthquake. Casagrande stated: "... whatever you agree, I will accept it, provided it does not contain the word liquefaction", making clear his position on this subject.

13.3 Passing away

In 1976, during investigations on the collapse of the Teton Dam on the Teton River (Idaho) in which Casagrande participated, Casagrande realized how serious the bone cancer disease he was suffering from was. This made Casagrande realize that, at the age of 74, the end of his life was near. But he did not stop working. On the contrary. Casagrande, with his characteristic strength of will, participated actively in his consulting work and in his investigations until a few months before his death.

In 1976, after knowing the sad news, he continued working 12 to 15 h a day during the investigations on the rupture of the Teton Dam, making sure that there was no unmarked field sample that could shed light on the cause of this important failure. His colleagues on the research team of eight[39] other engineers, including his former student Ralph Peck, were constantly surprised at Casagrande's ability to conduct investigations with sharp inspections and extensive writings in this important study (Peck, 1984).

In March of 1981 Casagrande entered the General Hospital of Massachusetts (Boston) for treatment of bone can-

[39] The other eight engineers, in addition to Arthur Casagrande, were Wallace L. Chadwick, who acted as president, Howard A. Coombs, Munson W. Dowd, E. Montford Fucik, R. Keith Hiffinson, Thomas M. Leps, H. Bolton Seed, and Ralph B. Peck.

Figure 10. Images of the rupture of the Teton Dam, on the river of the same name, on 5 June 1976, Rexburg, Idaho.

cer. Despite this, Casagrande continued to concern himself with the implications of liquefaction in the field of geotechnics. Proof of this was that during his stay at the hospital, Casagrande heard that the liquefaction issue was to be dealt with at the Waterways Experiment Station, so he wrote from his hospital bed with his views to make sure that his ideas on the topic were represented anywhere liquefaction was being discussed.

In the fall of 1981 Casagrande again entered Massachusetts General Hospital in Boston for new treatment for his bone cancer and remained there until he passed away. Arthur Casagrande died while sleeping in his hospital bed on Sunday, 6 September 1981, at the age of 79.

When he died his wife, Erna Mass, who lived in Boston, Massachusetts, was with him; his brother Leo lived in Winchester, Massachusetts; his sister Alix (Casagrande) Robinson lived in Arlington, Massachusetts; his daughters Vivien (Casagrande) McKanna lived in Nashville, Tennessee, and Sandra Casagrande lived in Belmont, Massachusetts, with her grandson James McKanna Jr. (NYTimes.com, 1981).

During his long career, Arthur Casagrande wrote or co-authored more than 100 professional articles. The profession lost one of the greatest civil engineers of the twentieth century.

13.4 Incomplete assignments and donations

With his death, Casagrande left three incomplete commitments, which he assumed a long time before but was not able to finish.

- The first was his book on the mechanics of soils. For nearly 40 years Casagrande wrote notes to include in the book, and in addition, he wrote and rewrote the introduction of the book. Casagrande wanted his book to be perfect, but he was too critical and strict with himself, which meant that he was never satisfied, and so the book was never finished.
- The second of these commitments was from 1950, when Casagrande was about to prepare a comprehensive report on the limits of Atterberg. Again, Casagrande's goal was too ambitious and he was never able to do it.
- Finally, the behavior of sands had always been a great challenge for Casagrande from the moment he developed the concept of a critical index of holes. Casagrande himself hoped that the missing elements, including the compression of the phenomenon of cyclical charges, could be solved during his life. However, the problem was too complex and progress too slow, so he was not able to meet this challenge.

Before his death, Casagrande took advantage of the new construction of a Waterways Experiment Station building in 1976, the year in which the first phase of construction was completed, to donate many of his books, archives, technical articles, soil samples, and rocks to the WES. He later decided that the rest of his technical belongings should also be given to the WES. The managers of the WES, in response to the generous gesture of Casagrande, decided to name the new geotechnical facilities the Arthur Casagrande Building. Construction of the second phase began in June 1978, a construction in which Casagrande and the Chief Engineer, Lieutenant General John W. Morris, were present at the inauguration ceremony.

14 Professional societies

Arthur Casagrande was an active member of many professional societies.

- Member of the National Academy of Engineering
- Member of the American Academy of Arts and Sciences
- Member of the Geological Society of America

- Honorary member of the American Society of Civil Engineering (ASCE)
- Member of the Boston Society of Civil Engineering (BSCE), of which he also was president between the years 1957 and 1958.
- Member of the Mexican Society of Soil Mechanics
- Member of the Venezuelan Engineering Society
- Member of the Japanese Society of Soil Mechanics
- Member of the National Academy of Exact, Physical and Natural Sciences of Argentina
- Member of the International Society of Soil Mechanics and Foundations Engineering (of which he was also president between 1961 and 1965)
- Member of the Board of Large Dams of the United States
- Member of the American Geophysical Union
- Member of the Highway Research Board
- Member of the American Society for Engineering Education
- Member of the Society of Harvard Engineers and Scientists
- Member of Sigma Xi

Figure 11. Arthur Casagrande in 1978.

15 Awards and honors

Casagrande received many awards and recognitions throughout his career, which are listed below.

- Twice Clemens Herschel Prize (BSCE, 1933 and 1951).
- Desmond Fitzgerald Medal (BSCE, 1936)
- Science Master (Hon.) Of Harvard University (1942)
- Certificate of War Department Recognition for services in positions of trust and responsibility during World War II
- Structural Section Prize (ASCE, 1947)
- Arthur M. Wellington Prize (ASCE, 1950)
- Honorary Doctor of Science (University of Mexico, 1952)
- Walter L. Huber Civil Engineering Research Prize (ASCE, 1950)
- First Rankine Lecture (British National Society of Soil Mechanics and Foundation Engineering, 1961)
- Honorary Member of the Venezuelan Society of Soil Mechanics (1961)
- He was the first person[40] to receive the Karl Terzaghi Award (ASCE, 1963).
- Honorary President of the Second Pan American Congress of Soil Mechanics and Foundations Engineering (1963)
- Second Terzaghi Lecture (ASCE, 1964)
- Honorary Member of the BSCE (1965)
- Honorary member of the ASCE (1965)
- Honorary Member of the National Academy of Engineering (1966)

[40] In the words of Casagrande himself: "On October 21, 1963, I spoke with Karl Terzaghi for the last time. I went to greet him after returning from several weeks of traveling, including attending the ASCE convention in San Francisco . . . With sincere interest he read every line of my Terzaghi Prize plaque, which I had brought to show it to him (Casagrande, 1965)".

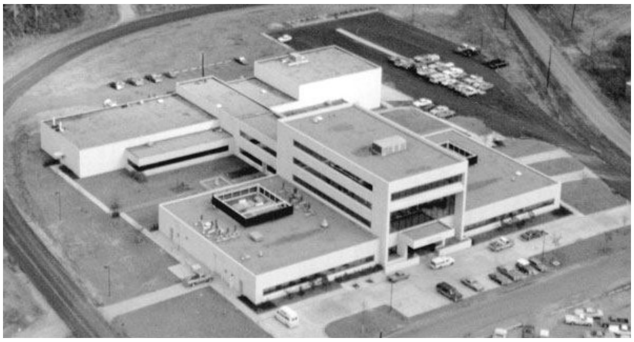

Figure 12. Arthur Casagrande Building. New WES facilities, Vicksburg, 1981.

- Award for "Distinguished Civil Services" (31 January 1967, granted by the Secretary of the Army)
- Edmund Friedman Professional Recognition Award (ASCE, 1968)
- Honorary Member of the Mexican Society of Soil Mechanics (1970)
- First Nabors Carrillo Lecture (Mexican Society of Mechanics of Soils, 1972)
- Decorated with the Del Rio Branco Order (Brazil, 1980)
- Award of Merit (American Consulting Engineers Council, 1973)
- Goethals Medal (Society of Military Engineers, 1976)
- Moles Award (1976)

In addition, Arthur Casagrande received two doctorates "Honoris Causa", from the Technical University of Vienna, in 1965, and from the University of Liege, in 1975.

Three months after his death, in December 1981, the Army Chief of Engineers Lieutenant General J. K. Bratton officially opened the Arthur Casagrande Building within the new WES facility (Fig. 12).

In recognition of his career, the ASCE established the Arthur Casagrande Prize for Professional Development in 1989. This award was established to provide professional development possibilities to outstanding young professionals no older than 35 years, in-service engineers, researchers, and professors of geotechnical engineering.

16 Conclusions

The story of Arthur Casagrande begins with serious difficulties. The first of these was the financial situation that the Casagrande family experienced during Arthur's youth, a fact that marked him and conditioned him for the rest of his life. Another very important event was the death of his father. Arthur was forced from an early age to carry the heavy burden of looking after his family, first when his father was taken prisoner of war, and then when his father committed suicide after being released from prison. Arthur's father was very depressed because of being a prisoner of war, which eventually drove him to take his own life. All these events took place when Arthur was between 12 and 22 years old, which influenced him greatly.

When after a year as full-time assistant to Professor Fitz Schaffernak, Casagrande decided to go to the United States, no doubt the bad situation of his family at the time was foremost in his mind. This situation of suffering and sadness combined with other conditions, such as financial needs, ended with the departure of Casagrande to the USA, despite attempts by his family and Schaffernak to stop him from leaving.

Once in the USA Casagrande looked for new challenges to face and found them when he started working with Terzaghi. The strong character of Terzaghi left a mark on Casagrande: it nurtured him with great determination, dedication, and an outlook in life to solve problems quickly. All of this served him well throughout his professional life. But in addition to all the habits of work and constancy that Casagrande acquired, the most important thing was Terzaghi himself, who probably influenced Casagrande most in geotechnics, guiding him definitively towards the world of soil mechanics.

Another factor that greatly conditioned Casagrande's life was his return to the Technische Hochschule with Terzaghi when he also took the opportunity to visit the soil mechanics laboratories in Europe. So important was this trip for Casagrande that, as soon as he returned to the United States, he applied for American nationality that was granted in 1931 at the age of 29 years.

In addition to his great work as a consultant and as a researcher, perhaps the work he carried out in the field of education was the most important for the development of geotechnics. His great dedication and passion for teaching were recognized and admired by all his students. Casagrande was a professor to many people who later developed a fundamental role in the field of geotechnics, as is the case of Ralph Peck. Although Casagrande did not want to acknowledge his passion for teaching, those around him did notice it, as observed by Peck himself: "Arthur Casagrande said that his interest, in order of importance, was research, teaching and practice" (Peck, 1984).

Another of Casagrande's great contributions to the field of geotechnics is undoubtedly the effort he invested in promoting the 1st International Congress of Soil Mechanics and Foundations Engineering at Harvard University. The success of this congress was essential for the development of geotechnics and Casagrande achieved great international recognition for his efforts. In addition, Casagrande's great determination not only influenced his profession, but also his family. This is shown in that even after being appointed as an adjunct professor at Harvard University in 1934 shortly after obtaining his doctorate, it was not until 1940 that he became a permanent lecturer. Soon after he married Erna Mass. Many would have married before, but his great sense of prudence made Casagrande wait until the right moment.

In short, the legacy left by Casagrande as a teacher, consultant, and researcher, in addition to his great personality, dedication, and determination forged through multiple experiences throughout his life, made Casagrande one of the key personalities in the field of geotechnics and the most important of the twentieth century.

Author contributions. The authors are professors of geotechnical engineering and construction at the Universidad Politécnica de Madrid. In this context, they are working on the biography of singular engineers as a tribute to the work of these.

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References

Blackall, T. E.: A. M. Atterberg 1846–1916, Géotechnique, 3, 17–19, 1952.

Casagrande, A.: Compressibility of Clay Increased by Remoldering, Engineering News-Records, 109, 159–161, 1932.

Casagrande, A.: Seepage through Dams, Journal of the New England Water Works Association, 51, 31–172, 1937.

Casagrande, A.: Notes on the Design of the Liquid Limit Device, Géotechnique, 8, 84–91, 1958.

Casagrande, A.: An Unsolved Problem of Embankment Stability on Soft Ground, Proceeding of the First Pan-American Conference on Soil Mechanics and Foundation Engineering, Mexico City, Mexican Society for Soil Mechanics, II, 721–746, 1960.

Casagrande, A.: The Role of the "Calculated Risk" in Earthwork and Foundation Engineering, Journal of the Soil Mechanics and Foundations Division, Proceedings of the American Society of Civil Engineers, 91, p. 4390, 1965.

Casagrande, A. and Shannon, W. L.: Strength of Soils under Dynamic Loads, Proceedings ASCE, 74, 591–608, 1948.

Casagrande, A., Rutledge, P. C., and Watson, J. D.: Editorial Board, Proceedings of the International Conference on Soil Mechanics and Foundation Engineering, 22–26 June, Vol. I to III, Graduate School of Engineering, Harvard University, Cambridge, 1936.

Casagrande, V. A.: Curriculum Vitae, Department of cellular biology, Vanderbilt University School of Medicine, Nashville, Tennessee, 2014.

Fatherree, B. H.: The history of geotechnical Engineering at the Waterways Experiment Station 1932–2000, U. S. Army Engineer Research and Development Center, Vicksburg, Mississippi, 2006.

Goodman, R. E.: Karl Terzaghi: The Engineer as Artist, American Society of Civil Engineers, 1999.

Hirschfeld, R. C. and Poulos, S. J.: Embankment-Dam Engineering Casagrande Volume, John Willey and Sons, New York, London, Sydney, Toronto, 454 pp., 1974.

Ishihara, K. and Jamilokowski, M: The ISSMGE from 1936 to 2011 a retrospective on the occasion of the 75th platinum jubilee anniversary, ISSMGE, 5, 44 pp., August 2011.

Montès, P.: Deuxième Guerre Mondiale/Conception de pistes d'aéroport militaire/Première classe d'Arthur Casagrande en 1942, Le Coin de Pierre – Génie civil, 2011.

NYTimes.com: Arthur Casagrande, Teacher and Innovator in Dam Design, Obituary, New York Times, 1981.

Peck, R. B.: Vignettes of four presidents 1936–1939, also included in: Dunnicliff, J. and Deere, D. U.: Judgment in Geotechnical Engineering. The Professional Legacy of Ralph B. Peck, Wiley-Interscience Publication, John Wiley & Sons, New York, 1984.

Peck, R. B.: The coming of age of soil mechanics: 1920–1970, The first Spencer J. Buchanan Lecture, Friday, October 22, Texas, A&M University, College Station, Texas, 1993.

The Harvard Crimson: Westergaard Made Engineering Dean; Clifford Resigns, News, Harvard University, 11 May 1937.

Wilson, S. D., Seed, H. B., and Peck, R. B.: Arthur Casagrande, 1902–1981 a tribute, Géotechnique, 32, 87—94, 1982.