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Karl Terzaghi's "Notes on construction" (1912-13)

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ABSTRACT: The paper presents Karl Terzaghi's Notes on construction prepared in 1912 and 1913 after visiting North America. The notes cover almost the entire field of civil engineering and led to the invention of soil mechanics. The Terzaghi 1912-1913 Notes on Construction collection consists of 51 short manuscripts assembling the experience from the 1910s. The collection has three parts: Part I, with 18 projects from the USA and Canada; Part II, with 30 descriptions of principles of construction work; and Part III, with aspects of geo-community exchanges. The paper presents examples of the contents in the Notes. The paper also discusses the importance of historical libraries to preserve the stories of our pioneers. The collection "Notes on Construct5ion " by Karl Terzaghi provides a unique insight into Karl Terzaghi's method of working and reveals him as a brilliant, fearless and enthusiastic scientist.

RÉSUMÉ: Cet article présente les Notes de construction de Karl Terzaghi écrites en 1912 et 1913 à la suite d'une visite en Amérique du Nord. Les Notes couvrent la quasi-totalité du domaine du génie civil et ont conduit à l'invention de la mécanique des sols de manière très claire et impressionnante. La collection « Notes de construction de Terzaghi 1912-1913 » se compose de 51 courts manuscrits rassemblant l'expérience des années 1910. L'ensemble des Notes est divisé en trois parties : la première partie comprend 18 projets ou études de cas aux États-Unis et au Canada ; la deuxième partie, 30 principes de la construction ; et la troisième partie, aspects des échanges géo-communautaires. L'article présente des exemples du contenu des Notes et quelques anecdotes. L'article aborde aussi l'importance des bibliothèques historiques pour préserver les expérience de nos pionniers. La collection offre un aperçu unique de Karl Terzaghi et sa méthode de travail. Elle révèle Karl Terzaghi comme un scientifique brillant, audacieux et enthousiaste.

KEYWORDS: Karl Terzaghi, construction projects, manuscript, geotechnical engineering, sluices, dams.

1 INTRODUCTION

In 1925, Karl Terzaghi published the book "Erdbaumechanik auf bodenphysikalischer Grundlage" (Introduction to Soil Mechanics, Terzaghi, 1925), creating a new discipline in civil engineering. In January 1960, Laurits Bjerrum (then NGI's director) wrote to Karl Terzaghi: "*I guess you have already forgotten how productive you must have been in the early days and how many pages you have written during the period up to 1925. I am especially proud of your Notes on Construction (1912-13) which cover almost the entire field of civil engineering and led to the invention of soil mechanics (…)*".

After completing his doctorate at Graz Technical University (1912), Karl Terzaghi was on his way to the United States. As a young engineer and geologist, Karl Terzaghi was troubled by the methods being used to forecast the settlement of structures, tunnel driving conditions, design of linings, to name just a few topics. It seemed to him a "little more than guesswork." While learning about the inadequacies of soil and rock construction, Karl Terzaghi was gaining self-confidence as an engineer (Goodman, 1999). He believed that earthwork construction was most advanced in the USA with the US Reclamation Services being the main pioneer. During his 2012-2013 trip to North America, Terzaghi developed his "Notes on Construction", which have remained unpublished.

This paper describes the contents of Karl Terzaghi's unique collection of Notes on Construction describing the birth of soil mechanics and geotechnical engineering. Barely 30 years old, Karl Terzaghi described his experience and reasonings to understand the behaviour of soils and rock.

2 TERZAGHI'S NOTES ON CONSTRUCTION

Laurits Bjerrum, in his homage to Karl Terzaghi at the 1965 ICSMGE in Montréal, said: *"Those who have had the good fortune to know Karl Terzaghi during the development of soil mechanics (…) have been privileged to witness the writing of a chapter in the history of civil engineering"*.

Terzaghi's "Notes on Construction 1911-1912" provide the initial steps of geotechnical engineering by describing the experience in the 1910s (Fig. 1). The collection can be divided in three parts: Part I with 18 projects or case studies from the USA and Canada; Part II, with 30 descriptions of construction principles; and Part III, with 3 pamphlets on geo-community. The notes are handwritten, often on very thin paper and contain carefully drawn illustrations. The texts are mostly in German, some are in English and some in a mixture of the two languages.

Figure 1. Terzaghi's Notes on construction 1912-1913.

3 PROJECTS

In 1911-1912, Karl Terzaghi travelled to North America to visit civil engineering projects. His observations, the techniques used and what he learned from the projects are summarized in the Notes. Table 1 lists the projects he visited: the second column reproduces the title on the Notes written by Karl Terzaghi (words originally in German are in italics). The State and Country were added by the authors. The third column lists the topic of each note, as perceived by the authors.

Most of the projects were managed by the United States Reclamation Service, US Department of the Interior (now US Bureau of Reclamation). Figures 2 to 5 give examples of the solutions studied by Karl Terzaghi. The Notes contain ample explanations, though at times in a difficult-to-read handwriting.

Table 1. Karl Terzaghi's Notes of Construction, Part I - Projects

No.	Title of Note and location	Topic discussed in Note
1	Big Eddy, BC, Canada	Sluices on Columbia River
2	Boise, Idaho, USA	Dewatering and review of geology
3	Los Angeles, *Grundwasser* California, USA	Groundwater
4	Minnidoka project, Idaho, USA	Sedimentation and head loss in 20-km long canals
5	Mississippi Delta, Mississippi, USA	Water regulation levees
6	Moloban Folesome Street, Pier 30 - 32 San Francisco	Piers and canalization; construction on Market St
7	North Platte River project, Wyoming, USA	Water diversion dam, Pathfinder dike
8	Portland, *Bauarbeiten,* Oregon, USA	Construction work
9	Rio Grande project, Colorado-N. Mexico USA	Dam construction; flood control,-basin control
10	Salt River project, Arizona, USA	Power and water utility
	Seattle, *Bauarbeiten*, Washing ton, USA	Construction work
12	Shoshone project, Wyoming, USA	Pathfinder Dam, reinforced concrete tunnel
13	Strawberry Valley project, Utah, USA	Indian Creek Dike, canal Strawberry Tunnel
14	Truckee Carson project, Nevada, USA	Irrigation to agricultural land
15	Tucson, *Grundwasser,* Colorado, USA	Groundwater, irrigation
16	Uncompahgre Valley, Colorado , USA	Geology and tunnelling
17	Yakima project, Idaho and several, USA	Basin reservoir storage
18	Yuma project, Arizona-California, USA	Irrigation of Yuma Valley

3.1 *Big Eddy project*

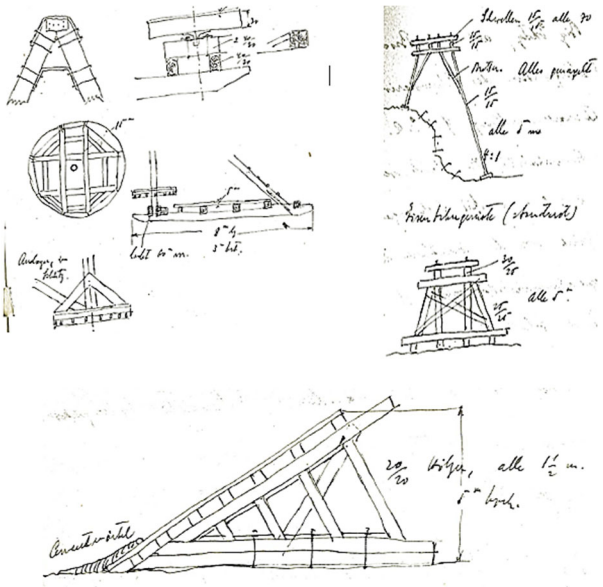

Figure 2. Sluice and construction solutions for Bigg Eddie Project, dimensions in ft (Note 1).

3.2 *Mississippi Delta Project*

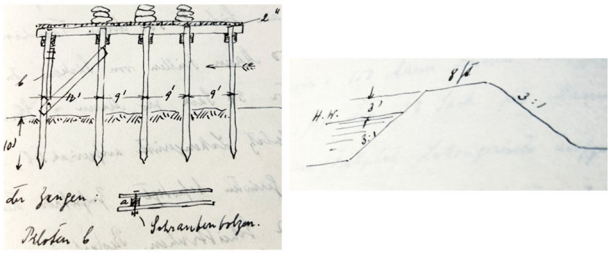

Figure 3. Mississippi Delta: Ramming system (rows 3 ft apart) and standard levee design (all dimensions in ft) (Note 5).

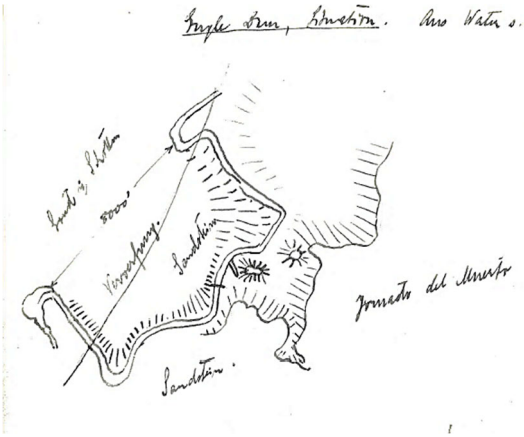

Figure 4. Geology of Yakima project (Note 17).

4 PRINCIPLES OF CONSTRUCTION WORK

While visiting the projects, Karl Terzaghi also discussed with practitioners the construction methods. He summarised his observations in 31 Notes (Table 2). Many of the projects were again managed by the US Bureau of Reclamation. Table 2 lists in the second column the title of the Notes as written by Karl Terzaghi. Words originally in German are in italics. The third column gives an approximate translation of the topic of the Notes.

Table 2. Karl Terzaghi's Notes of Construction, Part II - Principles for construction work (*table continues on next page*)

No.	Title of Note	Topic of Note
II-1	*Adaptierungs-, Demolier-ungs.- Pölzungsarbeiten*	Adaption, demolition, support measures
II-2	*und Setzung von Erde und Fels Versatzarbeiten*	Loosening and settling of soil and rock; Offsetting (surveying and stakeouts)
II-3	*Aushubarbeiten*	Excavation work (adding to construction)
II-4	*Bau-Methoden; Arbeitsmachinen*	Construction methods; equipment
II-5	*Bauvorbereitung*	Construction preparation
II-6	Belle Fourche, South Dakota, USA	Canal and reservoirs: authorised 1904.
II-7	*Bericht über die Dattelpalmkultur in Südkalifornien*	Report on date palm cultivation in South California
II-8	*Betonmischen und Hefe*	Concrete mixing and swelling
II-9	*Brunnen und Tiefbohrung*	Wells and deep drilling
II-10	*Camp*	Field work

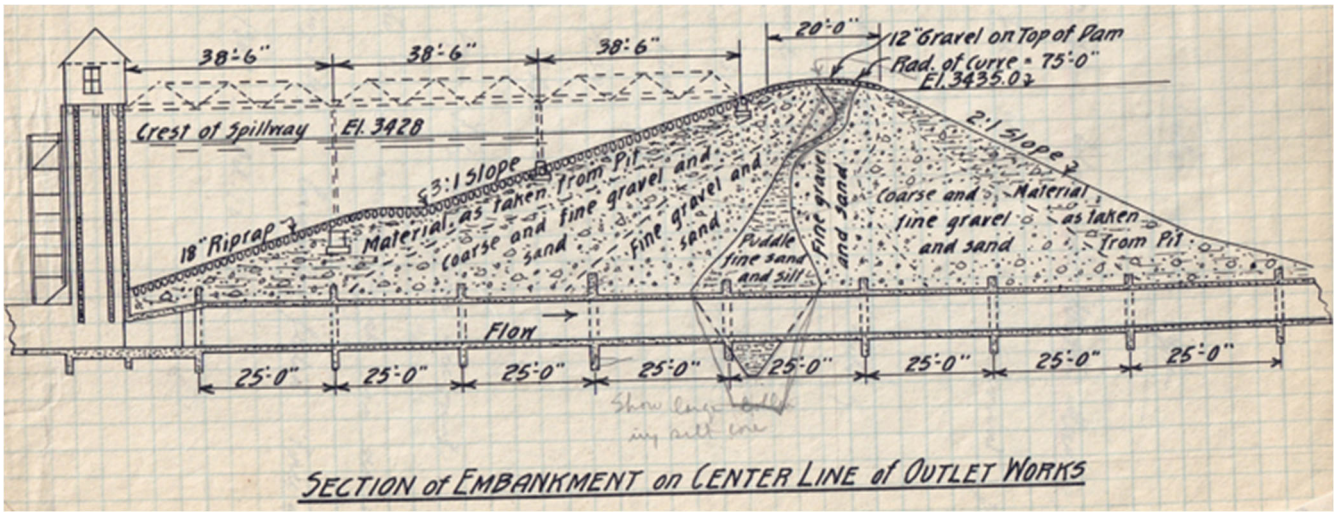

Figure 5. Cross-section, Yakima Project (Note 17). Dimensions in ft and inches.

Table 2. Karl Terzaghi's Notes of Construction, Part II - Principles for construction work (*continued*)

No.	Title of Note	Topic of Note
II-11	Colombia and Snake River *Gebiet; geologie*	Colombia and Snake River area; Geology
II-12	*Eisenkonstruktionen und Montage*	Steel construction and assembly
II-13	*Abschlussbeurteilung der Bauarbeiten*	Follow-up (verification) of construction work
II-14	*Erd-Kanäle*	Earth channels
II-15	Experiment – earth dams	*Tests of water levels, permeability tests,*
II-16	*Kosten von Bau- und arbeiten und Gründen*	Costs of construction and ground works
II-17	*Erddämme*	Earth dams
II-18	*Geologie*	Geology
II-19	*Geografie*	Geography
II-20	*Aufgeständerte Hängebahnen*	Elevated railways
II-22	Irrigation, agricultural	Summary of work done at University of Arizona
II-23	*Löhne*	Wages
II-24	Okanogan Project	Irrigation and hydraulic fill dam, State of Washington
II-26	*Rammarbeiten*	Piling work
II-27	*Reparaturwerkstätten*	Repair shops
II-28	*Schüttungsarbeiten, trocken und hydraulsich*	Dry and hydraulic fills work; Several dams
II-29	*Sprengarbeiten*	Blasting
II-29	Grouting (*Zementinjektionen*)	Grouting
II-30	*Tunnelbau*	Tunnel construction+
II-31	Waterpower, commercial	Data from Engineering News publication

4.2 *Adaptation, demolition, clearing work*

In his Note II-1, Karl Terzagahi described graphically in an exquisite manner what was done in the early 1910s (Figs 6, 7 and 8). Note II-1, as well as other notes, include several other illustrative sketches.

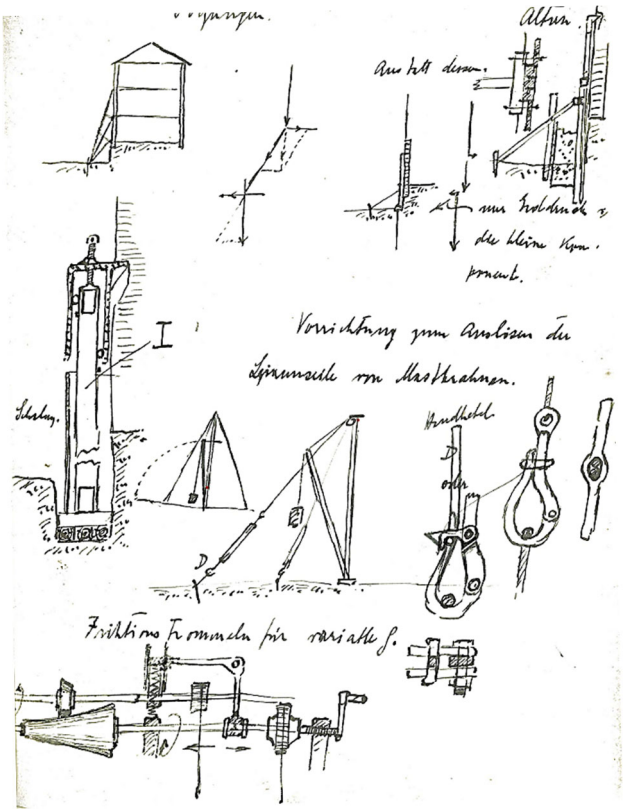

Figure 6. Installations and equipment for clearing work (Note II-1).

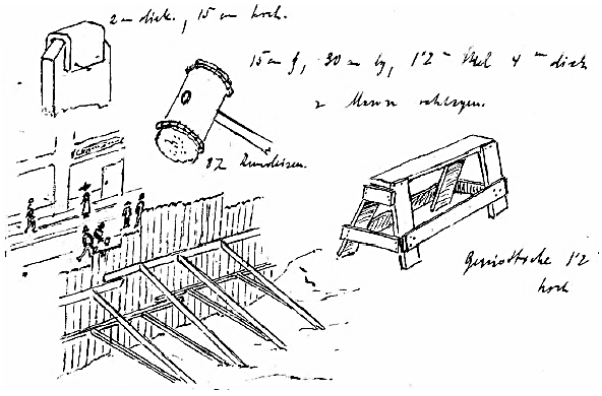

Figure 7. (a) Demolition and clearing work: sketches (Note II-1),

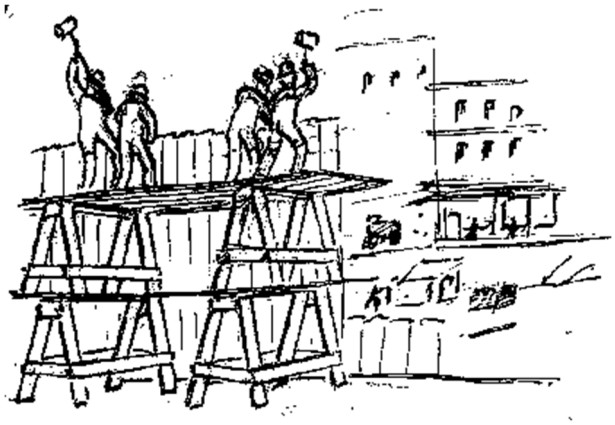

Figure 8. (b) Demolition and clearing work: sketches (Note II-1).

4.3 *Earth dams*

In Note II-17, Karl Terzaghi describes three earthfill dams (Fig. 9). In Note II-28, he started looking at hydraulic fills and problems related to their construction (Fig. 10).

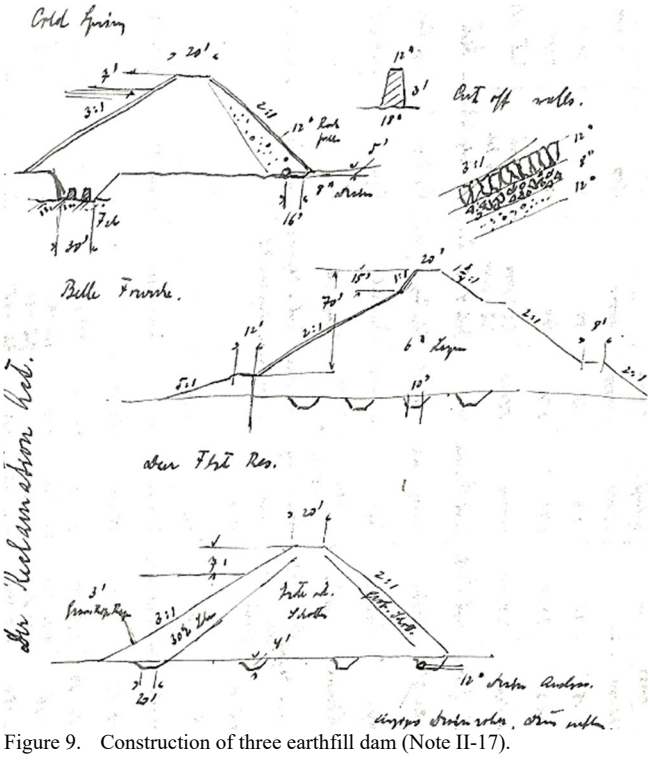

Figure 9. Construction of three earthfill dam (Note II-17).

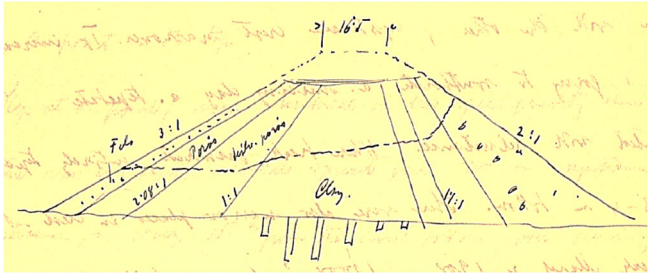

Figure 10. Necessity of zoned construction in hydraulic fills, Yakima project (Note II-28).

In Note II-17, Karl Terzaghi also started systematising the characteristics of fairly large embankment dams (heights 20 to 115 ft (6 to 40m) and up to 2 m long (Fig. 11).

5 OTHER NOTES OF CONSTRUCTION

Karl Terzaghi made a number of observations on the organisation and products of the societies and references. These appear in three notes (Table 3). One note (listed by Karl Terzaghi) may be missing (Table 4). Table 3 and 4 reproduce in the second column the title on the Notes as written by Karl Terzaghi. Words originally in German are in italics. The second column lists the topic treated in the notes, as perceived by the authors.

Table 3. Karl Terzaghi's Notes of Construction, Part III - Geo-community aspects and references

No.	Title of Note	Topic of Note
II	*Bericht an den Österreichischen Ingenieur- und Architektenverein, Wien*	Report to Austrian Society of Engineers and Architects, Vienna
II-25	*Organisation einer Anstalt für Tiefbaugeologie*	Organization of an Institute for civil engineering geology
II-21	*Ingenieur, Technische literatur*	Comments on technical references of the time

Table 4. Missing Notes of Construction

No.	Title of Note	Topic of Note
II-21?	*Hängebrücken*	Suspension bridges May be the same as Note II-20

6 ANECDOTE ON KARL TERZAGHI'S TRAVELS

In his 1912-13 travels, Karl Terzaghi stayed mainly in hotels and often wrote his notes on hotel paper. Figure 12 is a sample of two Idaho hotels, the Owihee Hotel in Boise with lovely scenery (founded 1910, still a cultural cornerstone today) and the Idaho Hotel in Rupert with "good clean beds" and "first class meals"!

7 WHY THE TERZAGHI LIBRARY AT NGI IN OSLO?

Why was the Terzaghi Library founded in Norway instead of in Austria where Karl Terzaghi was born and worked many years, or in the USA where he lived most of his adult life?

The idea of a Terzaghi Library started in the fall of 1957. Bjerrum recounts (Bjerrum, 1965): "*I was on my way to Yugoslavia when I stopped for a couple of days in Vienna to see Terzaghi's old laboratory and visit his successor at the Technische Hochschule, the late Professor O.K. Fröhlich. Fröhlich was just retiring at the time of my visit and he was busy removing all his papers in order to make his office ready for his successor. During our tour through the University, we stopped in Terzaghi's old office, and here Frölich took me into a small filing room and showed me a large pile of dusty papers on the floor in one of the corners. He explained to me that this material was left by Terzaghi when be left Vienna hurriedly, shortly after the Anschluss [the annexation of Austria into Nazi Germany on March 12, 1938]. The material had remained in the filing room for these many years and Fröhlich now asked me to advise him on what to do with it, as he hesitated to throw it away.*

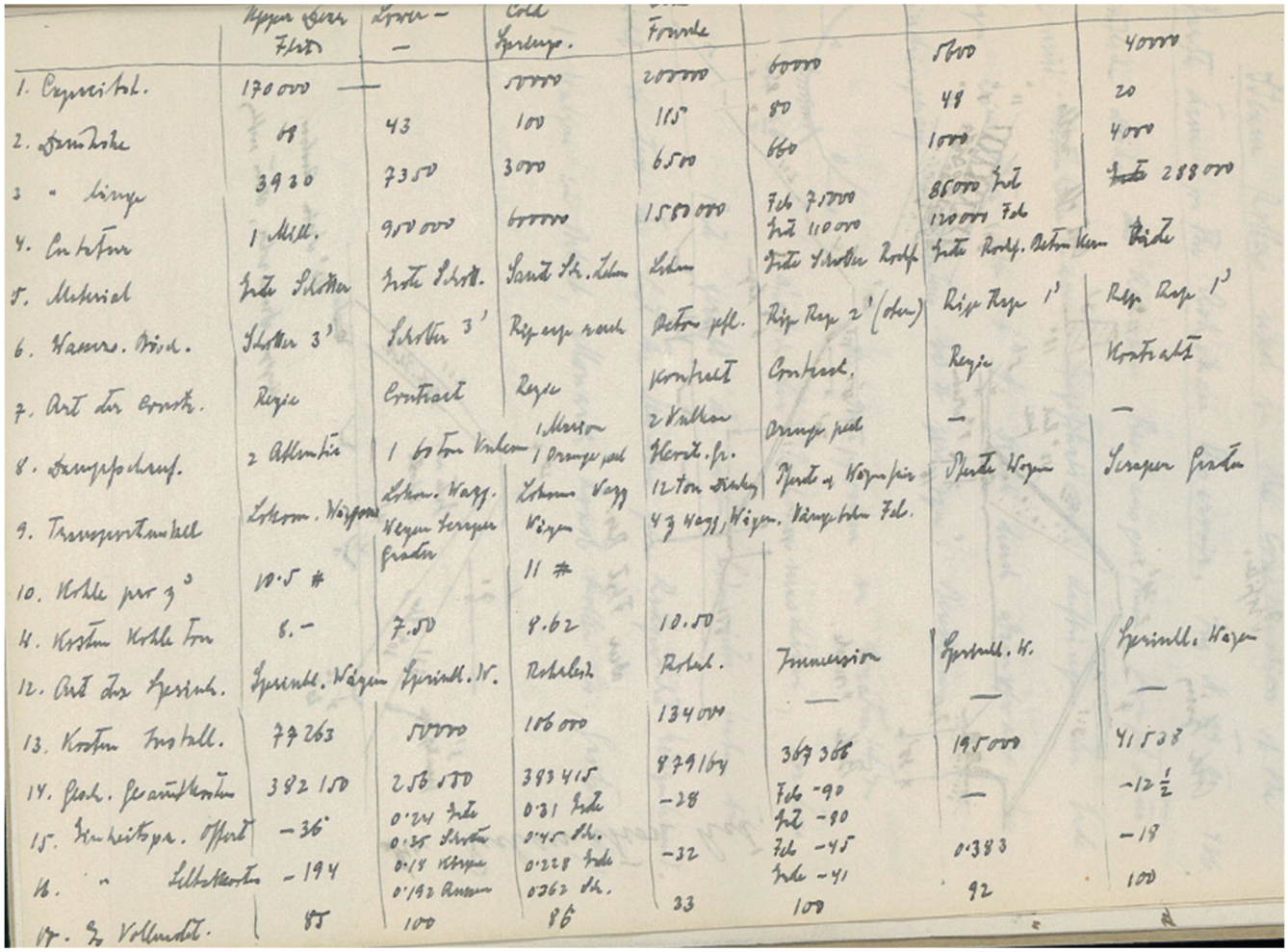

Figure 11. Characteristics of 17 embankment dams from Note II-17.

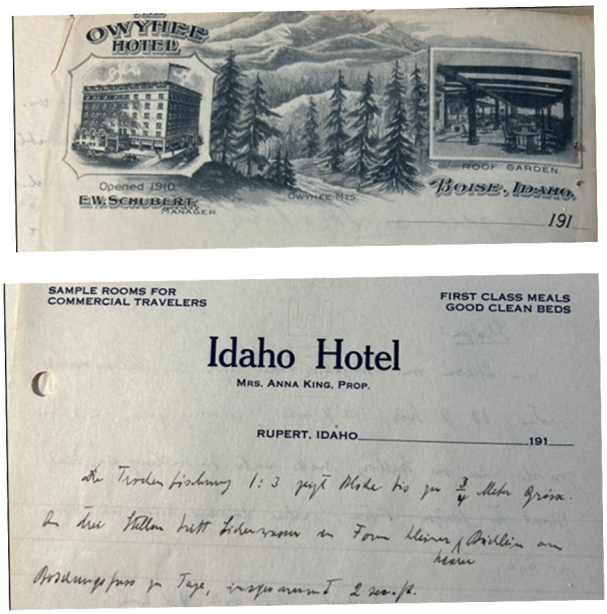

Figure 12. Hotels in Idaho where Karl Terzaghi stayed.

A quick look at the papers showed that they contained manuscripts, reports, and correspondence dating back as far as 1910, and that they included, for instance, material from Terzaghi's early work in Istanbul. I asked Fröhlich to keep the material until I had been in contact with Terzaghi and had received his personal instructions. In a letter to Terzaghi I pointed out that this material could prove invaluable for future generations. I offered to try to have the most valuable part sorted out and sent to him in the United States. As a result of our correspondence the material was sent to Oslo, where we performed the screening process and prepared a list of contents so that Terzaghi himself could decide which papers he was interested in having sent to the United States."

Out of this accidental occurrence grew the idea of a Terzaghi Library in Oslo. Terzaghi appreciated that his papers and reports were of interest. He asked NGI to keep the Vienna material and, in full agreement with his wife, Ruth Terzaghi, he [later] decided that the material collected in the United States should after his death also be included in a Terzaghi Library, and that this library should be established at NGI, in Oslo.

There was always a connection between NGI, MIT and Harvard geo-academics. The close mutual friendship and respect among five pioneers, Karl Terzaghi, Ralph B. Peck, Arthur and Leo Casagrande and Laurits Bjerrum started it all. Bjerrum's relationship with Terzaghi was remarkable. When Bjerrum became Head of NGI in 1951, one of Bjerrum's first acts was to discuss with Terzaghi what should be NGI's strategy. Characteristically, Bjerrum had ideas of his own, but his and Terzaghi's matched very well. Bjerrum came to visit and lecture at MIT and Harvard regularly. Bjerrum stayed with the at the Terzaghi's and quickly became one of the family.

Ralph Peck. in his tribute to Laurits Bjerrum upon his untimely death in 1973, said: "*Bjerrum is the one who came*

closest to appreciating Terzaghi's ideas and ideals as to the way soil mechanics should be developed and practiced." All of Terzaghi's fundamental studies came out of practical problems. NGI's strategy since 1951 has been based on this principle: research and practice hand in hand.

8 ROLE OF HISTORICAL LIBRARIES

In his ISSMGE homage to Karl Terzaghi in 1965, Bjerrum also said: "*Such a privilege* [of knowing Terzaghi's work] *also involves the responsibility to take care of the information and material for future generations to understand the development of our science and its originator"*. This is one of the purposes of the Terzaghi Library.

In days of home office, digital meetings, shared digitized conversation spaces, cloud storage and machine learning, is there a need for historical libraries? The authors' reply is an enthusiastic yes!

The Terzaghi Library (along with the Peck and Casagrande Historical Libraries) assembles the lifework of our pioneers and provides not only technical insight but also human insight in the great men of our profession. One example: Terzaghi while professor at Robert College, Istanbul wrote in 1923: "Happiness? I have learned the meaning of the word in this year: continuous creative activity, clarification of confused material and a sympathetic guiding influence on earnestly striving young men". (Authors' note: no women among Karl Terzaghi's students at the time).

NGI sees it as a privilege to be the custodian of part of the legacy of Karl Terzaghi and wishes to preserve his works for the coming generations.

Former ASCE Geo-Institute president Garry Gregory (2017) asked: "Are We Losing the History of Our Geotechnical Pioneers?" By pioneers, he meant prominent engineers and geoscientists who had had direct links to Terzaghi. Because fewer and fewer of our pioneers are still with us, young engineers should have the opportunity to meet Karl Terzaghi virtually and hear about the development of our science. The stories are fascinating.

Historical Libraries, like the Terzaghi Library, are a source of inspiration for NGI-employees, professional partners, university scholars, clients and visitors. NGI sees its role as the custodian of Terzaghi's documents on behalf of the geotechnical engineering and geoscientist profession. NGI wishes to preserve the works of Karl Terzaghi (and Ralph B. Peck and the Casagrande brothers) for posterity. The libraries are a physical or virtual working place where one can get to the roots of the thinking at the time of the development of our geotechnical engineering science.

The profession could include in the undergraduate and posts-graduate courses: (1) geotechnical history; (2) consultations of Historical Libraries (e.g., Imperial College has a "Skempton Collection" and Harvard University has a "Casagrande Collection"), or (3) reading of biographies of our pioneers, for example, Terzaghi (Goodman, 1999); Skempton (Niechcial, 2002); Bjerrum (Flaate et al., 2003); Peck (DiBiagio and Flaate, 2000; Dunnicliff and Peck-Young, 2006).

9 CONCLUSIONS

Two years before his death (1961), in a letter to his wife Ruth Terzaghi signed with his affectionate nickname "Bear," Karl Terzaghi expressed his last wishes to send his papers to NGI in Oslo to complete the Terzaghi Library. The documents continued to come until Ruth Terzaghi's death (1992).

Karl Terzaghi described his life as "Karl Terzaghi, a civil engineer. He has lived without compromising, served his chosen profession to the best of his abilities and died without having anything to regret". Karl Terzaghi was a good judge of his own contributions.

This paper summarized some of the contents in Karl Terzaghi's Notes on Construction from 1912-1913. Karl Terzaghi's collection provides insight into a giant of our profession, revealing that Karl Terzaghi was a brilliant, determined, fearless, enthusiastic and visionary scientist. The Notes on Construction also reveal some of Terzaghi exceptional personal characteristics: analytical mind, insatiable curiosity and sense of observation, a talent for sketching, a talent for recognising the essential in a maze of information, and definitively an interest in writing. Terzaghi also said that in a project "writing the report is always the best part".

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