Silos and warehouses complexes in five locations in Tanzania – case studies

Paweł Maria Kulczycki
Wroclaw University of Science and Technology, Faculty of Civil Engineering, Wyb. Wyspianskiego 27, 50-370 Wroclaw, Poland
E-mail: 234253@student.pwr.edu.pl

Abstract. In the end of 2016 National Food Reserve Agency of Tanzania (NFRA) ordered from Polish company FEERUM S.A. implementation of grain silo projects, production of designed silos, ensuring their transport to Tanzania, assembly and commissioning. Structure design of silo complexes was ordered from the design office, the subcontractor – TEK Projekt. The paper describes various aspects of data acquisition, design and execution of foundation works from the point of view of Central European contractor in Africa. In general it ends up with a kind of wake-up call to open designers eyes for situation of different countries and people, improving general knowledge about world problems.

1. Introduction - an overview of the situation
Tanzania is a country located in central part of African east coast. African countries have probably one of the most complicated food supplying situation in the world. The climate of central Africa, its flora, fauna, soils and weather are hard to find anywhere else in the world. It is also a place with high tectonic activity, which causes earth movements and earthquakes. Any human activity in Tanzania, from designing to living, for people from outside of the region, must be preceded by learning about it and understanding its rules and characteristics. The source of these characteristics is in the structure of these soils. Soil recognition plays a crucial role for most of infrastructural projects [1].

Figure 1. Example of erosion of Tanzanian soil (Own photo)

Figure 2. Wet soil preserving (Own photo)
Most of Tanzanian soils can be described with a term „collapsible soils” [2], which are considered to be one of problematic soils, and also problematic foundation materials. Collapsible soils are moisture sensitive, so an increase in moisture content is dangerous for buildings foundations, because it triggers volume reduction. These soils, which can be easily classified as weak soils, have very low dry density. They also demonstrate low bearing capacity when wetted, so they cannot be considered for a foundation or a pavement in their natural form.

They consist primarily of silt-sized particles arranged in a cemented honeycombed structure. This structure is held together by small amounts of water-softening or water-soluble cementing agents such as clay minerals and calcium carbonate. The introduction of water dissolves or softens the bonds between particles and allows them to take a denser packing under any type of compressive loading [2].

![Figure 3. Loaded hydro-collapsible soil before (a) and after (b) inundation with water [2].](image)

Some of common features for collapsible soils are: loose, cemented deposits; natural dryness; open structure; high void ratio; low dry density; high porosity; geologically young, recently altered deposit; high sensitivity; low inter-particle bond strength [3]. Kozubal proposed methods for the improvement of collapsible soils (loess) [4-7], however optimal design depends a lot of its origin and conditions.

2. Difficulties
The main difficulty for central European engineers was to face the standards of structure design in conditions much different from ones that surround them. Tanzanian designing conditions can be described as extreme and unique, because of soil structure and weather.

![Figure 4. Tectonic situation of east Africa](image)
When foundation work is considered, one of the biggest difficulties in this situation is risk of sudden and large amount of settlement. It takes place when the foundation subsoil is saturated from some kind of water intrusion, such as leakage from broken pipe lines, water from runoff and irrigations, pools, basins and much more. The conclusion is, that collapsible soils appear to be strong and stable in their natural dry state, but they consolidate rapidly under wetting, and can generate large and unexpected settlements. Settlement of foundation subsoil can cause massive damage to building structure, and in extreme situations can cause collapsing of the structure, so the main task of structure foundation is to reduce an impact of settlement on a structure.

Another difficulty, is that Tanzania is a tectonically active area. It is a place of a border between Arabian, African Somalian and African Nubian tectonic plates. The African (Nubian) plate is moving away from Arabian and Somalian plate. This phenomenon can cause earthquakes, which have an active and dynamic impact on the structure, which is easy to imagine. It is a factor that has to be considered during the process of structure designing, especially during foundation designing.

3. Research – acquiring of geotechnical data for analysis

Ground Investigation was made in every planned silos complex location: Songea, Mbozi, Makambako, Dodoma and Shinyanga, by Geoprimosi Engineering Limited from Dar es Salam, the capital of Tanzania. Soil types that were found:

- Songea: sandy silt, silt, clayey sand, silty sand.
- Mbozi: sandy silt, sandy clay, clay, silt.
- Makambako: sandy silt, sandy clay, clayey sand, silty sand.
- Dodoma: sandy clay, clayey sand, silty sand.
- Shinyanga: sandy gravel, sedimentary rock (sandstone), clayey sand, silty sand.

Dynamic probe light (DPL) tests was made in every location excepting Mbozi, near the drilled boreholes and in other points to establish soil profile and compare them. The charts for all locations are included in appendix A. This test shows how soft and easy to penetrate dynamically the soil is. The charts shows how many hammer drops are needed to reach certain depth. Test shown that soils are rather soft, and can be easily penetrated by the hammer, but in some research points, at a certain depth, the probe faced some hard types of soil, probably sedimentary rock.

![Figure 5. Stage after concreting of lower ring, with reinforcement of cores (Own photo)](image)

According to „Seismic design considerations for east Africa” [8] Tanzanian seismic design requirements code or standard is not known, so old British Standards (BS 8110, BS 5950) are generally used, and do not include any provisions for seismic design. In this case, consideration of seismic resistance of the structure have to be supported by local engineers who knows the Tanzanian conditions well. Polish engineers made a contact with scientists from University of Dodoma in Tanzania for consultation services, and to obtain an information how the seismic factor can be considered in designing process of a structure [9].
Polish designers ordered a research from University of Dodoma, which resulted in a report „The site specific bedrock probabilistic seismic hazard assessment” [10]. In this report, scientists outlined geographic, geological and tectonic situation of Tanzania, and a history of earthquake events. They have also made the Probabilistic Seismic Hazard Assessment (PSHA), which resulted in a table of Site Specific PGA values, which are factors that needs to be considered during the process of designing. These factors let engineers to use European norm Eurocode 8 to ensure safety of the structure.

![Image](https://example.com/image1)

**Figure 6.** Stage after adding sand stabilized with cement layer, waiting for upper ring concreting. (Own photo)

4. **Typical geotechnical conditions for various site locations.**

The figures below shows standardized results of dynamic probing from various site locations.

![Image](https://example.com/image2)

**Figure 7.** Dynamic Probe Light Test – Songea (combined DPL plots)

![Image](https://example.com/image3)

**Figure 8.** Dynamic Probe Light Test – Makambako (combined DPL plots)
5. Designing appropriate and safe structure for specified conditions.

Foundation of the silo was designed as a round strip footing. Specifically, there were two concrete rings connected by RC cores every 1.5m. The reason of designing two concrete rings, was that load-bearing soil was placed very deep (4 meters on example drawing). The loads from silo had to be leaded very deep, so they were collected by upper ring and leaded through RC cores and sand stabilized with cement to lower ring, and next to the soil. Space between rings and around cores was filled with sand stabilized with cement. This solution provided appropriate mass for foundation, which is required for prevention of earthquakes, and required load-bearing ability for the structure. Lower ring did not need any additional reinforcement, but upper ring had to be reinforced quite heavily because of load from silo that it has to carry. Designers also tried to keep the soil around foundation as dry as possible, so the water outflowing channel system was designed, to take away as much water as possible from the area of silos.

![Figure 9. Dynamic Probe Light Test – Dodoma (combined DPL plots)](image1)

![Figure 10. Dynamic Probe Light Test – Shinyanga (combined DPL plots)](image2)

![Figure 11. Section of Foundation structure from Makambako, taken from original structure drawing.](image3)
6. Conclusions
Designing in foreign countries, especially in places like Tanzania, where designing norms and regulations are not as clearly specified as in Europe, and environmental conditions are so different and extreme is always a difficult challenge. Another problem that may affect the communication is different attitude to recently imposed sustainable thinking about building processes [11,12]. In developing countries with limited financial resources, sustainable technologies may not be available despite their evident advantages for the environment. Engineers have to face many difficulties as limited access to information, different approach to designing by local people, lower or higher execution precision and demands on engineers work, extreme weather and natural phenomena or even different sanitary needs of local people, combined with severe requirements for silo operation [13]. Taking part in this kind of undertaking for ambitious engineer is a great chance for self-development and to become more complete in their profession. It also opens designers eyes for situation of different countries and people, improving general knowledge about world problems.

Acknowledgements
The authors would like to thank TEK-Projekt Sp. z o.o Sp. K. for making available their archives and valuable references. A special gratitude is expressed to Tomasz Kulczycki (TEK-Projekt Sp. z o.o Sp. K.) for technical support for the whole research program and financial support of the current study.

References
[1] Sobala D and Rybak J 2017 Role to Be Played by Independent Geotechnical Supervision in the Foundation for Bridge Construction. IOP Conf. Ser.: Mat. Sci. Eng., 245 (2), 022073
[2] Kalantari B 2013 Foundations on collapsible soils: a review. Proceedings of the Institution of Civil Engineers - Forensic Engineering. 166 (2), 57-63
[3] Noutasch M K, Hajialilue B M and Cheshmdoost M 2010 Prepounding of canals as a remediation method for collapsible soils. Proc. of the 4th Int. Conf. on Geotechnical Eng. and Soil Mechanics, Teheran, Iran
[4] Kozubal J and Steshenko D 2014 The compaction of collapsing loess soils by complex triple technology: Watering, deep explosions, soil columns. International Multidisciplinary Scientific GeoConference Surveying Geology and Mining Ecology Management, SGEM 2014, 2 (1), 885-892
[5] Kozubal J and Steshenko D 2015 The complex compaction method of an unstable loess substrate. Arabian Journal of Geosciences, 8 (8), 6189-6198
[6] Kozubal J, Szot A and Steshenko D 2014 Improved road embankment loess substrate under earthquake hazards, Underground Infrastructure of Urban Areas 3, 53-62
[7] Kozubal J, Steshenko D and Galay B 2014 The improvement of loess substrates with a new type of soil column with a reliability assessment. Road Mat. and Pavement Design, 15 (4), 856-71
[8] Lubkowski Z, Villani M, Coates K, Jiruska N and Willis M 2014 Seismic design considerations for east Africa. 2nd European Conference on Seismic Engineering and Seismology, Istanbul, Aug. 25-29, 1-12
[9] Kulczycki T and Wójcik T 2017 Makambako 20,000MT Silos Complex and 20,000MT Warehouse
[10] Msabi M M 2017 The site specific bedrock probabilistic seismic hazard assessment for the proposed silos installation project, College of Earth Sciences, University of Dodoma
[11] Lohnova O and Wyjadowski M 2018 Modification of vibratory driving technology for sustainable construction works. MATEC Web Conf., 251, 03063
[12] Ivanovik A L, Kongar-Syuryun C, Rybak J and Tyulyaeva Y 2019 The reuse of mining and construction waste for backfill as one of the sustainable activities. IOP Conf. Ser.: Earth Environ. Sci., 362 (1), 012130
[13] Hammadeh H, Askifi F, Ubysz A, Maj M and Zeno A 2019 Effect of using insert on the flow pressure in cylindrical silo. Studia Geotechnica et Mechanica, 41 (4), 177–183

6