COMPARISON BETWEEN DIFFERENT TYPES OF DEFLECTOMETERS USED IN FOUNDATION PREPARATION

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Bachelor’s thesis

Construction Engineering

2022

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Construction Engineering		Abstract
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Subject	Comparison between different types of deflectometers used in foundation preparing	
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The discovery and development of falling weight deflectometers (FWDs) in construction has improved the quality of buildings all around the world by letting engineers understand not only how resistant their base is against compressive loads applied on top, but also how the base is reacting to different surrounding factors. Nevertheless, knowing these factors many different methods have been created to help building foundation bases achieve the desired performance.

The main purpose of this report was to compare and analyze the differences and similarities between "LOADMAN II" and "TERRATEST 4000" light falling weight deflectometers (FWDs). To analyze these devices, several visits in construction sites have been conducted in Finland and abroad, where the devices were used to execute measurements through appropriate and exact procedure. The research has been realized using the before mentioned devices as well as applications such as AutoCAD and Excel for drawings and data, respectively. The results of this research interpreted the differences and similarities between the devices in a few different areas of study such as data input, data output, procedure of measurement, advantages, disadvantages etc.

In conclusion, the results of this research interpreted the behavior from both devices in different circumstances, explained their functionality and finally, it deduced what should and should not be done during the procedure. The results achieved from these measurements also highlight the importance of different project size capacity, procedure of working and output values for further analyzing.

Keywords Building, deflectometer, foundation, soil
Pages 27 pages and appendices 9 pages

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1 Introduction

1.1 Knowledge base of the research

Construction of buildings and other structures has always been the very core of creating an appropriate environment for living and functioning. It has ensured for humans to have places to live, transport, and more. By developing construction through years, many methods changed, and many different possibilities were considered but there is one principle that never changes and that is the damage that is constantly caused by nature to the buildings and structures created by humankind. This is the reason there is always a necessity to ensure that each part of the structure will be effective on its purpose and will resist each natural factor imposed on it, at least for the guaranteed life span that is planned and predicted. This need appears at each phase, from the very beginning of construction and through its whole life span. The hardest challenges tend to appear during construction, while other requirements that happen after the building is open to be used, are related to maintenance, renovation, or actions to be taken in case of natural disasters such as earthquakes, floods, or fire.

The grounds of this research stand on the work that is done during the preparation of the foundation for any type of buildings. This is one of the most important phases and the same concept of preparation applies to most of the cases on several types of buildings, except when special conditions come into consideration. During this part, the soil can, and will be subjected to several factors that will affect its performance in a foundation, more specifically its resistance and compactness. These factors can be either naturally produced, such as appearing of water capillaries and poor earth quality on the construction site, or they can be artificially produced, as vibrations caused by cylindrical rollers (or other rollers), extensive or poor amount of gravel used for layering and non-proper placing of all the needed layers.

2 Naturally produced factors that delay and prevent a proper foundation work

2.1 Appearing of water capillaries while digging

It is understood that the amount of water on earth mostly never changes, except in cases where water molecules are dissolved into smaller components and hence, released into outer space. However, due to that amount being small, it can be neglected. As the most basic principle of water circulation in nature comes in question, it allows understanding on how the water capillaries are created underground. This creation is affected by several surrounding elements, such as mountains, seas, lakes, and rivers that might be nearby, vegetation, climate of the region where the site is located, affection of water flow due to elevation of the terrain and more. These factors determine the size of water capillaries, their shape, pressure, ability to enlarge or break and more. An example is creation of capillaries due to infiltration of lakes, rivers into ground and other types of underground waters. (Figure 1, 2)

Figure 1 Foundation filled with gravel flooded by rising of water from water capillaries

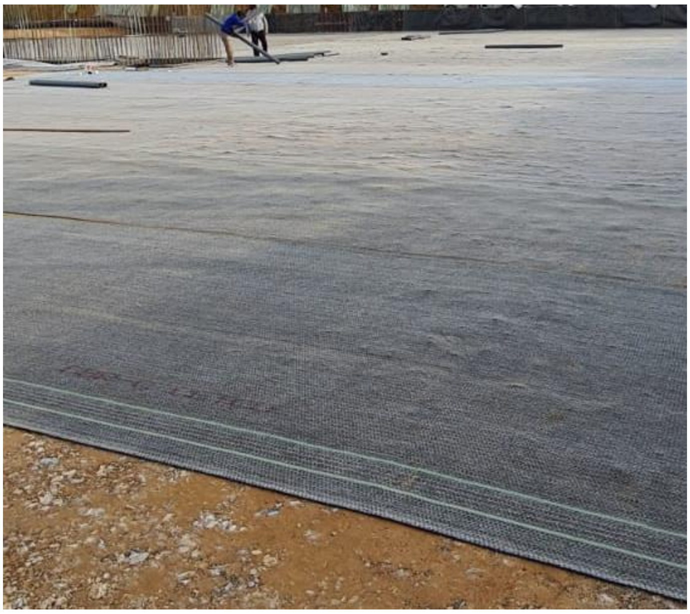
An event that often happens is the rising of capillary water, when its molecules are pulled upwards due to the soil particles, and the soil particles are pulled downwards due to a force of the same magnitude. In this case the soil particles will come closer and decrease on level. This same process happens in the foundation base, before, during and after its preparation and the water that rises on top does a lot of damage to common materials used in construction. Concrete as one is very porous and during its placing there is always cracks, especially on in-situ concrete, meaning that rising of water on that level will degrade the structures strength rapidly, and considering that concrete is the normal choice for foundations in concrete or hybrid structures (timber or steel structures with concrete foundation), several protective materials and layers must be applied to prevent the damage.

Figure 2 Highly damaged concrete slab used for foundation from heavy rain

The water that could be of any source, reacts in the same way as described in the previous paragraph, despite the applying of stones and gravel. To avoid the damage, the foundation must be protected. The most effective ways which date from the very beginning of construction known to humankind is to provide a proper drainage system that should depend on the buildings size and applying of waterproofing barrier. (Figure 3, 4)

Figure 3 4 mm waterproof barrier placed to protect slab foundation from being damaged

Figure 4 Geosynthetic clay barrier placed as protective layer of foundation slab for a residential building



The creation of a drainage system could be done through several methods (Dr. ir. Henk Ritzema, 2014). The most common example is placing the drainage pipe all around the footing of the structure, and covering it with gravel and a geotextile layer, whose thickness varies around 5 millimeters and depends on the size of the project. (Figure 5, 6)

Figure 5 Geotextile layer (5 mm) being applied to prevent water rising through the gravel for the foundation of a residential 8-story building

Figure 6 Geotextile

2.2 Poor soil quality on the chosen site

The soil quality on a certain location depends on many factors (Bünemann et al., 2018). The most common reasons that result in witnessing a poor soil quality are bad fertilization, water shortages, excessive water (e.g., too much rain), overfarming of the same land, transition of the land's purpose from farming to building etc. In cases where the soil is bad, the resistance is low and makes the building process much harder. A common solution to this issue is to provide pile foundations so they will reach the stronger part of earth below the construction place to achieve significantly higher support for the foundation (Mandolini et al., 2005).

All these factors could result in the sinking of the layers of the foundation, hence making the base unsuitable for any kind of building. If there is any part of the base where sinking is occurring, it might not always be visible to the naked eye, and that is the reason it needs to be checked, and fixed if necessary. While the foundation sinking is an issue that normally could occur on buildings after they start being used for their purpose, it causes difficulties to predict it in advance. One mistake that could happen is miscalculation of loads, especially live load, that might later increase in specific cases and impact more load through the building's structure to the foundation than originally assumed, and sometimes if not a miscalculation, the reason can simply be the weakening of main materials by external factors which through time will become less resistant against the same load. This is where the need for lightweight deflectometers appears, which are electronic devices (usually portable), that evaluate the base by releasing a weight from a certain height, which stimulates a compressive force that would normally be applied at that point (Shivamanth et al., 2015). These tests calculate a resistance result, which is usually immediately given by the devices in megapascal (MPa) and after it has been compared to a given diagram or table, can determine if the base is adequate for a building or not based on refering values from relevant codes. The deflectometer used in these cases can be of different producers, meaning that it can offer a different size, weight, utilization capacity, price, accuracy, range, data export options and sustainability. One more aspect they may differ on, could be the country it has been made for or in, resulting on the device being designed due to a specific kind of experience on a set region, a measure which is taken to ensure that the results calculated by the device will be as accurate as possible due to given conditions and soil quality on different parts of the world.

3 Aims of the study

The aims of this research were to compare the performances of two deflectometers affected by the conditions and cases used, analyze the conditions they have been used at and to interpret the obtained values, respectively.

4 Materials and methods

The measurements were taken using “LOADMAN II” and “Terratest 4000” devices, both being light-weight portable falling weight deflectometers (FWD). Both these devices calculate the E-value of resistance of the soil layers, in other words, E-value describes the stiffness of the material (Ville, 2019). Finland uses the Odemark’s theory for analyzing load resistance. Odemark’s theory can be used to plug in values into the formula and compare them to standards used during the analyzing such as SFS-EN standards, InfraRYL or MaaRYL, depending on the need. Odemark’s method requires several values to satisfy the requirements. E.g., For buildings roads, streets, and pavements they are:

- Total of minimum layer thickness of the superstructure
- Desired load capacity on top of the bearing layer
- E-value of the substructure
- Materials of the superstructure and their layer dimensions
- Type of material required and its minimum thickness

$$E_y = \frac{E_A}{\left(1 - \frac{1}{\sqrt{1 + 0.81 \times \left(\frac{h}{0.15}\right)^2}}\right) \times \frac{E_A}{E} + \frac{1}{\sqrt{1 + 0.81 \times \left(\frac{h}{0.15}\right)^2 \times \left(\frac{E}{E_A}\right)^{\frac{2}{3}}}}}$$

Terms of the formula:

- E_A -Load bearing capacity target under the layer
- E_Y -Load bearing capacity target above the layer
- E -E-value of the material of the layer
- h -Thickness of the layer
- 0.15 -Radius of washer of the plate loading device

4.1 "LOADMAN II" device

"LOADMAN II" is a falling weight deflectometer (FWD) and it can be used on a variety of cases. In comparison to other similar devices used for the same function, it offers the possibility to be used on all kinds of terrains and projects due to its small size and easy accessibility. It can also be used for material testing in a laboratory. Most of the FWDs are harder to use in all kinds of terrain due to the parts being very heavy and sometimes needing an extra trolley or crane to carry them to the designated place of use. "LOADMAN II" tests the base strength by releasing a weight from about 80 cm altitude and calculating an acceleration during the drop. This acceleration can be plugged in a double-integration formula, to calculate the deflection of the base in millimeters. In addition to the deflection, it also calculates the load bearing capacity modulus in megapascal (MPa) and gives a ratio of compaction between the most recent measurement and the initial measurement to compare the deflection increase between several measurement.

4.1.1 Technical specifications of "LOADMAN II"

Figure 7 Outputs of results in the screen on top of the device

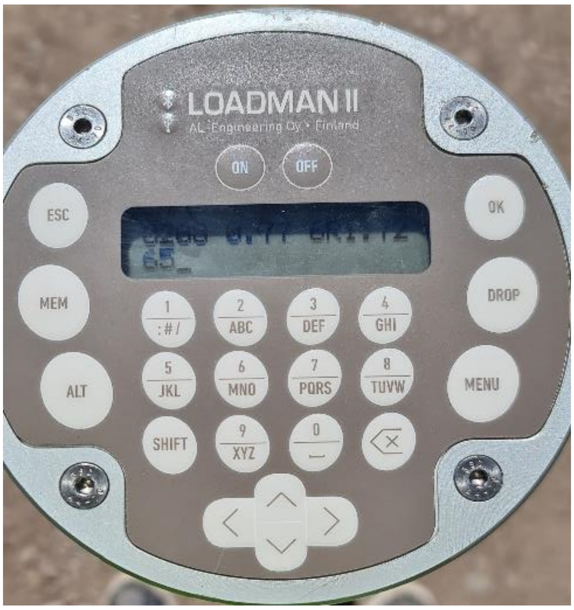


Figure 8 The device during the measurement process

Figure 9 Extra plate placed on the base before measurement

Table 1 Technical specifications of "LOADMAN II" device (AL-Engineering OY)

Total weight	16 kilograms (kg)
Height	117 cm
Loading plate diameter	132 mm, up to 300 mm with one extra plate
Mass of falling weight	10 kg
Falling height	80 cm
Operating voltage	6V
Measuring range	0.1 mm to 5 mm (approx.)
Duration of loading	20-30 ms (approx.)

4.2 "Terratest 4000" device

4.2.1 Technical specifications of "Terratest 4000"

Figure 10 Setup of Terratest 4000 during the procedure including measuring computer, connecting cable, plate, and load

4.2.1.1 Technical details of measuring computer

Table 2 Technical details of measuring computer

Dimensions	230 mm x 220 mm x 170 mm
Weight	4 kg
Deflection range	0.1 mm to 0.2 mm (±0.02 mm)

Measuring range	$<225\ \frac{MN}{m^2}$
Temperature range	0 °C to 40 °C
Protection against dust and	IP53
Graphic display	40 mm x 72 mm
Processor	32-bit
GPS-system precision	< 10 m
Data storage	USB Device
Printer	Thermal printer
Connection system	Bluetooth
Available number of languages	10
Battery	Panasonic power battery 6.9 Volt (Capacity: 2000 Tests)

4.2.1.2 Technical details of load mechanism (10 kg falling weight)

Table 3 Technical details of load mechanism

Material	ST52 steel, chemically nick plated
Weight	10 kg (± 100 g)
Max. impact force	7.07 kN (± 70 N)

Time of impact	17.0 ms (± 1.5 ms)
Spring	17 disk springs

4.2.1.3 Technical details of load plate

Table 4 Technical details of load plate (TERRATEST®)

Material	ST52 steel, chemically nick plated
Diameter	300 mm (± 0.5 mm)
Plate thickness	20 mm (± 0.2 mm)
Plate weight	15 kg (± 250 g)
Acceleration meter	Yes
Grips	2 Aluminum grips

5 Presentation of results

5.1 Case 1 –Single family house, Kottaraisentie 2, 02660 Espoo (Device used: “LOADMAN II”)

In this case, 78 drops have been executed to measure the deflection of soil foundation in 13 different points. On each point, 6 measurements are taken one after another, and during the measuring process, the base was not affected by vibrations of rollers or nearby construction work.

Table 5 Results from drop 1 of case 1 measurements

Measurement code	Number of drops	Code of drop 1	Drop 1		
			Strength (MPa)	Deflection (mm)	Ratio to previous measurement
1	6	#0011	64	2.48	1
2	6	#0021	62	2.55	1
3	6	#0031	53	3.02	1
4	6	#0041	54	2.93	1
5	6	#0051	123	1.3	1
6	6	#0061	73	2.19	1
7	6	#0071	72	2.22	1
8	6	#0081	55	2.9	1
9	6	#0091	76	2.09	1
10	6	#0101	63	2.52	1
11	6	#0111	45	3.54	1
12	6	#0121	88	1.81	1
13	6	#0131	88	1.8	1
13	78		70.46154	2.411538	1

Table 6 Results from drop 2 of case 1 measurements

Measurement code	Number of drops	Code of drop 2	Drop 2		
			Strength (MPa)	Deflection (mm)	Ratio to previous measurement
1	6	#0012	67	2.39	1.04
2	6	#0022	100	1.6	1.6
3	6	#0032	107	1.49	2.02
4	6	#0042	110	1.45	2.03
5	6	#0052	128	1.25	1.04
6	6	#0062	135	1.18	1.84
7	6	#0072	148	1.08	2.06
8	6	#0082	110	1.45	2
9	6	#0092	133	1.2	1.74
10	6	#0102	120	1.32	1.9
11	6	#0112	77	2.06	1.72
12	6	#0122	110	1.44	1.26
13	6	#0132	135	1.18	1.53
13	78		113.8462	1.468462	1.675385

Table 7 Results from drop 3 of case 1 measurements

Measurement code	Number of drops	Code of drop 3	Drop 3		
			Strength (MPa)	Deflection (mm)	Ratio to previous measurement
1	6	#0013	127	1.25	1.98
2	6	#0023	123	1.3	1.97
3	6	#0033	124	1.28	2.35
4	6	#0043	130	1.23	2.39
5	6	#0053	139	1.14	1.13
6	6	#0063	150	1.06	2.06
7	6	#0073	158	1.01	2.19
8	6	#0083	129	1.23	2.35
9	6	#0093	164	0.98	2.14
10	6	#0103	140	1.14	2.21
11	6	#0113	79	2	1.77
12	6	#0123	114	1.4	1.3
13	6	#0133	150	1.06	1.69
13	78		132.8462	1.236923	1.963846

Table 8 Results from drop 4 of case 1 measurements

Measurement code	Number of drops	Code of drop 4	Drop 4		
			Strength (MPa)	Deflection (mm)	Ratio to previous measurement
1	6	#0014	127	1.25	1.98
2	6	#0024	123	1.3	1.97
3	6	#0034	124	1.28	2.35
4	6	#0044	130	1.23	2.39
5	6	#0054	139	1.14	1.13
6	6	#0064	150	1.06	2.06
7	6	#0074	158	1.01	2.19
8	6	#0084	129	1.23	2.35
9	6	#0094	164	0.98	2.14
10	6	#0104	140	1.14	2.21
11	6	#0114	79	2	1.77
12	6	#0124	114	1.4	1.3
13	6	#0134	150	1.06	1.69
13	78		132.8462	1.236923	1.963846

Table 9 Results from drop 5 of case 1 measurements

Measurement code	Number of drops	Code of drop 5	Drop 5		
			Strength (MPa)	Deflection (mm)	Ratio to previous measurement
1	6	#0015	127	1.26	1.97
2	6	#0025	144	1.11	2.31
3	6	#0035	138	1.15	2.62
4	6	#0045	142	1.12	2.62
5	6	#0055	140	1.14	1.14
6	6	#0065	169	0.94	2.32
7	6	#0075	173	0.92	2.4
8	6	#0085	155	1.03	2.81
9	6	#0095	187	0.85	2.45
10	6	#0105	152	1.05	2.4
11	6	#0115	110	1.45	2.44
12	6	#0125	129	1.24	1.46
13	6	#0135	158	1.01	1.78
13	78		148	1.097692	2.209231

Table 10 Results from drop 6 of case 1 measurements

Measurement code	Number of drops	Code of drop 6	Drop 6		
			Strength (MPa)	Deflection (mm)	Ratio to previous measurement
1	6	#0016	149	1.07	2.32
2	6	#0026	151	1.06	2.41
3	6	#0036	141	1.13	2.67
4	6	#0046	144	1.11	2.64
5	6	#0056	139	1.15	1.13
6	6	#0066	174	0.92	2.39
7	6	#0076	176	0.91	2.43
8	6	#0086	169	0.94	3.07
9	6	#0096	187	0.85	2.45
10	6	#0106	155	1.03	2.45
11	6	#0116	119	1.34	2.64
12	6	#0126	128	1.24	1.46
13	6	#0136	156	1.02	1.77
13	78		152.9231	1.059231	2.294615

Figure 11 Comparison of base resistance from case 1 between drops on all measurements

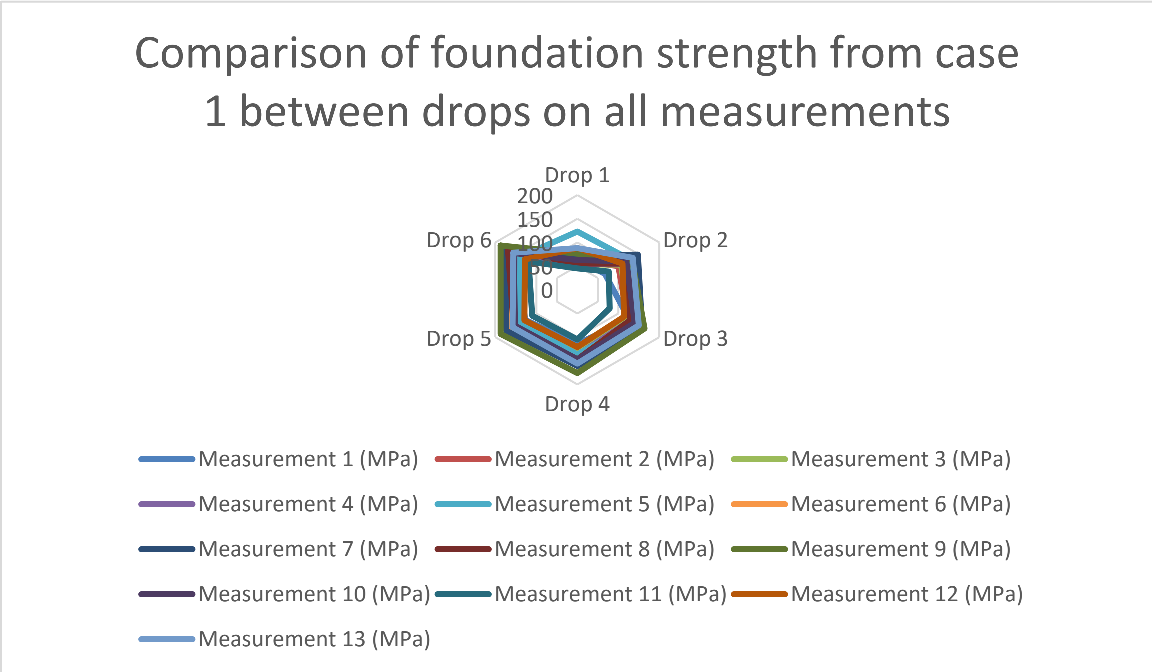
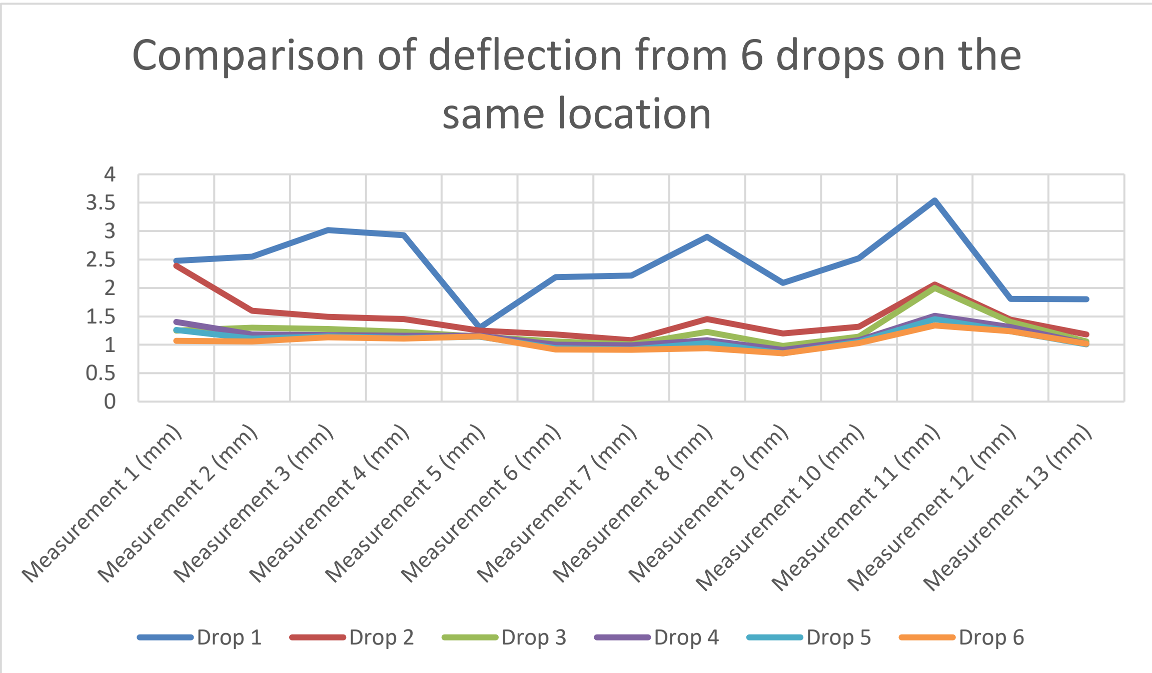


Figure 12 Comparison of deflection from 6 drops on the same location of case 1



5.2 Case 2 – Residential building, Särkiniementie 3, 00210 Helsinki (Device used: "LOADMAN II")

As part of analyzing this case, 64 drops have been executed on 8 separate locations, meaning that 8 drops were loaded for each location.

Table 11 Results from drop 1 of case 2 measurements

Measurement code	Number of drops	Code of drop 1	Drop 1		
			Strength (MPa)	Deflection (mm)	Ratio to previous measurement
1	8	#11	95	1.68	1
2	8	#21	75	2.11	1
3	8	#31	101	1.57	1
4	8	#41	89	1.79	1
5	8	#51	106	1.5	1
6	8	#61	121	1.32	1
7	8	#71	95	1.68	1
11	8	#111	90	1.77	1
8	64		96.5	1.6775	1

Table 12 Results from drop 2 of case 2 measurements

Measurement code	Number of drops	Code of drop 2	Drop 2		
			Strength (MPa)	Deflection (mm)	Ratio to previous measurement
1	8	#12	181	0.88	1.91
2	8	#22	132	1.21	1.75
3	8	#32	166	0.96	1.63
4	8	#42	166	0.96	1.86
5	8	#52	161	0.99	1.51
6	8	#62	181	0.88	1.5
7	8	#72	201	0.79	2.12
11	8	#112	145	1.1	1.61
8	64		166.625	0.97125	1.73625

Table 13 Results from drop 3 of case 2 measurements

Measurement code	Number of drops	Code of drop 3	Drop 3		
			Strength (MPa)	Deflection (mm)	Ratio to previous measurement
1	8	#13	190	0.84	2.01
2	8	#23	147	1.08	1.95
3	8	#33	181	0.88	1.78
4	8	#43	173	0.92	1.94
5	8	#53	163	0.98	1.53
6	8	#63	194	0.82	1.61
7	8	#73	214	0.74	2.26
11	8	#113	159	1	1.76
8	64		177.625	0.9075	1.855

Table 14 Results from drop 4 of case 2 measurements

Measurement code	Number of drops	Code of drop 4	Drop 4		
			Strength (MPa)	Deflection (mm)	Ratio to previous measurement
1	8	#14	194	0.82	2.04
2	8	#24	167	0.95	2.22
3	8	#34	183	0.87	1.8
4	8	#44	161	0.99	1.8
5	8	#54	169	0.95	1.59
6	8	#64	194	0.82	1.61
7	8	#74	225	0.71	2.37
11	8	#114	172	0.93	1.9
8	64		183.125	0.88	1.91625

Table 15 Results from drop 5 of case 2 measurements

Measurement code	Number of drops	Code of drop 5	Drop 5		
			Strength (MPa)	Deflection (mm)	Ratio to previous measurement
1	8	#15	200	0.8	2.11
2	8	#25	176	0.91	2.33
3	8	#35	174	0.92	1.71
4	8	#45	186	0.86	2.08
5	8	#55	181	0.88	1.7
6	8	#65	192	0.83	1.59
7	8	#75	228	0.7	2.4
11	8	#115	177	0.9	1.96
8	64		189.25	0.85	1.985

Table 16 Results from drop 6 of case 2 measurements

Measurement code	Number of drops	Code of drop 6	Drop 6		
			Strength (MPa)	Deflection (mm)	Ratio to previous measurement
1	8	#16	137	1.16	1.45
2	8	#26	170	0.94	2.25
3	8	#36	173	0.92	1.7
4	8	#46	188	0.85	2.11
5	8	#56	168	0.95	1.58
6	8	#66	208	0.77	1.72
7	8	#76	227	0.7	2.39
11	8	#116	186	0.86	2.06
8	64		182.125	0.89375	1.9075

Table 17 Results from drop 7 of case 2 measurements

Measurement code	Number of drops	Code of drop 7	Drop 7		
			Strength (MPa)	Deflection (mm)	Ratio to previous measurement
1	8	#17	194	0.82	2.05
2	8	#27	180	0.89	2.39
3	8	#37	196	0.82	1.92
4	8	#47	198	0.8	2.23
5	8	#57	182	0.88	1.71
6	8	#67	221	0.72	1.83
7	8	#77	235	0.68	2.47
11	8	#117	172	0.93	1.91
8	64		197.25	0.8175	2.06375

Table 18 Results from drop 8 of case 2 measurements

Measurement code	Number of drops	Code of drop 8	Drop 8		
			Strength (MPa)	Deflection (mm)	Ratio to previous measurement
1	8	#18	189	0.84	1.99
2	8	#28	184	0.87	2.44
3	8	#38	196	0.81	1.93
4	8	#48	200	0.8	2.24
5	8	#58	146	1.09	1.38
6	8	#68	208	0.77	1.72
7	8	#78	235	0.68	2.47
11	8	#118	188	0.85	2.09
8	64		193.25	0.83875	2.0325

Figure 13 Comparison of base resistance from case 2 between drops on all measurements

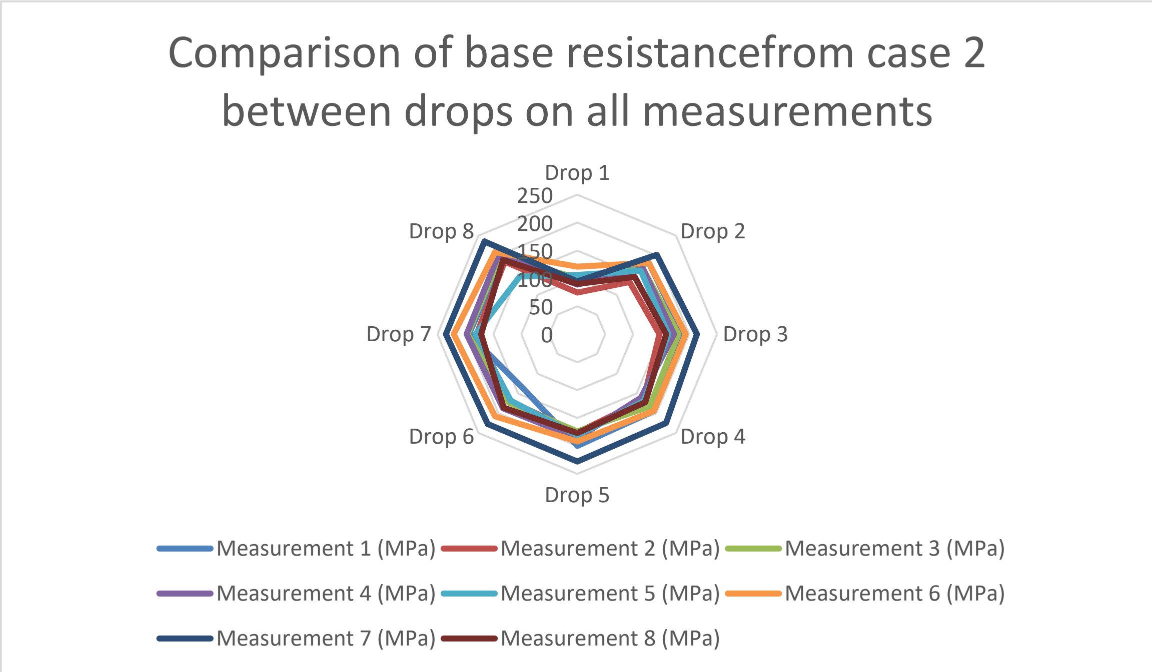
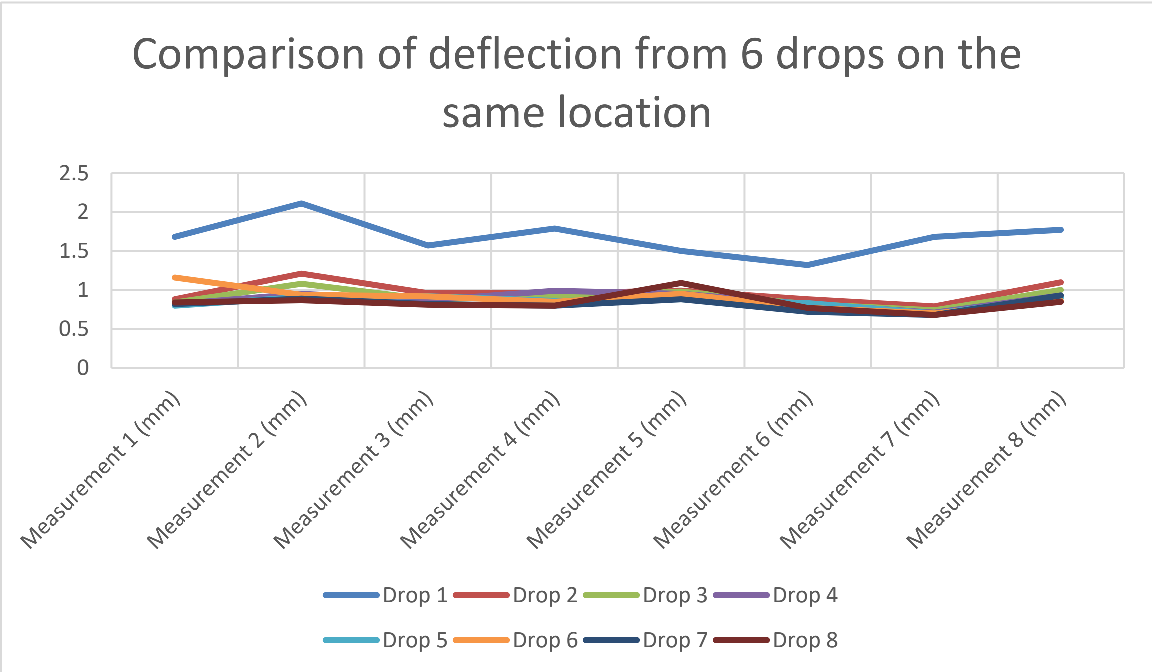


Figure 14 Comparison of deflection from 6 drops on the same location of case 2



5.3 Case 3 – Family house, Prishtina, Kosovo (Device used: "Terratest 4000")

In this case, the subject was a small family house located in Kosovo, where Terratest 4000 was used as the measuring devices. 3 locations in the building site have been measured to calculate data given in tables 16, 17 and 18 below.

Table 19 Locations of 3 measurements with Terratest 4000 and deflection on the first 3 drops of each measurement

Number	GPS Location		Strength E_{Vd} (MPa)	Deflection from 3 initial drops (mm)
	N	E		
1	42° 34.2809'	21° 07.6120'	91.8	0.1
2	42° 34.3007'	21° 07.5948'	68.4	0.1
3	42° 34.3293'	21° 07.6425'	56	0.1

Table 20 Deflection from drops 4,5,6 of locations corresponding to table 16, their average and ratio to velocity v

Number	Deflection s (mm)			Average (mm)	s/v (ms)
	Drop 4 (mm)	Drop 5 (mm)	Drop 6 (mm)		
1	0.245	0.244	0.246	0.245	2.053
2	0.348	0.332	0.307	0.329	2.586
3	0.416	0.413	0.377	0.402	2.512

Table 21 Velocity from drops 4,5,6 of locations corresponding to table 16, their average and ratio to deflection s

Number	Velocity v (mm/s)			Average (mm/s)	s/v (ms)
	Drop 4 (mm/s)	Drop 5 (mm/s)	Drop 6 (mm/s)		
1	118.9	119.9	119.1	119.3	2.053
2	133.2	127.8	120.6	127.2	2.586
3	162.8	164.3	153	160	2.512

6 Examination of results and conclusions

The results found from Case 1 - Single family house, Kottaraisentie 2, 02660 Espoo (Device used: "LOADMAN II" , Case 2 – Residential building, Särkiniementie 3, 00210 Helsinki (Device used: “LOADMAN II”) and Case 3 - Family house, Prishtina, Kosovo (Device used: "Terratest 4000") have provided information that shows the differences and similarities between the two types of light weight deflectometers used. In the first two cases, “LOADMAN II” has been used on two different conditions. The first case had a smaller base, with layers of gravel size varying from 400 mm stones to 30 mm stones, including geotextile layers below. During the measurement process, no construction work was ongoing, meaning that the devices results were not affected anyhow by anything other than the resistance of the base layers itself.

In the second case, the area of the base was much bigger and separated in two parts to prepare, due to the need for a pipe area to be excavated in the middle. In this case, there was construction work ongoing during measurements, including one part of the base still being compressed by a roller, which affected the performance of the device. If compared, tables 11, 12, 13, 14, 15, 16, 17 and 18 show a spike in results which is not common in a deflectometer’s performance. E.g., measurement 1 of case 2 from all tables, include drops with code #11, #12, #13, #14, #15, #16, #17 and #18 (See in before mentioned tables: Code of drop: #number). Drops #11 to #15 show an increasing resistance and decreasing deflection which is normal for this process, but drop 16 shows the opposite, because the layers were affected at that moment by roller vibrations. The same situation occurs again till drop 17, before decreasing resistance again during drop 18, also because the device was affected by vibrations.

A similarity between “LOADMAN II” performances in both cases, was that the value of first drop on each measurement, changes a lot. This happened due to the highest layer of the base being most affected by vibrations, as it is normally the most brittle layer, hence affected by a dropping load much more. In contrast, the bottom layers which are the strongest ones, show a higher resistance and smaller deflection.

In case 3, “Terratest 4000” has been used as measuring device. Differently from “LOADMAN II” which has up to 9 drops available by default, “Terratest 4000” has a set number of drops for each measurement, where each one requires exactly 6 drops. The first 3 drops are the initial drops, and their purpose is to balance and calibrate the device. Usually these first 3 drops give the same deflection, as it is shown on table 16. The last 3 drops measure the deflection, resistance, and velocity, giving an average for result as shown in table 16, 17 and 18. During case 3, there was no ongoing work close to the measuring location, which similarly as the first case, worked in benefit of the device, providing more accurate result.

6.1 Conclusions

In conclusion, both devices showed similar precision and performance under similar conditions, however “LOADMAN II” provided less accurate results on sites with larger soil amount on the base and more errors when it was affected by other factors, such as vibrations. Both devices are quite easy to use and carry-on sites and provide particularly valuable information about the base.

The results achieved by this research can be used to further analyze the performance of light weight deflectometers and other falling weight deflectometers in different construction sites and compare their features.

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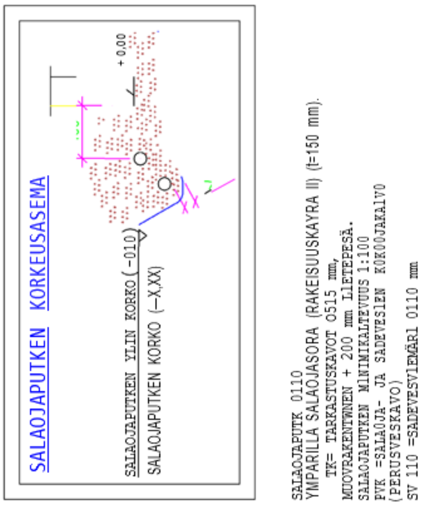
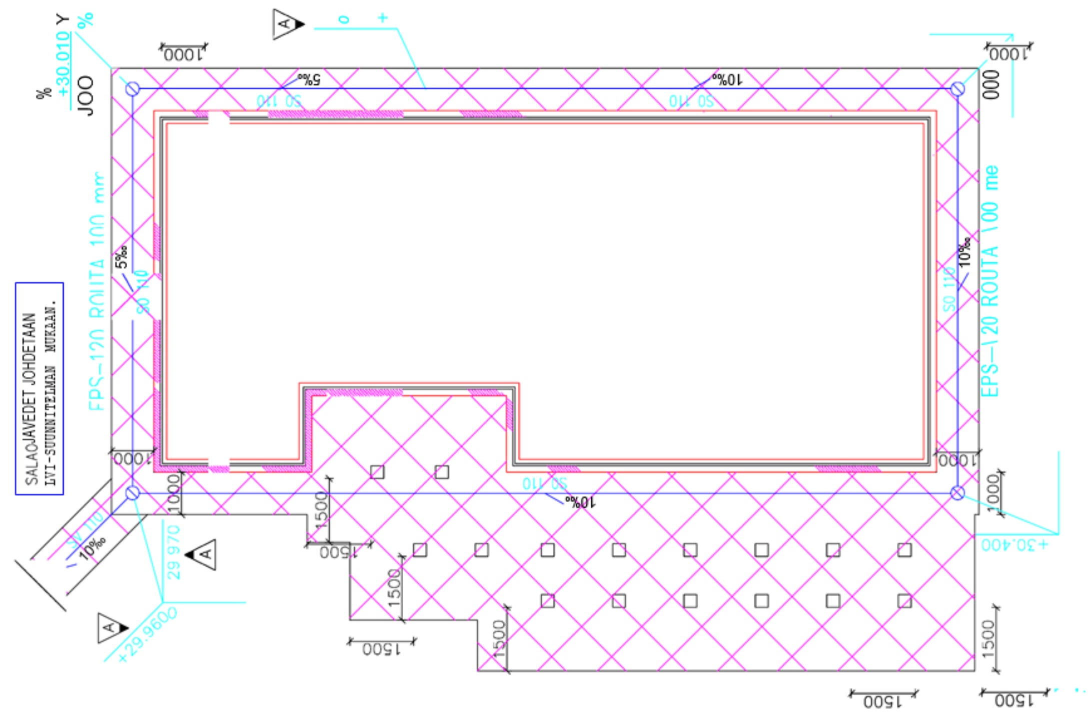
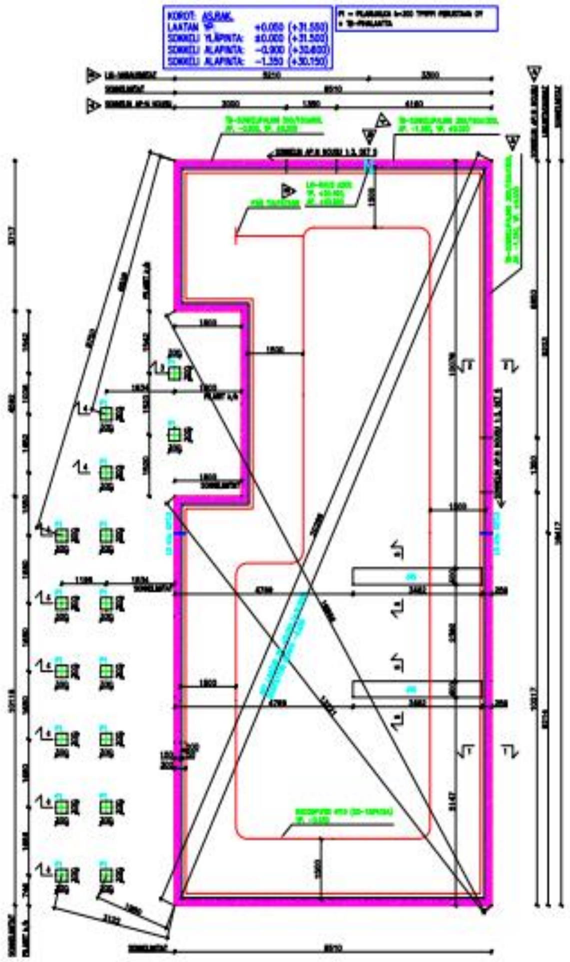
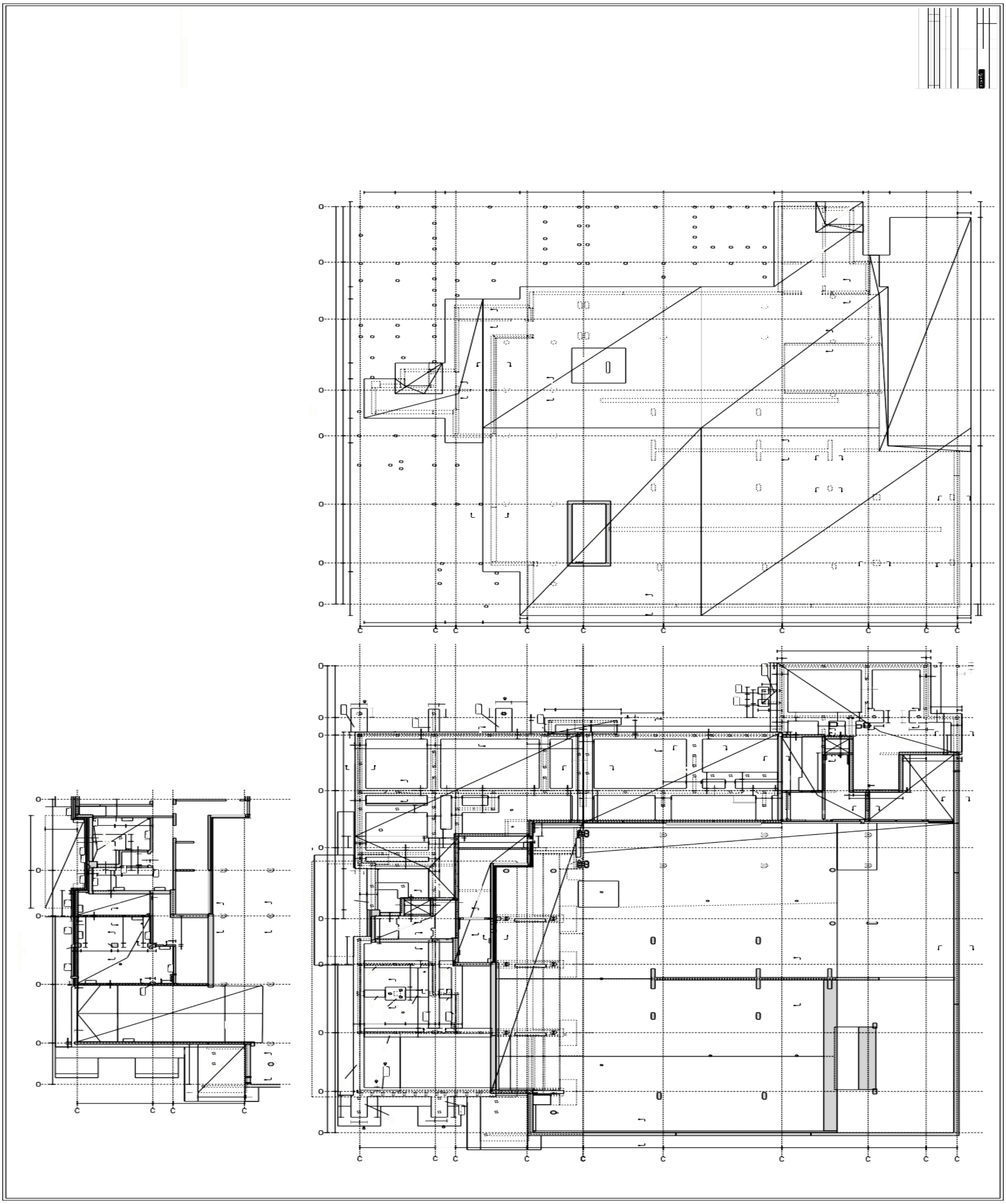
Appendix 1: Drawing of family house plan from Case 1 –Single family house, Kottaraisentie 2, 02660 Espoo






KOROT: AS.RAK.
LAATAN YP: +0.050 (+31.550)
SOKKELI YLÄPINTA: ±0.000 (+31.500)
SOKKELI ALAPINTA: −0.900 (+30.600)
SOKKELI ALAPINTA: −1.350 (+30.150)
5210
3300
8510
3050
1300
4160

Appendix 2: Drawings from [Case 2 – Residential building, Särkiniementie 3, 00210 Helsinki] including top view of the buildings structure, front view of the buildings structure and document of structural types of the building belonging to the base



Tunnus	Päiväys	Muutos	Muuttanut	Päiväys	Tarkastanut
E	6.5.2022	Päivitetty YP6	HENKO		
D	26.4.2022	Lisätty KS3	LOO		
C	19.4.2022	Päivitetty YP 3, 4, 5, lisätty AP 5, 6, YP 7, 8	HEIKAU		
B	15.2.2022	Lisätty VP 8	HEIKAU		
A	4.2.2022	Päivitetty YP 6, poistettu eristeet			
		Päivitetty YP 1 kevytsorayläpohjaksi	SARKA		

Vastaava rakennesuunnittelija (nimi, tutkinto, allekirj.)	Päiväys
Jarno Pausio, ins (amk). 01.08.2021 alkaen Esko Jussila, DI	14.4.2021

K.osa/Kylä	Kortteli/Tila	Tontti/Rno	Viranomaisten merkintöjä
31	120	14	LP-091-2020-11607

Rakennustoimenpide: UUDISRAKENNUS

Piirustuslaji: RAKENNE

Juokseva no:

Rakennuskohteen nimi ja osoite:

AS OY HELSINGIN SÄRKINIEMENPUISTO
Särkiniementie 3 b
00210 Helsinki

Piirustuksen sisältö: RAKENNETYYPIT

Mittakaava: 1:10

RAMBOLL

Ramboll Finland Oy
Itsehallintokuja 3, PL 25
02601 Espoo
puh. 020 755 611
etunimi.sukunimi@ramboll.fi

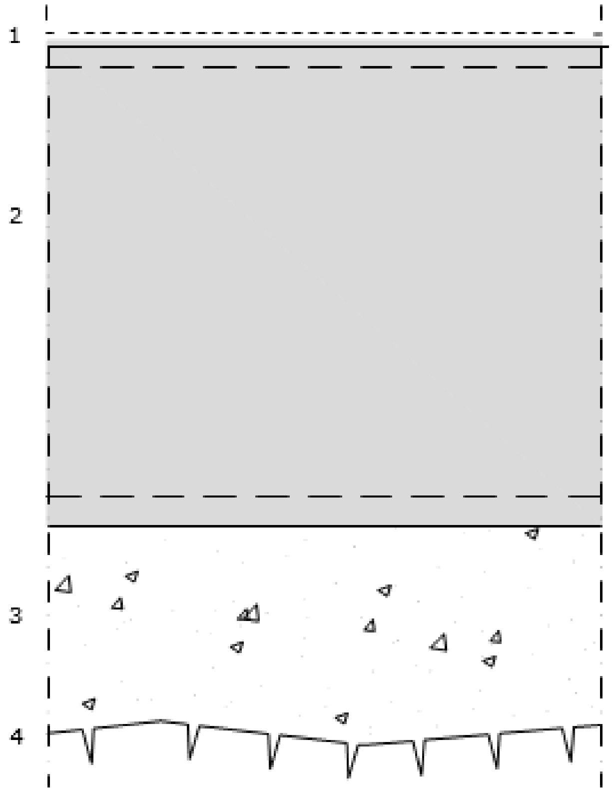
Suunn.ala	Työnumero	Tiedosto
RAK	1510060023	r+++rt101.dwg

Piirustusno	Muutos
R+++RT101	E

Suunnittelija (nimi, tutkinto, allekirj.): Jarno Pausio, ins (amk)

Piirt.	Tark.	Päiväys
JAPAU	KSU	31.12.2021

Suunnittelija	Työnumero		
RAMBÖLL	1510060023		AP 1
	Päiväys 4.6.2021	Tekijä JAPAU	
Rakennuskohde AS OY HELSINGIN SÄRKINIEMENPUISTO	Sisältö K2-KELLARIN VESITIIVIS ALAPOHJA		



1 Diffuusioavoin pintamateriaali ja -käsittely huoneselostuksen mukaan

700 mm — 2 Xypex-lisäaineistettu vesitiivis teräsbetonilaatta, C25/30, raudoitus rakennesuunnitelmien mukaan
- laatuluokitus BY 45 2018 luokka A-4-I (käytävä) tai A-3-III (päällystettävät lattiat, sisätilat) tai B-2-I-K (autohalli)
- tiiviysluokka 1
- halkeamaleveys ≤ 0,2 mm

>300 mm — 3 Sorapatja /täyttö, ks. pohjarakennussuunnitelmat

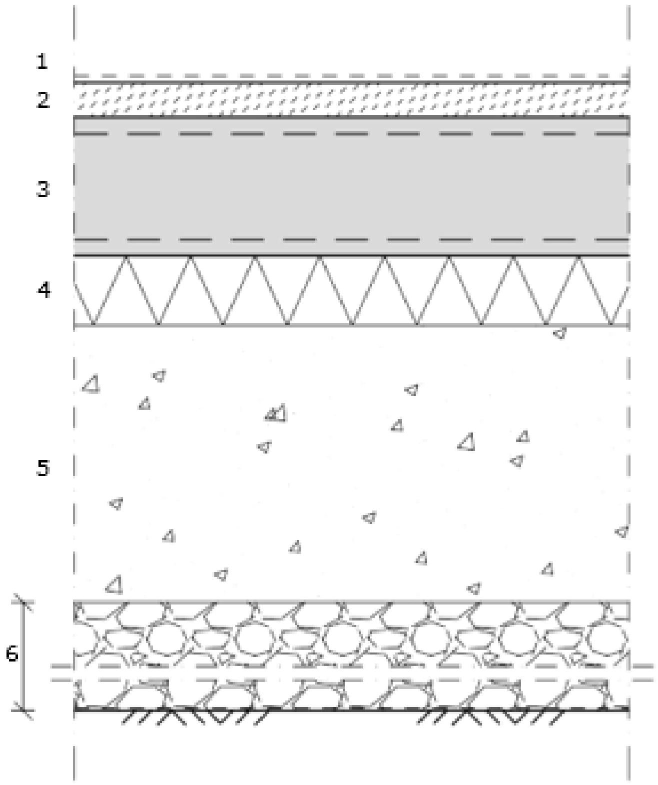
4 Louhittu kallio

Toteutus- ja suunnitteluohjeet:

- lattiabetonin maksimiraekoko vähintään 32 mm, karkeimman kiviainesfraktion osuuden kiviaineksesta suositeltavaa olla vähintään 30 % ja # 4 mm seulan läpäisyarvon hiukan yli 50 % yhdistetyssä rakeisuuskäyrässä
- sementtiliima hiotaan pois laatan pinnasta 2 viikon jälkeen valusta, kuivumisen ja mahdollisen tartuntapinnan parantamiseksi
- vesihöyrytiiviitä päällysteitä ei saa käyttää
- työsaumat ja saumajako erikoispiirustuksen mukaan
- mahdollinen lattialämmitys LVI-suunnitelmien mukaan

Lämmönläpäisykerroin: ---
Suunnittelukäyttöikä: 50 vuotta

Suunnittelija	Työnumero		
RAMBOLL	1510060023		AP 2
	Päiväys	Tekijä	
	4.6.2021	JAPAU	
Rakennuskohde	Sisältö		
AS OY HELSINGIN SÄRKINIEMENPUISTO	K1-KELLARIN VESITIIVIS ALAPOHJA SIVU 1/2		



Suunnittelija	Työnumero		
RAMBOLL	1510060023		AP 2
	Päiväys: 4.6.2021	Tekijä: JAPAU	
Rakennuskohde: AS OY HELSINGIN SÄRKINIEMENPUISTO	Sisältö: K1-KELLARIN VESITIIVIS ALAPOHJA SIVU 2/2		

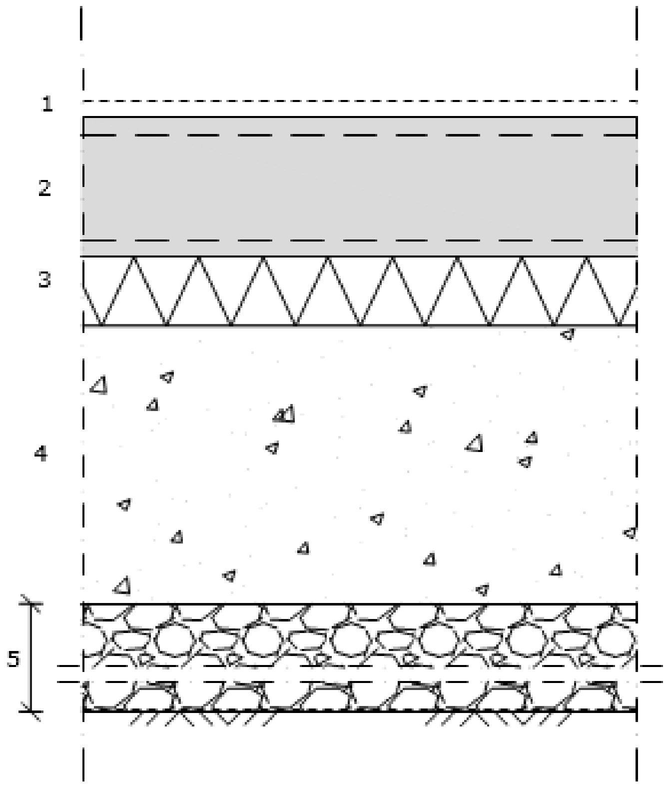
	1 Diffuusioavoin pintamateriaali ja -käsittely huoneselostuksen mukaan
≥ 50 mm	2 Teräshierretty tasausbetoni - laatuluokitus BY 45 2018 luokka A-4-I (käytävä) tai A-3-III (päällystettävät lattiat, sisätilat) - rasitusluokka XC1 (BY 65 2016)
≥ 200 mm	3 Xypex-lisäaineistettu vesitiivis teräsbetonilaatta, C25/30, raudoitus rakennesuunnitelmien mukaan - tiiviysluokka 1 - halkeamaleveys ≤ 0,2 mm
100 mm	4 Lämmöneriste paisutettua polystyreenimuovia, λ_{Design} ≤ 0,037 W/mK. Lyhytaikainen puristuskestävyys 100 kPa, esim. EPS 100 Lattia. Laipalliset rst-kiinnikkeet Ø4,0 ≥ 4 kpl/m2.
> 400 mm	5 Tiivistetty salaojituksen luokan 1a (RIL 126-2009 kuva 3.6) vaatimukset täyttävä sepeli tai kuivaseulottu sepeli #6-16...32, tiivistys >92% (parannetulla Proctor-kokeella) Salaojitus: RT-ohjekortin 81-11000 mukaisesti Radonputkitus: RT-ohjekortin 103123 mukaisesti
	6 Perusmaa / tiivistetty murskekerros, kallistus salaojiin 1:50 / täyttö, ks. pohjarakennussuunnitelmat Suodatinkangas N2 perusmaan päällä

Toteutus- ja suunnitteluohjeet:

- lattiabetonin maksimiraekoko vähintään 16 mm, karkeimman kiviainesfraktion osuuden kiviaineksesta suositeltavaa olla vähintään 30 % ja # 4 mm seulan läpäisyarvon hiukan yli 50 % yhdistetyssä rakeisuuskäyrässä
- raudoitus detalji- ja tasopiirustusten mukaan
- betonilaatan suurin sallittu kosteuspitoisuus ennen pintamateriaalin asennusta BY47 2019 kohdan 4.4.2 mukaan tai materiaalin ilmoittama arvo, jos alempi
- sementtiliima hiotaan pois laatan pinnasta 2 viikon jälkeen valusta, kuivumisen ja mahdollisen tartuntapinnan parantamiseksi
- vesihöyrytiiviitä päällysteitä ei saa käyttää
- työsaumat ja saumajako erikoispiirustuksen mukaan
- mahdollinen lattialämmitys LVI-suunnitelmien mukaan
- humusmaa poistetaan ennen sepelikerroksen asennusta
- tasausbetonin teko-ohjeet:
  - laatan pinnan oltava puhdas tartuntaa heikentävistä epäpuhtauksista pöly, öljy yms.
  - tartuntaa voidaan parantaa tarvittaessa muovidispersioaineilla
  - laatan pinta ei saa olla liian kuiva, eikä sen päällä saa olla vettä, liian kuiva pinta on kasteltava 1 vrk ennen pintavalua, pinnan tulee olla "mattakostea"
  - pinnan lämpötila tulee olla yli +5 °C
  - betonin harjaus pintaan työn edetessä

Lämmönläpäisykerroin: U = 0,16 W/m²K
Suunnittelukäyttöikä: 50 vuotta

Suunnittelija	Työnumero		
RAMBOLL	1510060023		AP 5
	Päiväys 4.6.2021	Tekijä ABV	
Rakennuskohde	Sisältö		
AS OY HELSINGIN SÄRKINIEMENPUISTO	AJOLUISKAN VESITIIVIS ALAPOHJA SIVU 1/2		



Suunnittelija	Työnumero		
RAMBOLL	1510060023		AP 5
	Päiväys: 4.6.2021	Tekijä: ABV	
Rakennuskohde	Sisältö		
AS OY HELSINGIN SÄRKINIEMENPUISTO	AJOLUISKAN VESITIIVIS ALAPOHJA SIVU 2/2		

1 Diffuusioavoin pintamateriaali ja -käsittely huoneselostuksen mukaan

200 mm — 2 Xypex-lisäaineistettu vesitiivis teräsbetonilaatta, C25/30, raudoitus rakennesuunnitelmien mukaan
- laatuluokitus BY 45 2018 luokka A-4-I (käytävä) tai A-3-III (päällystettävät lattiat, sisätilat)
- Rasitusluokka XC3,4,XF2;XD1 (BY 68 2016)
- tiiviysluokka 1
- halkeamaleveys ≤ 0,2 mm

100 mm — 3 Lämmöneriste paisutettua polystyreenimuovia, λ_{Design} ≤ 0,037 W/mK. Lyhytaikainen puristuskestävyys 100 kPa, esim. EPS 100 Lattia.

> 400 mm — 4 Tiivistetty salaojituksen luokan 1a (RIL 126-2009 kuva 3.6) vaatimukset täyttävä sepeli tai kuivaseulottu sepeli #6-16...32, tiivistys >92% (parannetulla Proctor-kokeella)
Salaojitus: RT-ohjekortin 81-11000 mukaisesti
Radonputkitus: RT-ohjekortin 103123 mukaisesti

5 Perusmaa / tiivistetty murskekerros, kallistus salaojiin 1:50 / täyttö, ks. pohjarakennussuunnitelmat
Suodatinkangas N2 perusmaan päällä

Toteutus- ja suunnitteluohjeet:

- lattiabetonin maksimiraekoko vähintään 16 mm, karkeimman kiviainesfraktion osuuden kiviaineksesta suositeltavaa olla vähintään 30 % ja # 4 mm seulan läpäisyarvon hiukan yli 50 % yhdistetyssä rakeisuuskäyrässä
- raudoitus detalji- ja tasopiirustusten mukaan
- betonilaatan suurin sallittu kosteuspitoisuus ennen pintamateriaalin asennusta BY47 2019 kohdan 4.4.2 mukaan tai materiaalin ilmoittama arvo, jos alempi
- sementtiliima hiotaan pois laatan pinnasta 2 viikon jälkeen valusta, kuivumisen ja mahdollisen tartuntapinnan parantamiseksi
- vesihöyrytiiviitä päällysteitä ei saa käyttää
- työsaumat ja saumajako erikoispiirustuksen mukaan
- mahdollinen lattialämmitys LVI-suunnitelmien mukaan
- humusmaa poistetaan ennen sepelikerroksen asennusta

Lämmönläpäisykerroin: U = 0,16 W/m²K
Suunnittelukäyttöikä: 50 vuotta