Polymer pillar, a new innovation for underpinning.

Colonne de polymère, une nouvelle innovation comme support de fondation.

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ABSTRACT: A new innovation, polymer pillar, has been developed for small and light weight buildings where the settlement of the structure or the building must be stopped or the rate of settlement must be decreased. Polymer pillar is a patented product where expanding high density geopolymer is injected inside a geotextile tube. Depending on the soil conditions, the polymer pillar can establish geotechnical bearing capacity with several ways. The tip of the pillar can be extended to a hard soil layer for an end bearing pillar. With thick sand and silt layers polymer pillars can be used as friction pillars. If there is a thick clay layer, they can be used as cohesion pillars. Polymer pillar can also be used to compact loose friction soils. While injected, the pillars volume expands to one hundred times the size of the pillar element. The soil around the pillar displaces and compacts. Polymer pillars have been used in several underpinning projects around the world. The projects have taken place in many countries: The Great Britain, Finland, Sweden, Australia, New Zealand, Belgium, The Netherlands and Germany. Totally there have been over 500 projects so far.

RÉSUMÉ : Une nouvelle innovation, la colonne de polymère, a été développée pour des bâtiments légers et petits, afin d'arrêter ou diminuer le taux des tassements. La colonne de polymère est un produit breveté, dans lequel une géopolymère expansive de haute densité est injecté dans un tube géotextile. Selon les conditions du sol, la colonne de polymère peut établir une capacité portante géotechnique à plusieurs façons. L'extrémité de la colonne peut atteindre une couche de sol dur pour une colonne qui porte les charges à la pointe. Dans les couches épaisses du sable et du limon, les colonnes de polymères peuvent être utilisées comme des colonnes travaillant en frottement. S'il ya une couche d'argile épaisse, elles peuvent être utilisées comme des colonnes cohésives. La colonne de polymère peut également être utilisée pour compacter les sols lâches. Pendant l'injection et l'expansion, le volume de la colonne s'étend à une centaine de fois de la taille de l'élément de base. Le sol autour des colonnes est déplacé et compacté. Les colonnes de polymères ont été utilisées dans plusieurs projets de support de fondations autour du monde. Les projets ont eu lieu dans plusieurs pays: au Royaume-Uni, la Finlande, la Suède, l'Australie, la Nouvelle-Zélande, la Belgique, les Pays-Bas et en Allemagne. En total, plus que 500 projets ont été réalisés à ce jour.

KEYWORDS: polymer pillar, PowerPile, geopolymer, underpinning.

1 INTRODUCTION

The need for underpinning houses and structures has been increasing around the world. Most of the urban areas are close to the waterfront, where the soil is usually soft (Lehtonen, 2011). Also the value of the land has increased, the good ground for construction has often already been used and the quality standards for buildings have tightened.

Polymer pillar is a new innovation for underpinning. The basic idea of polymer pillar is to accomplish underpinning for old houses with minimal disturbance. The use of polymer pillars minimizes the disturbance for the old foundation structures and also for the use of the building during the installation.

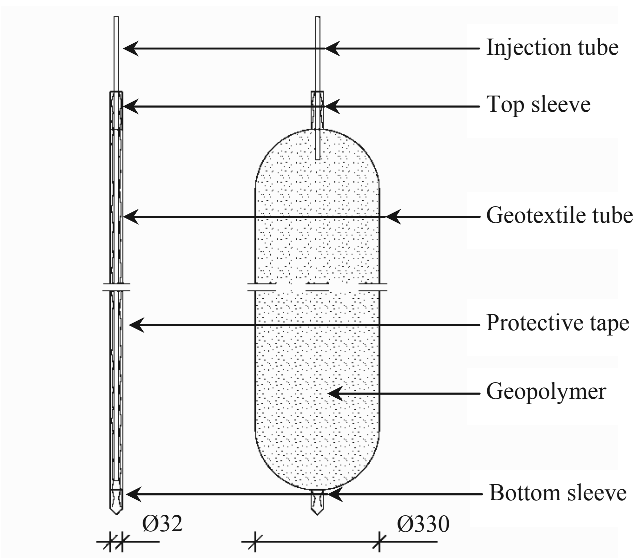
1.1 *The use of polymer pillars*

Polymer pillars are used to stop or to reduce the settlement of old building or structure. Usually polymer pillars are used under light weight buildings like 1 to 2 storey one family houses or row houses.

There have been also some test projects on roads. In those projects the settlement of the road in deep clay areas has been reduced with cohesion polymer pillars.

1.2 *The structure of the polymer pillar*

The polymer pillar element is a slender tube. Outside diameter of the element is only 32 millimeters. The element consist of metallic injection tube, very tightly wrapped geotextile tube and metallic sleeves on both ends. The element can be bent. The minimum radius of bending is around 1.5 meters. This enables installation in very low spaces like old cellars.



Picture 1. Polymer pillar element and injected polymer pillar.

During the installation the element is filled with expanding geopolymer. The geopolymer fills the geotextile tube and the diameter of polymer pillar increases. After the installation the diameter of the polymer pillar is approx. 330 millimeters. The final diameter depends on the counter pressure of the soil and the amount of geopolymer injected.

1.3 *Installation*

The polymer pillars are installed directly under the old foundation. First there will be a hole drilled through the foundation. The diameter needed for the hole is only 65 millimeters.

After the hole has been drilled, the casing is installed through the hole to the ground. The casing is only temporary aid and it will be removed after the installation of pillar element. The casing can be made either from plastic or steel, depending on the soil conditions. The steel casing is normally used on very soft clayey soils.

The injection of pillar is made through the injection tube inside the element. The injection tube is pulled up simultaneously with the injection. Therefore the element is filled continuously from bottom to top. The amount of injected geopolymer per linear meter can be adjusted by chancing the pulling speed of injection tube.

The injection is continued until it reaches the bottom of the old foundation. The level of the old structure is monitored during the injection. Usually injection will be stopped when there is approx. 1 to 2 millimeters of raise in the structure.

1.4 *Materials used*

The polymer pillar is a composition of geotextile and geopolymer. The geotextile at the outside surface of the pillar keeps the geopolymer in specified space. This ensures certain diameter for polymer pillar. With specific diameter and specific amount of geopolymer injected per linear meter, the structural capacity of polymer pillar is designable.

The geotextile has very high tensile strength. It is designed particularly to be used in polymer pillars. The geotextile also allows small amount of geopolymer to pass through. This feature actually helps gaining good grip with surrounding soil.

The geopolymer consists of several components. There are also several different geopolymers to be used. Choose of the geopolymer depends on the properties of the surrounding soil.

The materials are environmentally safe. There have been a lot of tests for the materials. These tests show that the ground water has no effect on the materials. On the other hand the materials have no effect on the ground water (Sauerwald 1994, Kwarteng and Füchtjohann 2011). The materials have also good or excellent resistance against several chemicals i.e. gasoline, mineral oil, sodium hydroxide and ammonium hydroxide (van der Wal 2010).

2 STRUCTURAL BEHAVIOR

The structural behavior of polymer pillars has been tested with three samples. The samples were cut from polymer pillars that were dig from ground. The original polymer pillars were used to test the geotechnical capacity of polymer pillars in Turku as described in chapter 3.

The measures of the samples are shown in Table 1. The length of samples varies, because it was not possible to get original pillars from ground as whole. The grip between ground and pillars were so strong that the pillars got broken into two or more pieces.

Table 1. Measures of the samples.

	2	4	5
Lenght L (mm)	850	589	499
Diameter D_1 (mm)	321	358	357
Diameter D_2 (mm)	320	263	264
Cross Section A (mm^2)	80676	73948	74022

Sample 2 is from original pillar T7 and samples 4 and 5 are from original pillar T3.

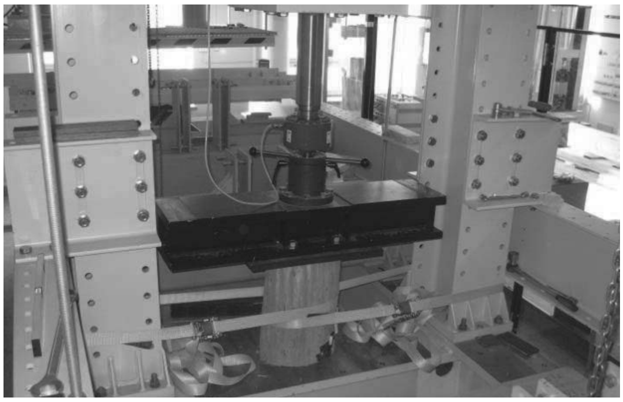
The samples were slightly ellipse. Therefore the smallest and biggest diameter was measured and the cross section was calculated with equation 1.

$$A = \pi \cdot D_1 \cdot D_2 \quad (1)$$

2.1 *Stress-strain behavior*

The elastic behavior of polymer pillars was tested in laboratory of Turku University of Applied Sciences. The maximum compression capacity of test facility was 450 kN. With that compression force the samples did not break.

At the test the compression force was increased at the rate of 5 kN/minute. The test arrangement is shown in picture 2.



Picture 2. Test arrangement for Stress-strain behavior.

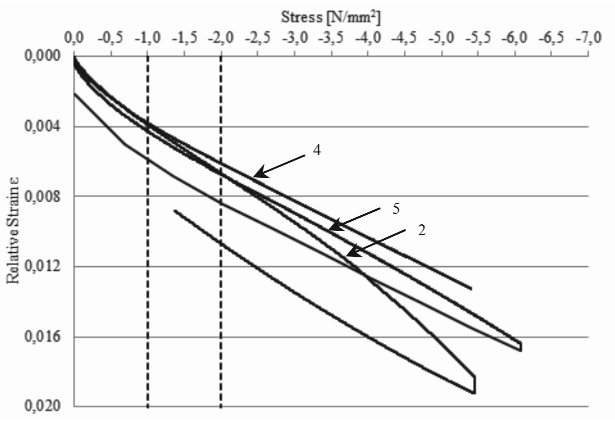


Figure 1. Stress-strain behavior of the samples.

As shown in Figure 1, the elastic modulus of the material is not constant. It varies little depending on the stress level. The elastic modulus was determined at the stress range from 1.0 N/mm² to 2.0 N/mm². This stress range represents the average stress level of the polymer pillars in serviceability state.

The curve of sample 4 ends sooner than other curves. That is because of a malfunction in a computer operating the hydraulic jack. It suddenly just stopped the test and lifted the jack up. Therefore there is no data from release.

Table 2. Elastic modulus at compressive stress range from 1.0 N/mm^2 to 2.0 N/mm^2.

	2	*4*	*5*
E (N/mm^2)	254	304	274

3 GEOTECHNICAL CAPACITY

So far there have only been two load tests for the cohesive polymer pillar. Both of the load tests have taken place in Southwest of Finland. The first load test was in June 2010 in city of Turku. The second load test was in November 2012 in city of Salo.

Both of the load tests were made in co-operation with Tampere University of Technology. The pillars were tested until they could not hold the load any more.

The test pillars are named with a letter T or S depending on the city and a number.

3.1 *Load test in Turku, 2010*

The load test was accomplished at the front yard of a test project. The polymer pillars for the load test were installed into a soft clay layer. Undrained shear strength of the clay was measured with vane test and the result was 15 kPa.

Total of five polymer pillars were tested. The top of each pillar was excavated to sight and they were cut to achieve smooth surface for loading. Therefore the lengths of pillars are not equal. The lengths of pillars and amounts of injected geopolymer are shown in Table 3.

Table 3. Tested polymer pillars in Turku 2010.

	T2	*T3*	*T4*	*T6*	*T7*
Original length (m)	4.0	4.0	4.0	4.0	8.0
Tested length (m)	3.65	3.53	3.54	3.00	6.21
Total injection (kg)	210.5	165.8	196.0	142.5	300.8
Injection (kg/m)	52.6	41.4	49.0	35.6	37.6

The arrangement of the load test is shown in Picture 3. The loading was achieved with hydraulic jack against steel beam and counterweights. Applied load was measured with load sensor and the movement was measured as relative to normal ground surface.

Picture 3. Arrangement of the load test in Turku 2010.

The load-movement curve was drawn from the results as shown in Figure 2. Because of different lengths of pillars, the load-movement curve does not give the information needed. Therefore was needed to calculate the shear stress between shaft of pillar and clay. The shear stress-movement curve is shown on Figure 3.

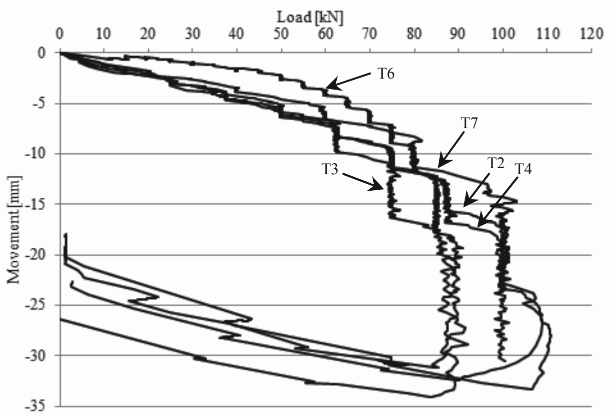


Figure 2. Load-movement curves of the load test in Turku 2010.

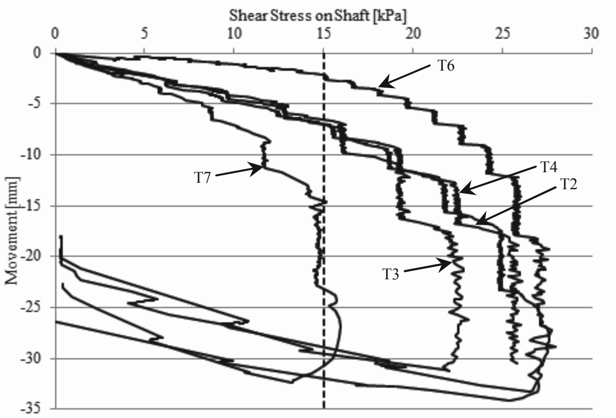


Figure 3. Shear stress-movement curve of the load test in Turku 2010. The measured C_u value of the clay is shown with dashed line.

The installation on test pillar T7 was not succeeded. There had been some problems with the injection pump during the injection. Nevertheless it was decided to be tested. The result is significantly worse than the result of the shorter pillars.

With other pillars the test succeeded. The test shows the cohesive grip between pillar and clay is good. The shear stress between the shaft of the pillar and the clay is bigger than the undrained shear strength of the clay. Partly this can be explained with the speed of the load test. Each load step was 30 minutes and the entire loading took about 4 hours per pillar.

3.2 *Load test in Salo, 2012*

This load test was also accomplished at the front yard of a test project. The polymer pillar for the load test was installed into a soft clay layer. Undrained shear strength of the clay was measured with vane test and the result was 10 kPa.

Only one pillar was tested at this site. The preparing procedure for pillar was similar to the test pillars in Turku. The length of pillar and the amount of injected geopolymer is shown in Table 4.

Table 4. Tested polymer pillar in Salo 2012.

	S1
Original length (m)	3.0
Tested length (m)	2.36
Total injection (kg)	90.0
Injection (kg/m)	30.0

The arrangement of the load test is shown in picture 4. The basic idea of the arrangement was similar to the load test in Turku. The loading was again achieved with hydraulic jack against steel beam and counterweights. Applied load was measured with load sensor and the movement was measured as relative to normal ground surface.

Picture 4. Arrangement of the load test in Salo 2012.

The load-movement curve was drawn from the results as shown in Figure 4. As a comparison to the test pillars in Turku, the shear stress-movement curve was also drawn. The shear stress-movement curve is shown on Figure 5.

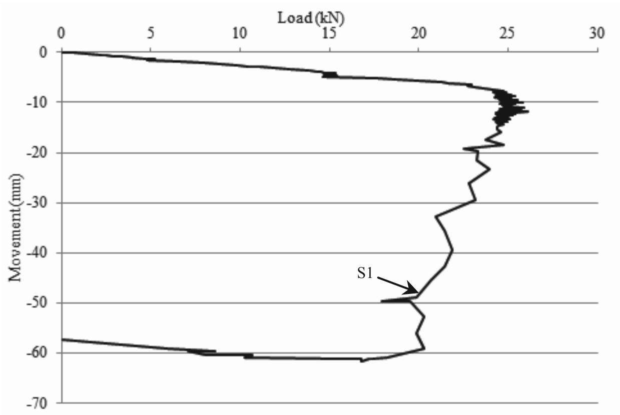


Figure 4. Load-movement curve of the load test in Salo 2012.

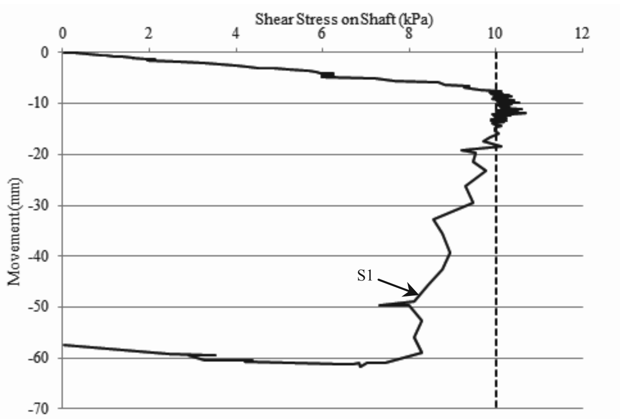


Figure 5. Shear stress-movement curve of the load test in Salo 2012. The measured C_u value of the clay is shown with dashed line.

The load steps in Salo were estimated a bit too high. Therefore there were only 3 steps before the failure of the pillar.

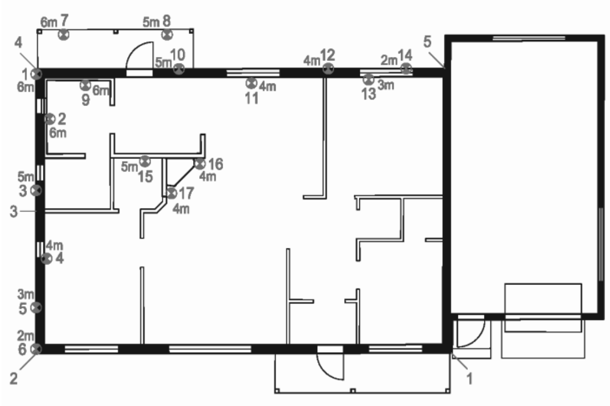
The ratio between shear stress and undrained shear stress of the clay was not as big in Salo as it was in Turku. Reason for this is probably the size of the load steps.

4 MONITORING OF SETTLEMENT

There have been monitoring of settlements in some test projects in Finland. Unfortunately there is not any settlement history before the installation of polymer pillars, because these houses are privately owned. Also the monitoring period after the projects is still quite short. The longest monitoring period is only less than two years.

The relative settlement of the houses show the settlement slows significantly with cohesion polymer pillars. In these test projects the polymer pillars have usually been installed under only part of the building.

Pillars and settlement monitoring points of one test project are shown in picture 5. The relative settlement of the monitoring points is presented in Table 5. The first monitoring was made before the installation and the second after the installation.



Picture 5. Pillars and settlement monitoring points of a test project.

Table 5. Relative settlement of the test project in millimeters.

	1	*2*	*3*	*4*	*5*
25.05.2010	± 0	- 20	-	- 105	- 32
23.01.2012	± 0	- 6	- 46	- 98	- 28

5 CONCLUSION

The polymer pillar is a relatively new product. There have been some load tests and material tests as presented in this paper. Nevertheless there are still a lot of tests to be done to determine the bearing capacity and the suitability of the polymer pillar in different types of soil conditions. Beside these tests, there are projects done all the time and there is a lot of data to be collected from these projects.

6 ACKNOWLEDGEMENTS

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