Simultaneous pull-out filling method of retaining piles that contributes to the SDGs (GEOTETS method)

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ABSTRACT

As a temporary construction method that contributes to the SDGs, the GEOTETS method can pull out earth retaining piles, such as steel sheet piles, while suppressing the subsidence of the surrounding ground. It can be safely used even in close construction work, such as railways and urban buildings. Additionally, it is possible to recycle steel materials, make effective use of underground space, and prevent the spread of soil contamination.

Key words: *SDGs, Environment, Recycling*

1. Introduction

When constructing a structure in the ground for public works using of the open-cut method, in order to prevent subsidence of the surrounding ground, steel sheet piles are continuously driven before excavation, and then excavation is started to construct the target structure. Once the structure is completed, the steel sheet piles are no longer needed and are pulled out of the soil. However, there is a concern that the removal of steel sheet piles will cause ground deformation in the surrounding area over a wider area than expected due to loosening of the ground and the occurrence of adhering sediment.

Peck, and Horiuchi and Shimizu classify the excavation depth, the amount of back-ground subsidence, and the range of their influence in the open-cut method by ground type based on many actual values. They derive the relationship between the amount of land surface subsidence (S) and the distance from the mountain retaining wall (D).

In order to solve these problems, this paper describes the principles and characteristics of the newly developed GEOLETS method (Geo-technology for prevent ground subsidence by pulling out the pile and solidified material injection operation at the same time).

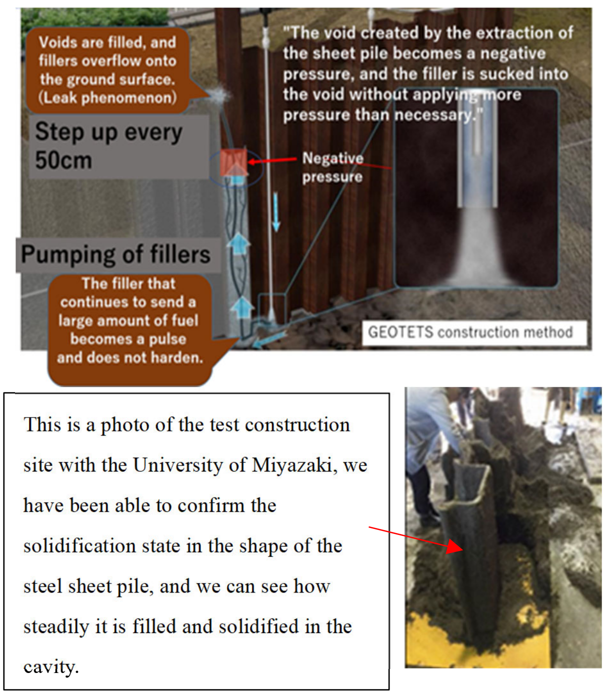

Fig. 1 Simultaneous filling method of pulling out earth-retaining materials

2. What is the simultaneous filling method for pulling out the steel sheet pile?

In this method, when extracting piles such as temporary steel sheet piles, the pile is pulled out and at the same time the tip of the pile is filled with a material mixed with cement, hardening accelerator, water, etc. the surrounding ground is quickly solidified, thereby suppressing the subsidence of the surrounding ground (top of **Fig. 1**). It is mainly used in pile extraction work near railways, roads, and private houses. In addition, since the consolidated filler has high water blocking properties, it is also adopted as a construction method to prevent the spread of soil pollutants. The solidified filler takes the shape of a steel sheet pile, and it can be confirmed that the cavity is filled reliably (bottom of **Fig.1**).

3. Comparison with existing methods and advantages and effectiveness of this method

At construction sites, steel sheet piles driven into the soil as retaining wall material are pulled out when they have finished their role. In this case, if the filling material is not put into the cavity after the piles are removed, the surrounding soil will enter the cavity, leading to ground subsidence over time. As a countermeasure, a common method is to fill the cavity with sand or water from the ground after pulling out piles (**Fig.2.1**). However, the limit is to bury up to 2~3m from the ground. In addition, in soft ground, soil particles around the cavity flow into the cavity quickly, which causes subsidence. Another method involves leaving the steel sheet pile buried in the soil as it is (**Fig.2.2**). In this case, ground subsidence does not occur, but problems such as obstacles in the soil and inability to make effective use of steel materials arise. The next method is to inject the chemical solution from the ground after extraction (**Fig.2.3** Chemical Grouting Method). This method is also not very effective because it is injected after the pile is pulled out, Another method involves leaving the initial behavior of the surrounding sediment. Compared with the above construction methods, this construction methods **(Fig.2.4**), hereinafter referred to as the GEOTETS method, fills the void immediately after extraction and begins to solidify in about 1 minute, so the initial behavior of the soil can be suppressed, and ground subsidence can be prevented. The filler has a material that does not shrink over a long period of time, ensuring long-

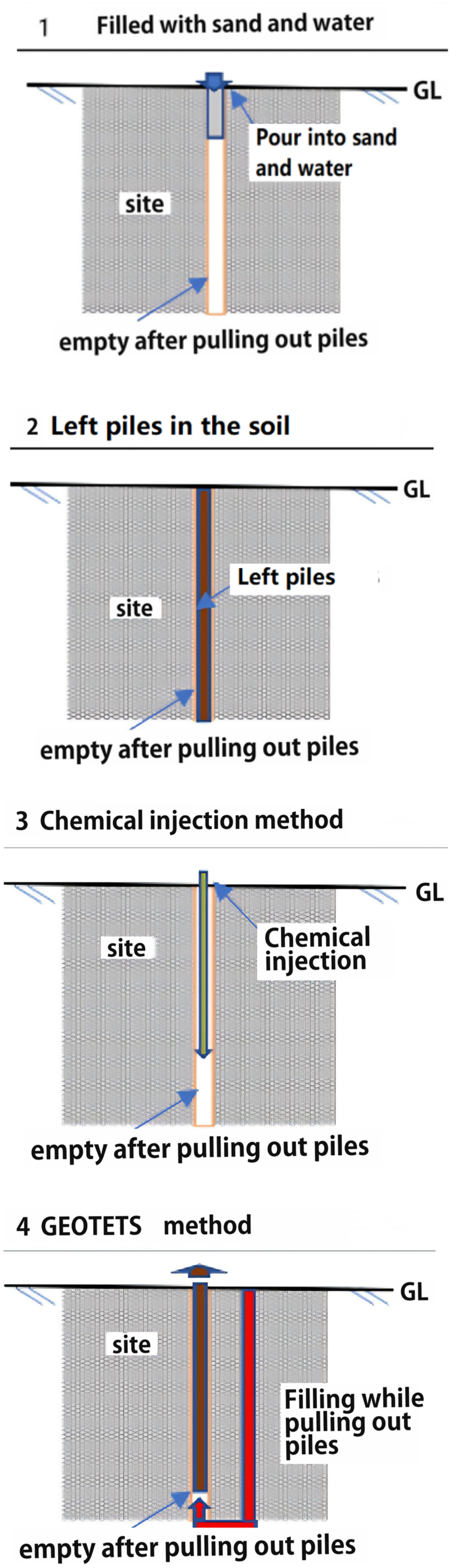

Fig. 2 Construction method comparison table

term suppression of ground subsidence. Therefore, when there are houses or railways in close proximity to the construction site, it can be said that the subsidence control measures by this method are very effective in avoiding the risk of business loss.

4. Impact and prediction of steel sheet pile extraction on the surrounding ground

Horiuchi and Shimizu Another method involves leaving the measurement data regarding ground subsidence behind the steel sheet piles in chronological order. As shown in **Fig.3**, the amount of settlement was measured by a measuring pile installed perpendicular direction to the steel sheet pile. **Fig. 4** shows the relationship between the distance from the steel sheet pile and the amount of ground subsidence as a parameter of the number of days elapsed at each construction stage. It can be confirmed that the amount of settlement increased rapidly around 230 days following the sheet pile withdrawal. At the zero-distance point, the amount of subsidence increased rapidly from 7 cm to 15 cm in 220 to 230 days. The sinking due to sheet pile extraction greatly exceeded the values at the time of excavation and backfilling in both the area of impact and the rate of settlement.

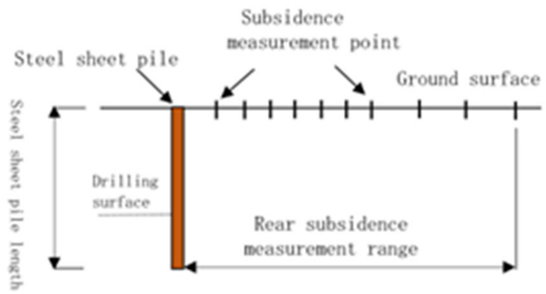

Fig. 3 Rear subsidence measurement diagram

Furthermore, **Fig.5** shows the relationship between the number of days elapsed in each construction stage and the amount of ground subsidence Among the overall processes, when the amount of settlement generated during extraction is the largest, and at the zero-distance point, subsidence occurs about 2.5 times that of 17 cm compared to 7 cm at the time of backfilling. In addition, the area of influence of subsidence ends when it exceeds 10 m from the steel sheet pile during excavation and backfilling. However, the area of influence of land subsidence due to steel sheet pile extraction is up to 40 m away from the steel sheet pile. Even at 30 m, a subsidence of 2 cm occurred, indicating a significant impact on neighboring houses.

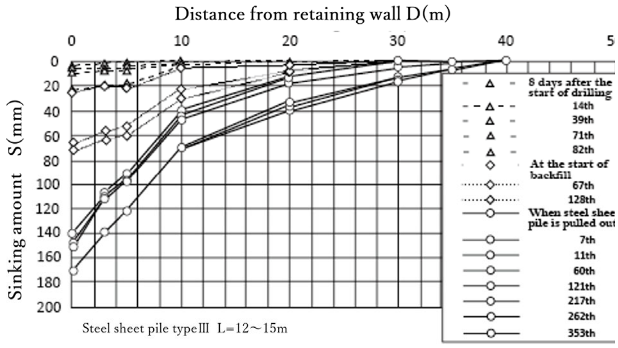

Fig. 4 Subsidence curve of the background

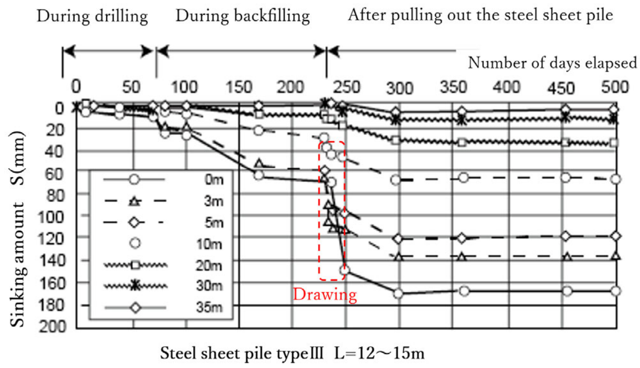

Fig. 5 Amount of subsidence over time of the background

(By distance from steel sheet piles) By **Horiuchi and Shimizu** 1)

In general, as a prediction of the subsidence influence range of the surrounding ground at the time of pile pulling, it is common to set the influence range to the point where the ground intersects with the line drawn at 45 degrees + φ/2 from the lower end of the pile. **Fig. 6** shows a method for estimating ground subsidence. Subsidence after the pile is pulled out is simply estimated by drawing a line of 45°+φ/2 from the lower end of the pile to the ground surface.

However, the above amount of subsidence indicates that ground subsidence occurs beyond that range. In fact, similar cases have been confirmed at many pile extraction sites during our survey inquiries.

Watanabe measured the subsidence effect of the surrounding ground on the removal of steel sheet piles for the construction of a rainwater pumping station and summarized it as a subsidence curve as shown in **Fig.7**.

Since the measurement location is soft ground and houses are in close proximity, the effects of land subsidence were measured in advance by conducting a test of the extraction of steel sheet piles. **Fig.7** shows the temporal change in the amount of subsidence at a point 26 m away from the steel sheet pile after the steel sheet pile (L = 30 m) is removed, and the maximum amount of subsidence is measured at 36 mm after 56 hours.

The numerical values confirmed in this case are plotted on **Fig.4** created by Horiuchi and Shimizu at point A, and the same correlation can be confirmed.

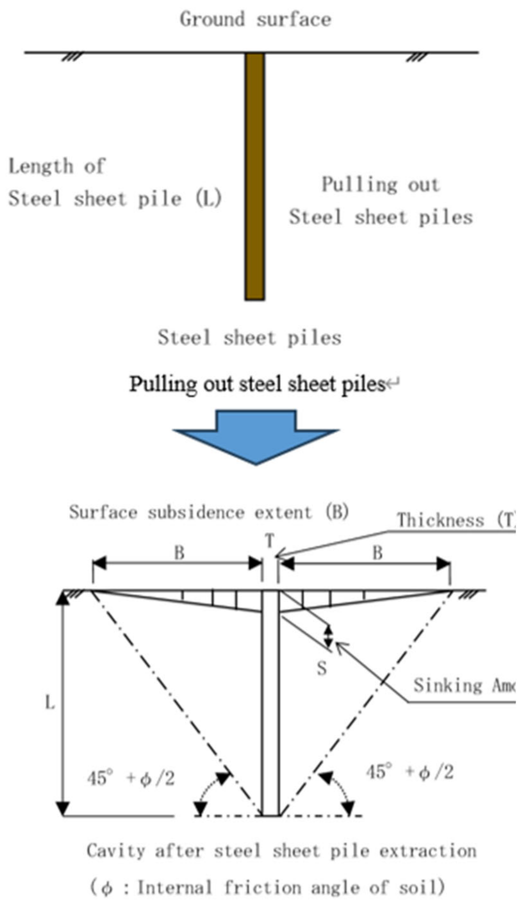

Fig. 6 Estimation of land subsidence

5. Principle of the construction method

In this method, the filling pipes are first installed along the steel sheet pile. Then, at regular intervals (50cm), the pile pulling machine extracts the pile, and every time a void is created, the fillers are injected through the filling pipes. This process is repeated until all the steel sheet piles are pulled out. Since the filler begins to solidify and fills the void in about 1minute, it enables semi-permanent ground subsidence prevention. When the steel sheet pile is pulled up, the space occupied by the sheet pile is in a negative pressure state. However, the filler is injected at a pressure above this negative pressure level at the same time as extraction, so the filler enters the cavity before the soil particles around the cavity can flow into the cavity.

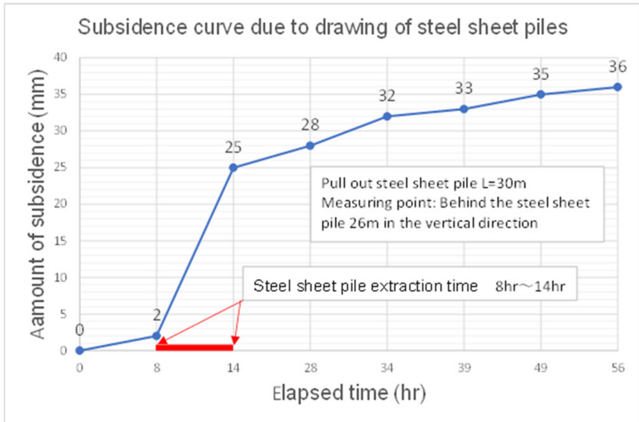

Fig.7 Amount of subsidence over time of the back ground (By Watanabe)

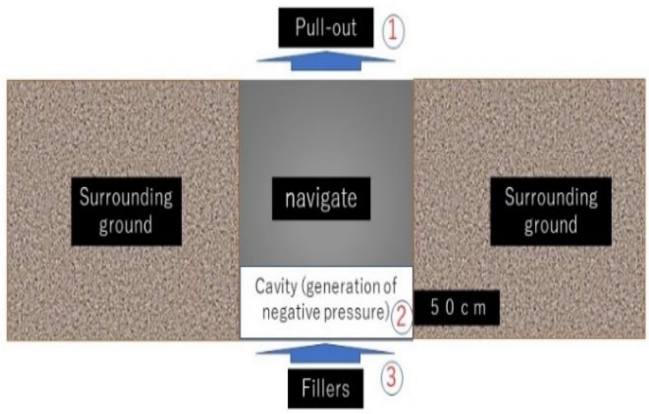

Fig. 8 Principle of the construction method

Fig.8 shows an image of the filler entering the void, representing the principle of this method. When the sheet pile is pulled up by 50 cm, the space occupied by the sheet pile becomes hollow, creating a negative pressure state. The soil particles, moisture, and air around the cavity are drawn toward this space. As a result, the filler is quickly filled only in the space under negative pressure, and the space shaped like a steel sheet pile is filled with the filler, hardening begins in 1 minute. Then, in 2 to 3 hours, the filler solidifies to a predetermined strength, and the cavity becomes a continuous wall body with the filler solidified.

Fig.9 shows the amount of subsidence of the surrounding ground when the steel sheet pile is removed. The amount of subsidence in the case of pulling out steel sheet piles around underground structures using the conventional method and the GEOTETS method is compared with the amount of subsidence up to 33 days after extraction. The GEOLETS method has a maximum subsidence amount of 3 mm, whereas the conventional method results in a subsidence of 28 mm.

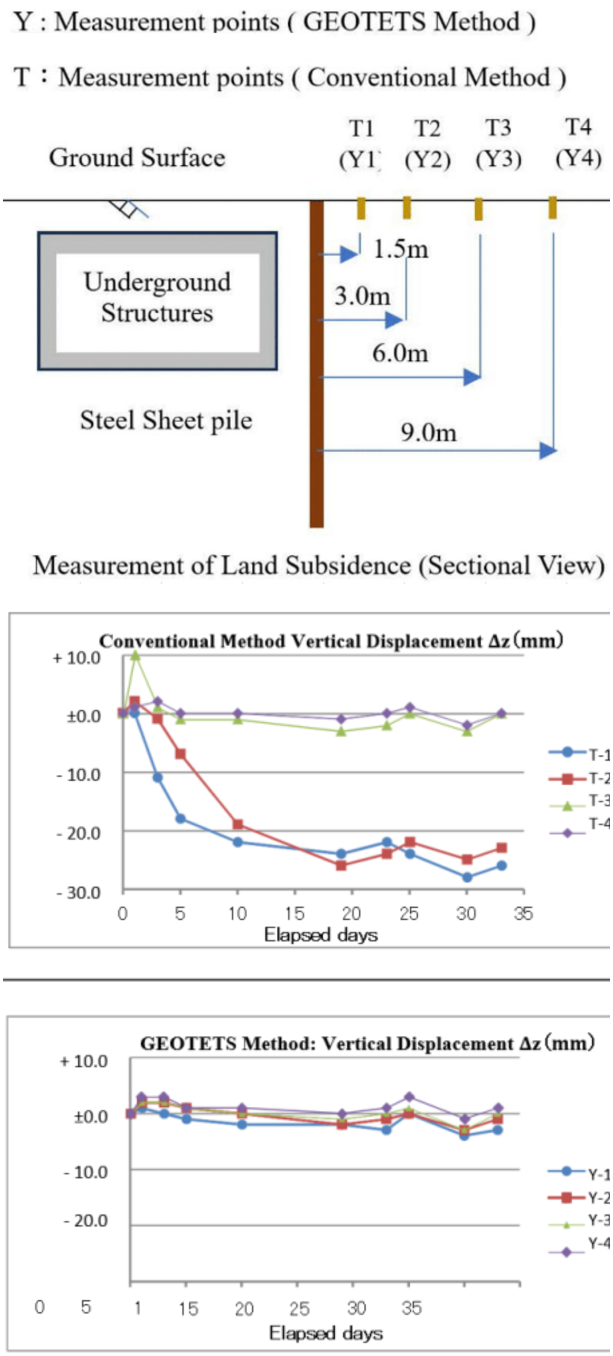

Fig. 9 Measurement of subsidence in the surrounding ground

6. Filling material properties

The filler material is one of the permanent cementitious pouring materials originally developed for this method. It is created by blending two liquids: Liquid A, which is a mixture of cement, accelerator and water, and Liquid B, which is a mixture of hardening material and water. When mixed, it solidifies into a gel form with a gel time of about 1 minute (the time when it runs out of fluidity). After that, in about 3 hours, it becomes hard enough to break even if a person rides it, and it is characterized by a rapid onset of strength. The final N value ranges from 15 to 30 or so, so it will not be an underground obstacle for other construction projects that utilize underground space in the future.

As a result of measuring the degree of shrinkage after solidification of the filler, the rate of change is very small at 0.07%, even after 180 days. The filler consists of liquid A($3CaO \cdot SiO_2 + Ca(OH)_2 + Ca(OH)_2 + H_2O$) and Liquid B($Na_2CO_3 + nNA_2O + mAl_2O_3 + H_2O$). Liquids A and B are fed separately in a double tube. Then, at the same time as the steel sheet pile is pulled out (every 50 cm), the two liquids are merged and sent out at the tip of the double tube (the lowest end of the steel sheet pile). When the cavity caused by pulling up the steel sheet pile by 50 cm is filled with the filler, the filler material will overflow into the ground along the steel sheet pile. After confirming this condition, the steel sheet pile is pulled up another 50 cm. This process is repeated.

If one steel sheet pile is removed, the flow of the filler will be completely stopped, and the degree of coagulation will be high.

7. Preventing business losses due to the implementation of public works

If a steel sheet pile is pulled out in the immediate vicinity of a residential building, then over time, damage such as subsidence and cracks in surrounding houses may be reported. In this case, it will take time to negotiate the cause of the subsidence and compensation for business losses, and in the worst case, it may lead to litigation (**Fig.10**).

In order to avoid these, for example, when constructing a new box culvert under a road, only the upper part of the steel sheet pile may be cut about 1 m for fear of subsidence, leaving the deeper part intact. This not only interferes with future underground space planning, but also causes groundwater to flow along the remaining steel sheet piles, which can lead to cavities and cave-ins in the summer, leading to serious accidents **(Fig.11)**.

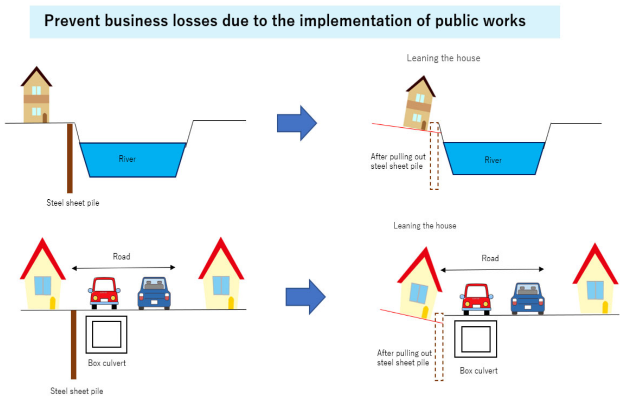

Fig.10 Impact on buildings in river and road

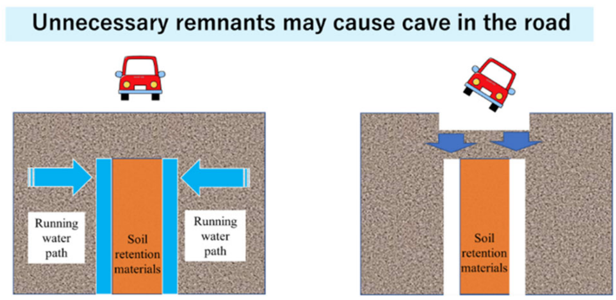

Fig.11 Depression of the road surface due to steel material existing under the road

In addition, when constructing road bridges, railway bridges, etc. across rivers, temporary structures such as steel sheet piles will be installed in the soil of the embankment and the construction will proceed.
After the construction is completed, the steel sheet pile is pulled out, but there are cases where the void in the soil after the removal is not sufficiently filled. In this case, over time, an underground channel can form, and in the worst case, it becomes a channel through which water flows into the river, and there is a risk of embankment breakdown (**Fig.12**).

In this method, the cavity is filled at the same time as the extraction, and shrinkage does not occur even in the long term, so the risk of forming a flowing channel can be greatly reduced.

Public objects formed by public works ensure the safety of the lives of many citizens and are used for a long time. Therefore, it is necessary to maintain stable functions into the future, and it is important to eliminate possible risks in advance. In particular, the phenomena that occur in the soil are parts that cannot be confirmed on a daily basis, and it is necessary to pay attention.

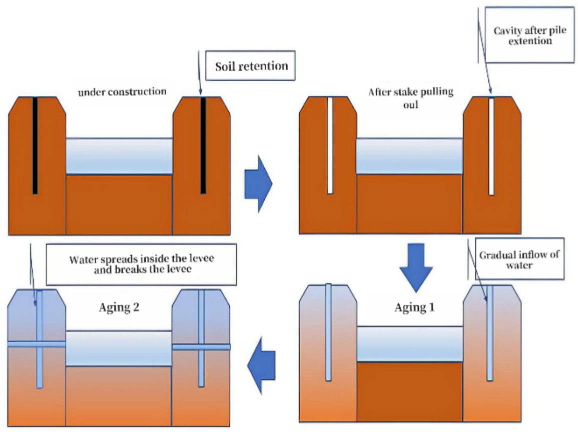

Fig.12 Embankment collapse caused by the pull out of steel used in river embankments

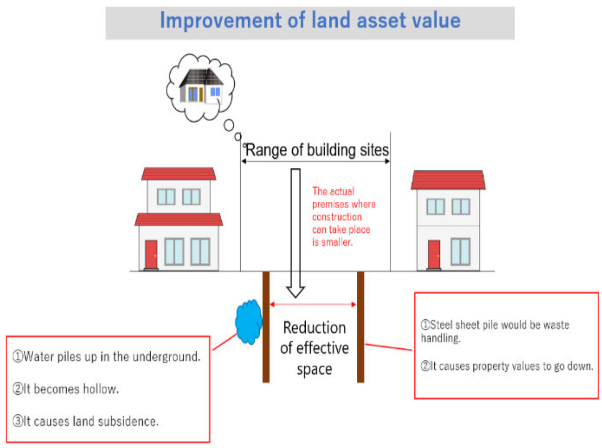

Fig.13 Constraints of underground space due to piles in the soil left behind

In addition, in the case of urban redevelopment or reconstruction of high-rise buildings, if there are piles left in the soil, the range of underground use will be narrowed, and effective underground space cannot be secured.

For example, when planning an underground parking lot, a plan that maximizes the use of the building site is adopted in order to secure the maximum number of parking lots. However, since there are soil piles shown in the figure, the planning range will inevitably be narrowed. In addition, piles left in the soil not only reduce the scope of underground construction, but also cause many other adverse effects. As shown in **Fig.13**, the flow of water is blocked by a continuous earth retaining pile, and the water environment in the soil changes. As shown by the blue part of the figure, the flow of water is blocked, and stagnation occurs. In the dry season, this leads to into cavities and depressions near the surface of the earth. In addition, the presence of discarded earth retaining piles will lower the land valuation.

8. Construction method

In this construction method, there are two approaches depending on the installation method of the filling pipe. The YT-1 method (YT: Y and T of Yamashita Taichi, the developer of the construction method), in which the filling pipe is welded and fixed before driving the steel sheet piles, and the YT-3 method, in which the filling pipe is installed by drilling with a boring machine near the steel sheet piles after they have been driven in. Since the YT-1 construction method does not require drilling, it has excellent workability in hard ground that is difficult to drill. The advantage of the YT-3 construction method is that it can be retrofitted to steel sheet piles that have already been driven in, and either construction method can be selected depending on the site conditions (**Fig.14**).

Fig.14 Installation type of filling pipe

Fig.15 illustrates the construction procedure. The filling tube is pressed into the center of the six steel sheet piles colored in yellow, and the filler is injected following the flow of red arrows from the bottom edge. At the same time, by pulling up the pile with a silent pile, the filler is filled into a cavity with negative pressure.

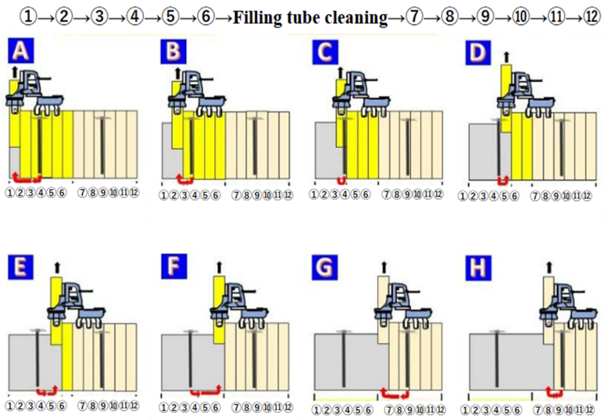

Fig.15 Construction pattern

Fig.16 is a comparison with a general chemical injection method. The left side of the drawing shows the chemical injection method, and the right side is the GEOTETS method. The most significant difference is the timing of when the filler is injected into the cavity after extraction.

In the chemical injection method, there is a time lag between the extraction of the pile and the injection of the chemical solution, due to the replacement of the machine. During this time, soil flows into the area around the cavity, which causes the surrounding ground to subside over time.

On the other hand, in the GEOTETS method, the filler is injected at the same time as the steel sheet pile extraction. the filler starts to solidify in 60 seconds, so it is possible to prevent sediment from moving into the cavity after the steel sheet pile is removed.

Compare items	Conventional construction method（Chemical injection）	GEOTETS method
(1) Outline of countermeasures		
(2) Filling (injection)timing	After it has already been disturbed by the pull-out Against the ground	At the same time as pulling out against the ground before disturbance
(3) Features of filling (injection)	Apply pressure and push in slowly	Use negative pressure without applying extra pressure Quickly and in large quantities
(4) Fill the injection tube	After maintaining a safe distance from the pull-out point, follow the boring machine and move it Installed while letting	Installed in advance at least one day before withdrawal 1@6 is standard
(5) Filling (injection)amount	Unpredictable how much injection will be required	Based on construction performance data, it is possible to plan in an appropriate amount according to construction conditions.

Fig.16 Comparison with the chemical injection method

Fig.17 shows that cavity filling into piles with a large cross-section has become possible due to the improvement of the pumping capacity of the GEOTETS method. Initially, as shown on the left side of the figure, only small cross-sections were supported, but it became possible to apply the method to large cross-sections (about 80 cm in diameter), such as PC piles shown in the center of the figure. Moreover, as shown on the right side of the figure, there are cases where highly viscous soil adheres to the pile and is lifted when the pile is pulled out. In such cases, the cavity after withdrawal becomes larger, but it is possible to fill it steadily.

As a result, it is now possible to fill almost all earthen retaining piles with cavities at the time of withdrawal. In densely populated urban areas, it is now possible to pull out the foundation piles of buildings that were previously left on the building site securing effective underground space and improving of land evaluation.

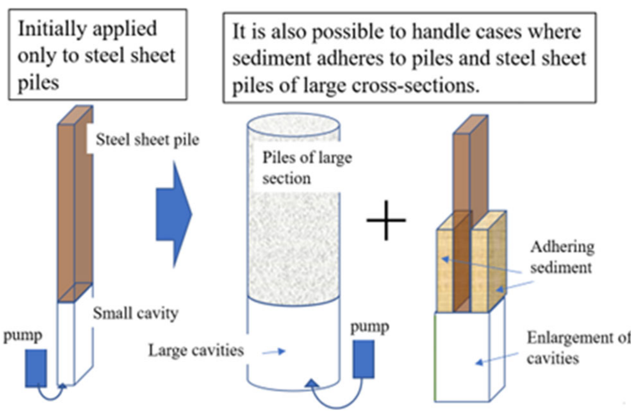

Fig.17 Application to large diameter cross-sections

9. Construction examples

Fig.18 is an example of construction newly conducted on a railway. Since railway operators are conducted sinking rails, strict standards are set for construction. However, this method has been used to safely pull out piles while the railway is in operation. The standards for subsidence of railway operators have also been cleared.

In the past, in most cases, railway projects were completed leaving piles on railway sites. It is now possible to pull them out enabling their reuse and stabilizing the soil in the ground. Adoption of this method by Japan Railway (JR) and many private railways is increasing.

Fig.19 is a case of pulling out a pile in close proximity to a house. In the case of ordinary houses, there are cases where reconstruction is forced due to the effects of pile pulling, and depending on the situation, there are cases which led to lawsuits against the construction contractor over the construction method. By eliminating these risks and making it possible to pull them out safely, underground spaces can be effectively utilized and the reduction of real estate value due to the retention of piles can also be prevented.

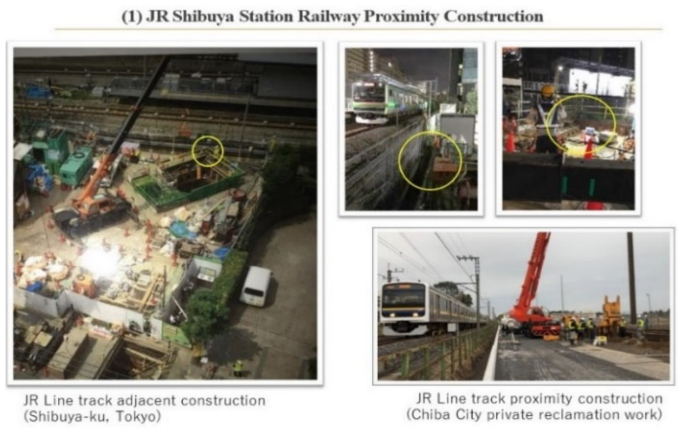

Fig.18 Examples of construction in close proximity to railways

Fig.19 Private houses

Fig.20 shows the site of improvement work on a national highway. The white part on the left side of the figure is the abutment of the newly built bridge. The part that is enclosed in yellow is the part where the earth retaining pile used for construction was pulled out. At the same time as the pull-out, a crack appeared on the national highway, and emergency measures were taken by closing the road to vehicles in a hurry. It clearly shows the subsidence of the surrounding ground due to the removal of piles.

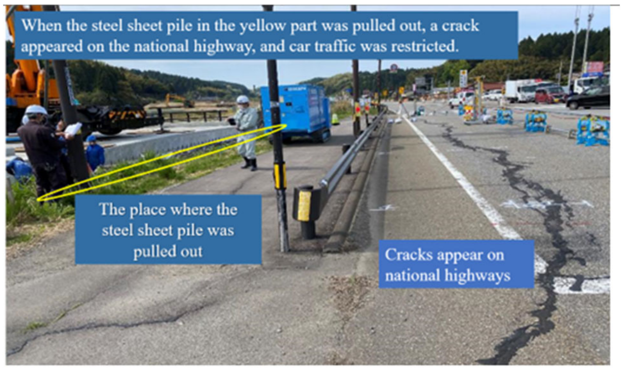

Fig.20 Cracks in the road that occurred after the removal

10. Soil Countermeasures: SDGs Initiatives

The wall body continuously formed in the soil by this method is also effective as a means of preventing the influence of underground pollutants on the penetration of the surrounding ground. By continuously forming a highly water-blocking wall body constructed of a filler that solidifies quickly and does not shrink for a long time, it is possible to enclose underground pollutants and suppress their penetration into the surrounding area. Compared to methods such as constructing large-scale pollution prevention structures made of steel underground, the cost is greatly reduced, and steel sheet piles can be used repeatedly **(Fig.21**).

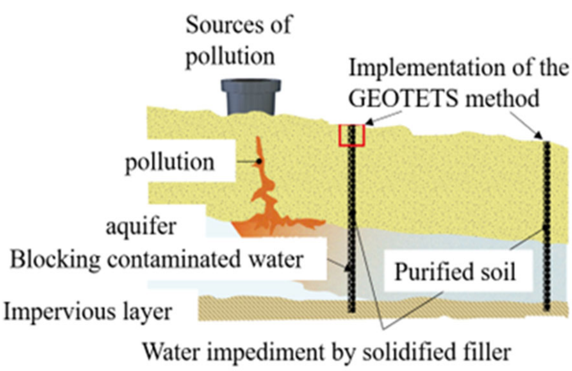

Fig.21 Use for soil contamination countermeasures

Furthermore, by developing filler materials, it is possible to respond according to the contamination level. In addition, pulling out piles buried in the underground space of a road or underground building site will eliminate obstacles for the future facility planning of the underground space, allowing for efficient utilization. Overall, reducing unnecessary energy consumption by reusing sheet piles, preventing damage to buildings, and making effective use of underground space is an effective initiative for the SDGs (**Fig.22**).

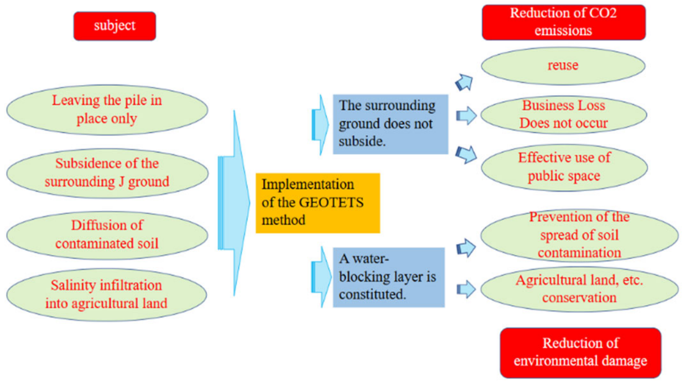

Fig.22 Impact on SDGs

11. Conclusion

In general, as a prediction of the subsidence influence area of the surrounding ground at the time of pile removal, it is common to set the influence area from the lower edge of the pile to the point where the ground intersects with the line drawn at a 45 degrees + $\varphi/2$.

However, in reality, there are many cases where land subsidence has occurred beyond that range, resulting in damage to houses. This paper has discussed the principles of the GEOLETS method, which solves these problems, its construction method, and its effectiveness in preventing land subsidence, illustrated with construction examples. In addition, it is stated that this construction method eliminates business losses due to the implementation of public works and contributes to the SDGs. In the future, we will proceed with research and development to further improve this method, enhance its effectiveness, and reduce its environmental impact.

12. Acknowledgements

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