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SOIL IMPROVEMENT BY VACUUM PRELOADING FOR A POWER PLANT PROJECT IN VIETNAM

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ABSTRACT: A power plant project in South Vietnam was to be constructed on 16-30m depth very soft muddy clay layer. The project covered an area of 25.3 hectare. The very soft clay layer had a natural water content of around 58%, initial void ratio 1.594, and compression index 0.615. Vacuum preloading with an average PVD length of 26m and vacuum pressure of more than 80 kPa, was employed to improve the soft soil. The vacuum degree, surface and subsoil settlement, pore water pressure and lateral displacement were carefully monitored during the preloading period. After the vacuum preloading period of 117 - 150 days, ground surface settlement of 1.254-1.655 m correspond to a degree of consolidation over 90% was achieved. The maximum lateral displacement was 176mm in the direction towards the improved area. The after treatment Vane Shear Test yields undrained shear strength, Su, is 40 ~ 70 kPa.
KEYWORDS: ***Vacuum preloading; soft muddy clay; vacuum degree; ground surface settlement; pore water pressure; lateral displacement.***

INTRODUCTION

The proposed power plant is located at the entrance between two tributaries of Mekong River flowing into South China Sea. The landform is a typical delta formed by sea-land interaction and flood land at an edge of alluvial plain. Soil investigation result indicated that there is an extremely soft muddy clay layer with a thickness of 16.0~30.0 m.

Vacuum preloading method was adopted to improve soft soil in this project which covered an area of 25.3 hectare, divided to 10 zones during construction. The vacuum degree, surface and subsoil settlement, pore water pressure and lateral displacement were carefully monitored during the preloading period. The mechanism of vacuum preloading method and the monitoring data are presented and discussed in this paper.

STRATUM CHARACTERISTICS

According to the survey result, from 100m depth to the ground surface, all deposits are of Quaternary age. The subsoils where vacuum preloading soil improvement was applied were described below (from top to bottom):

Layer ①-Backfill layer: embanked soil and late marine deposits. Light grey, hoar, loose, slightly dense, mainly filled with silty sand, newly formed and untreated, with thickness from 0.30m to 7.80m.

Layer ②-Clay: Swamp and marine deposits. Dark grey, brownish grey, very soft, liquid-plastic, contain large amount of organic matter and shell pieces, partially with lenses and pockets of fine sand, with thickness from 17.5m to 25.0m. Initial soil properties of layer ② are listed in Table 1. Thickness contour of layer ② is shown in Fig 1.

Sub-layer ②a-Fine sand: Marine deposits, dark grey, black, loose, partially slightly dense. This layer is exposed in most boreholes and the distribution is continuous at 6.00 ~ 10.00m depth under the ground. The thickness is normally 0.50m~3.00m and maximum is 13.4m.

Layer ③-Fine sand: Marine deposits, light grey, brown yellow, medium dense, partially slightly dense or dense.

Below layer ③ is stiff ~ very stiff soil.

Table 1. Original soil properties of layer ②.

Items	Unit	Average value
Water content w	%	57.9
Unit weight γ_w	g/cm^3	16.3
Void ratio e_0		1.594
Compressibility Index C_c		0.615
Coefficient of consolidation	$10^{-3}cm^2/s$	C_v 0.74 C_h 0.93

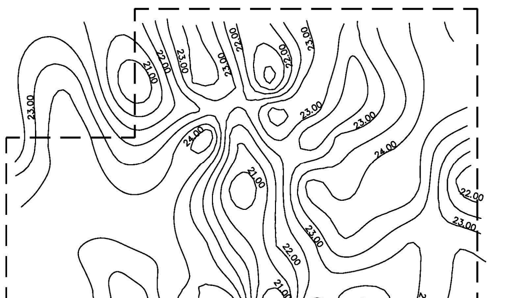


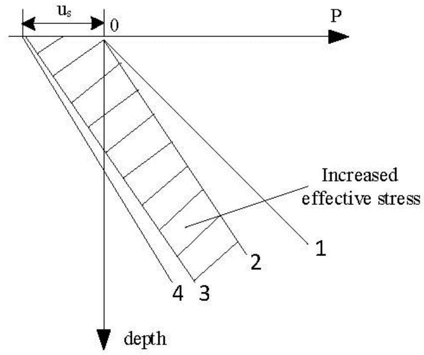
Fig 1. Thickness contour of the soft soil.

DESIGN & CONSTRUCTION

Vacuum preloading method utilizes atmospheric pressure as surcharge load to accelerate soil consolidation. Its principle is presented in Fig 2.

Basically, whole vacuum preloading system consists of drainage system, sealing system and vacuum pumps. Vacuum pressure, generated in vacuum pumps, spreads into soils along drainage system, taking out water and accelerating soil consolidation. The whole system is depicted in Fig. 3. The drainage system is an interconnected network of PVD, horizontal filter pipes and sand layer, forming a complete path for spreading of vacuum pressure and water flow. The sealing system is an airtight isolation system to prevent leakage of water & air below it. It consists of geomembrane, slurry wall and the soft clay itself. Due to its high permeability, the existence of sub-layer ② which is a-fine sand in this project became a serious threat for the vacuum degree. Slurry wall was employed to cut off the water & air flow in this sub-layer ②a.

The improvement area, total 253,083 m^2, was divided into 10 zones as shown in Fig 4. PVD were installed in square pattern of 1.0 m x 1.0 m spacing and an average depth of 26 m. The soil improvement target is to achieve 90% average degree of consolidation under vacuum pressure and backfilling loads. The information about backfilling height, preload and preloading time of each zone is listed in Table 2.



1-Total stress line, 2-initial water pressure line, 3-water pressure line after vacuum applied, 4-water pressure line if without head lose

Fig 2. Principle of Vacuum Preloading

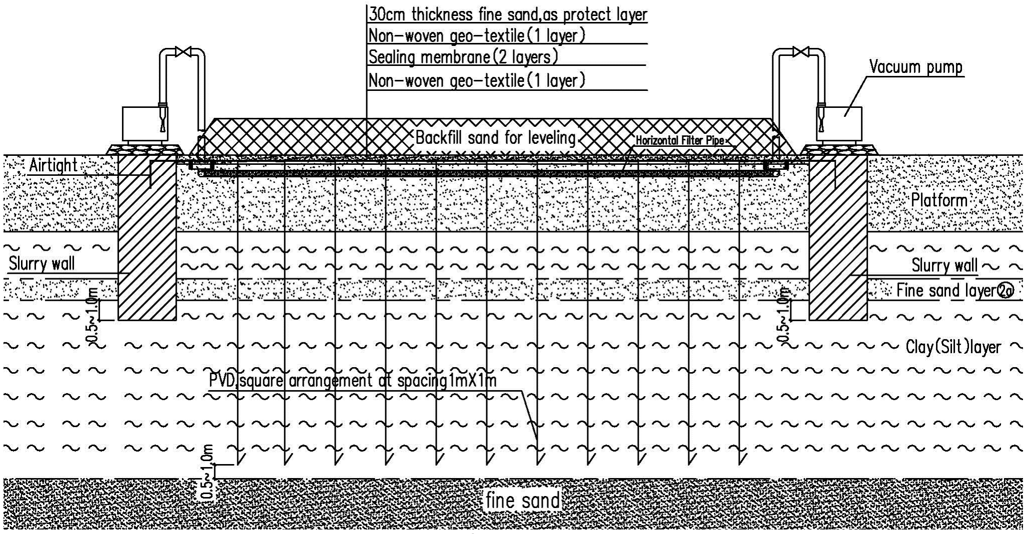


Fig 3. Description of vacuum preloading system.

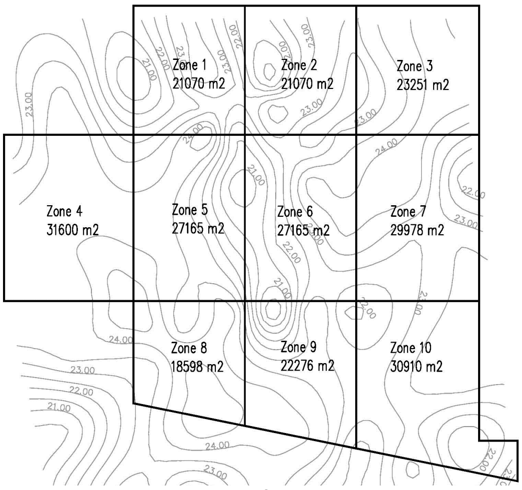


Fig 4. Layout of zone partition.

Table 2. Construction Information of each Zone

No.	H(m)	P(kPa)	T(day)
Zone 1	2.41	127	150
Zone 2	2.43	129	133
Zone 3	1.48	108	147
Zone 4	1.21	103	147
Zone 5	2.19	120	132
Zone 6	2.41	125	137
Zone 7	1.48	108	143
Zone 8	2.34	124	142
Zone 9	2.5	128	117
Zone 10	1.5	110	134

Note:
H -- Backfilling Height
P -- Total preload = vacuum pressure + backfilling load
T – Preloading time.

MONITORING

Monitoring System

In order to control the effect of vacuum progress, the following monitoring schemes were conducted:

 Vacuum degree -- Vacuum gauges were installed to monitor vacuum degree under the geomembrane, 9 gauges for every zone.

- Ground surface settlement -- Surface settlement plates were installed on top geotextile layer to monitor ground surface settlement, at least 9 plates for every zone.

- Subsoil settlement -- Layered settlement meters (extensometer) were installed at -4 m, -8 m, -12 m, -16 m, -20 m and -24 m in one borehole for every zone.

- Pore water pressure -- Water pressure meter (piezometer) were installed at -5 m, -10 m, -15 m and -20 m in one borehole, 3 boreholes for every zone.

- Lateral displacement -- Lateral displacement boreholes (inclinometers) were located at outside of boundary, total 4 boreholes.

The monitoring layout and arrangement, taking zone 2 for example, is shown in Fig. 5. Monitoring frequency of each item is shown in Table 3.

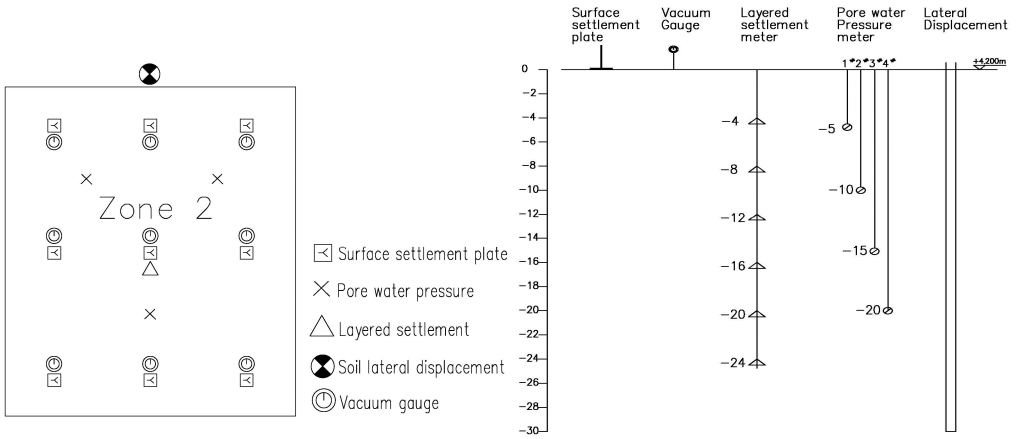


Fig 5. Monitoring meters arrangement.

Table 3. Monitoring Frequency

Monitoring frequency (interval)	Vacuum Preloading Period		
	First Month	Consolidation Period	Last Month
Vacuum Pressure	1 day	2 days	2 days
Surface Settlement	1 day	3 days	1 day
Layered Settlement	1 day	3 days	2 days
Pore Water Pressure	1 day	3 days	2 days
Lateral Displacement	3 days	5 days	7 days

Monitoring Data Analysis

Vacuum degree is the key-point for vacuum preloading, especially the vacuum increasing in the beginning several weeks. Vacuum degree had been monitored and recorded very carefully and the result is shown in Fig 6. In this project, it takes 8 ~ 33 days for vacuum pressure to reach 80 kPa for different zones. The shortest is 8 days in zone 8 and zone 9 but the longest is 33 days in zone 6. Basically, after the beginning period, the vacuum pressures were maintained over 80 kPa except some power off accidents which are clearly showed in Fig 6.

Asaoka method was used to calculate consolidation degree for each zone based on surface settlement monitoring data. After 117 ~ 150 days preloading, all zones had reached consolidation degree requirement with surface settlement ranging from 1254 mm to 1655 mm. The average consolidation degrees are listed in Table 4.

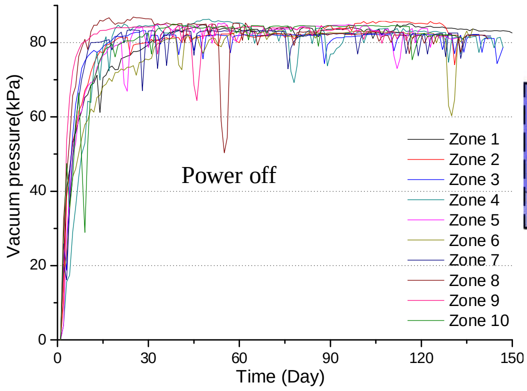


Fig 6. Vacuum degree curves.

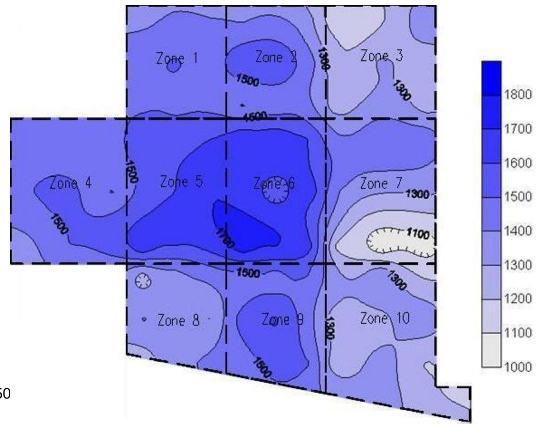


Fig 7. Contour of surface settlement.

Table 4. Average Consolidation Degrees

No.	T day)	P kPa)	S_{con} (mm)	$\overline{U}$
Zone 1	150	127	1454	97%
Zone 2	133	129	1445	97%
Zone 3	147	108	1254	91%
Zone 4	147	103	1458	99%
Zone 5	132	120	1607	99%
Zone 6	137	125	1655	99%
Zone 7	143	108	1295	99%
Zone 8	142	124	1353	99%
Zone 9	117	128	1496	96%
Zone 10	134	110	1291	99%

Notes:

S_{con} -- Surface settlement during preloading.

$\overline{U}$ -- Average consolidation degree (by Asaoka method).

Among the 10 zones, zone 6, zone 2 and zone 3 are typical zones which represent middle, side and corner zone respectively. Therefore, the monitoring data in these 3 zones will be further analyzed.

Surface settlement of the whole area is shown in Fig 7 which clearly indicates that maximum settlement took place in the middle and decreased from center to boundary. Relationship between load, settlement, pore water pressure and time in zone 2, zone 3 and zone 6 are showed in Fig 8, Fig 9 and Fig 10 , respectively.

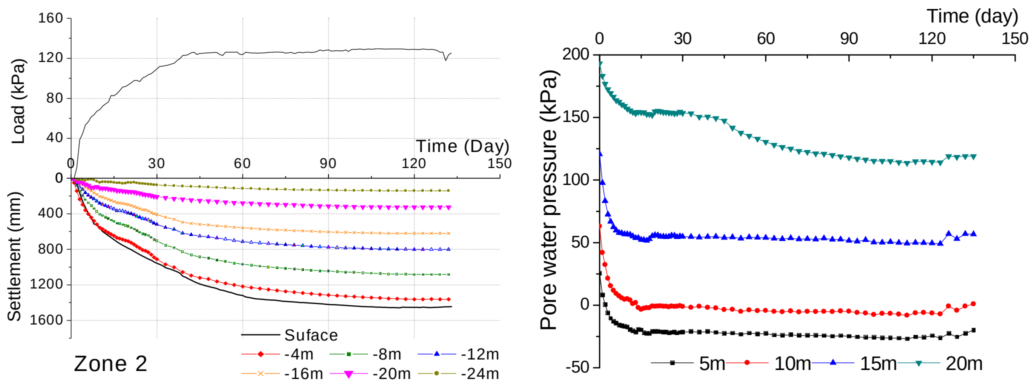


Fig 8. Relationship between Load, Settlement, Pore Water Pressure and Time in Zone 2.

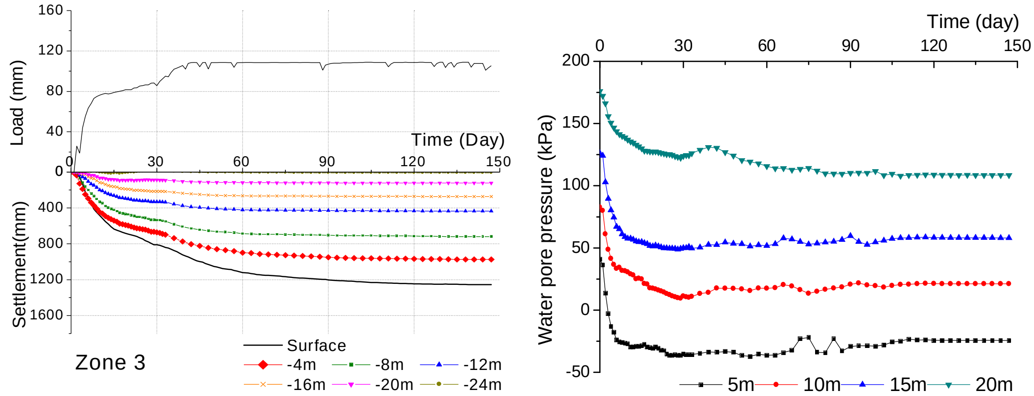


Fig 9. Relationship between Load, Settlement, Pore Water Pressure and Time in Zone 3.

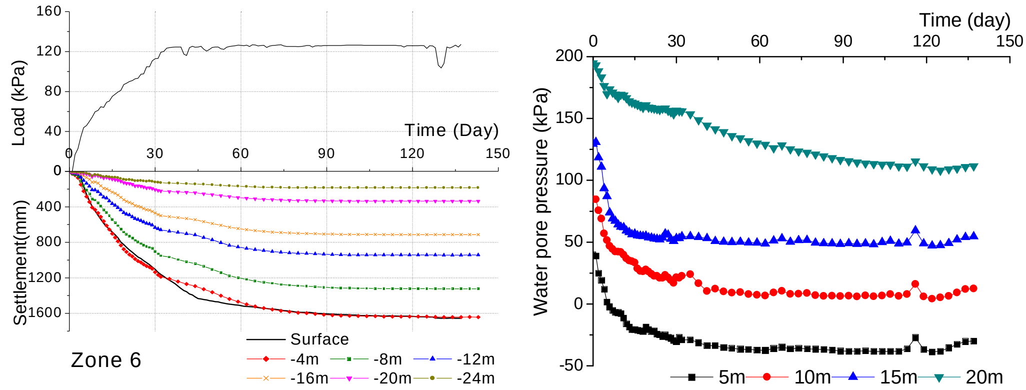


Fig 10. Relationship between Load,Settlement, Pore Water Pressure and Time in Zone 6.

In zone 2, most settlement occurred at -4 ~ -24 m depth and the layered settlement seems nearly homogeneous. On the other hand, the settlement from 0 m to -4 m depth was quite small, this is due to the fact that this 4m is the thickness of the platform, which could had been densified by the movement of trucks and equipment during the course of the site backfilling and preparation. Pore water pressure (u) decreased by 60 ~ 80 kPa rapidly after vacuum applied, especially in 0 ~ -15 m. However, at -20 m depth, the decreasing rate occurred in 2 stages, 1st stage in the beginning 15 days and 2nd stage in the following 30 ~ 90 days. This phenomenon can be found also in zone 3 and zone 6, which indicates that the influence of vacuum pressure could reach -15m rapidly and tends to extend into deeper soil as time developing.

In zone 3, distribution of layered settlement is different with zone 2, 0 ~ -4 m offered 22% of total settlement but below -24m only offered 1%. However, the situation in zone 6 is very similar with zone 2. The distributions of layered settlement in these 3 zones are shown in Fig 11.

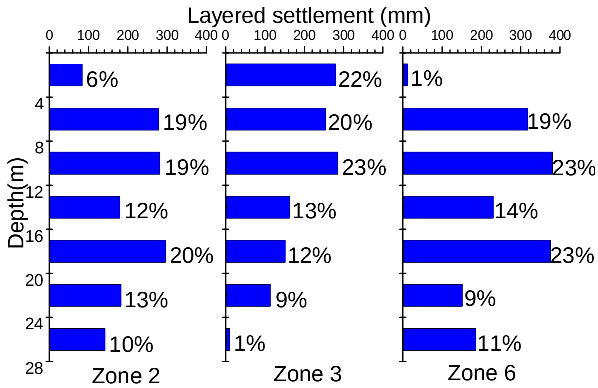


Fig 11. Distributions of Layered Settlement.

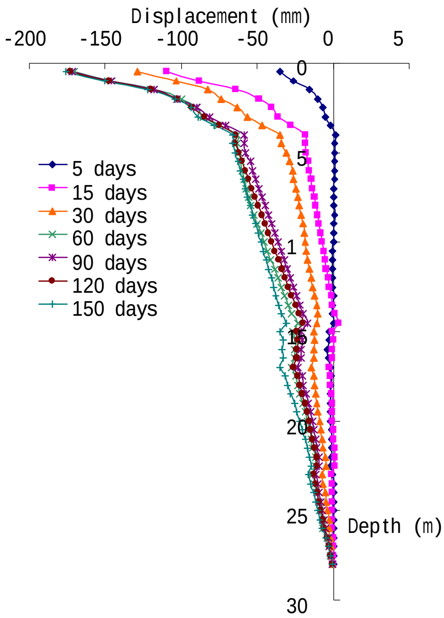
The monitoring data shows that vacuum degree, settlement and pore water pressure monitoring data clearly proved that the consolidation of soft clay had been almost finished due to the application of vacuum preloading method in this project and the influence of vacuum effect could reach -24 m or deeper.

Lateral displacement monitoring result near zone 2, showed in Fig 12, clearly showed that the soil movement direction is inward with a maximum lateral movement of 176 mm. Since the vacuum pressure is isotropic, therefore, in the lateral direction an inward force is exerted on the subsoil which is totally different with surcharge preloading where no inward force is exerted. This means, in most cases, the sliding failure mechanism in vacuum method could be eliminated.

POST TREATMENT SOIL TEST

After vacuum preloading, laboratory test and field vane shear strength test were performed to check the soil property. The lab test result is listed in Table 5. Water content is reduced by 8.9% and compression index has been significantly improved.

The vane shear strength test results, shown in Fig 13, indicates that the Su max is larger than 40 kPa and the average sensitivity is 3.0.



Note: - represents inward direction,
+ represents outward direction.

Fig 12. Lateral displacement curves near zone 2.

Table 5. Soil Parameter Comparison

Items	Unit	Original	Improved
w	%	57.9	49.0
γ_w	kN/m^3	16.3	17.0
e_0		1.594	1.352
C_c		0.615	0.307

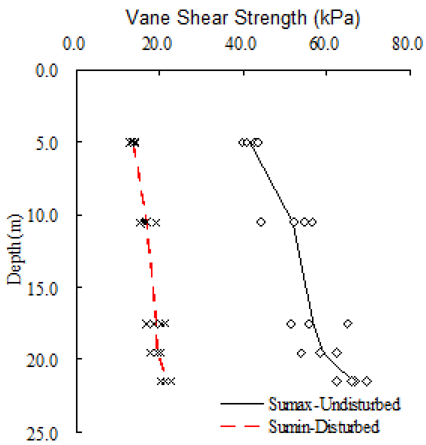


Fig 13. Field Vane Shear Strength Test Result.

DISCUSSION

So far, many papers have discussed the mechanism of vacuum preloading method and several theories have been developed to explain the mechanism of this method. Besides, a lot of experiments and practices have been performed which provide precious data and cases to help understanding and applying this method better.

In the authors' opinion, the basic mechanism of vacuum preloading is the pore water pressure difference between vertical drains and the subsoil forces water to seep from thes subsoil into the vertical drains. For deep soil, although vacuum effect could not reach it by itself, the decreasing of pore water pressure in vertical drains still creates basis for consolidation. That is the reason why vacuum preloading influence can reach deeper soil. Furthermore, the suction forces generated by vacuum pumps keep accelerating water and air flowing, which effectively reduces the resistance in drainages. Therefore, consolidation time for vacuum preloading is usually shorter than conventional soil surcharging method.

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