International Journal of Psychosocial Rehabilitation, Vol. 24, Issue 2, 2020
ISSN: 1475-7192

Estimation and Controlling of Excavation Wall Deformation Using Elasto-plastic Calculation with Nonlinear Ground Considerations

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Abstract---*In the excavation work, the calculation of lateral pressure is very important, because it concerns the safety and smoothness of construction work. In fact, in the field the calculation of the movement of the retaining wall is very complex. This is because the soil has mechanical properties that are not linear, so it requires calculation in other ways, which also takes into account the nonlinearity of the soil and the spring properties of the soil and retaining wall itself. In the case study of this paper outlines the calculation of the nature of the soil and the retaining wall in order to estimate and evaluate the movement of the retaining wall during excavation work. The results of calculations show there is a good correlation between the results of calculations and the results of monitoring the movement in the field. So that this method can be used for similar calculations in excavation works.*

Keywords*--- Excavation, elasto-plastic, nonlinear behaviour*

I. Introduction

Deep excavation is the removal of large amounts of land and water by a process that is resulting in loss of burden. Release of total pressure and absence of pore pressure will result ground movements around it, therefore supervision of this movement is a basic requirement inside deep-engineering. Land response is influenced by several factors that are interrelated with one another, namely: soil properties, groundwater control, time, dimensions, support systems including excavation stages included anchoring, and the presence of the structure and its foundations in the immediate vicinity, as well as cargo while those who are burdening[1].

The excavation of earth retaining works in railway is basically designed by elasto-plastic based consideration. The ground spring considered in the design that is used as a linear spring modeled by a bilinear model with the effective passive side pressure as the upper limit. However in actual, the ground is not an isotropic elastic body but has anisotropy and nonlinearity, and the deformation coefficient (ie, ground spring) depends on the strain level. It changes with existence. In the design, a linear spring value is set using a deformation coefficient at a relatively large strain level on the safe side.

In many cases, it is not easy to accurately predict the deformation behavior of the retaining wall during the excavation process. In addition, when using burrs or ground anchors for support on temporary works of excavation, since there are some problems on steel support deformations, is appropriate to use linear spring calculation. However when the reinforced earth method is applied to the shoring method, the shear spring on the peripheral surface of the stiffener becomes the

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supporting spring which similarly non-linear[2]. Therefore, when the calculation of the reinforced material use linear spring method, the deformation behavior would be differ from the actual one.

The purpose of this study is to evaluate the application of the nonlinearity of each spring by comparing the measurement of the real data form excavated section field and to realize measurement data of retaining wall displacement. The elasto-plastic analysis was performed in consideration of the measurement results and the current design results.

II. Method of analyses

The structural system of excavation conducted in this study uses a sheet pile wall and strutting system that the system becomes statically indeterminate at many levels, which means calculations cannot be solved statically. The soil deformation is analyzed theoretically based on beam on elastic subgrade theory of Winkler. In the Winkler model an elastic beam is used to evaluate pressure acting at the ground side and lateral ground pressure on the side of excavation. It was then developed by modeling the wall as a beam supported by the ground as a spring and then called winkler-spring with a stiffness of k_h [3]. The basic equation for the beam spring model is as follows:

$$EI = \frac{d^4y}{dx^4} + p\,.\ B = w.B \qquad (1)$$

where EI is the flexular stiffnes of the wall (kN.m2), y is dicplacement (m), x is depth (m), p is lateral subgrade reaction on the excavation side (kN/m^2) and B is reference width (m). The soil is modeled as elasto-plastic with soil pressure is limited to active pressure and passive pressure values. If the wall is allowed to deform until active pressure and passive pressure are mobilized, then the problem will be similar to the beam on elastic foundation system. However, usually the deformation that will be experienced for the above conditions cannot be allowed. Generally wall movement is restricted, as a result the active pressure is not fully mobilized and the pressure is present between soil pressure in at rest and active conditions. The subgrade reaction on the excavation side equals to the differences between the lateral pressure on the excavation side and the equilibrium lateral pressure, and the external pressure behind the retaining wall equals to the difference between the lateral pressure behind the retaining wall and the equilibrium lateral pressure[4].

The evaluation of wall deformation included the calculation of the load acting on the pile wall according to the stages of construction and the deflection of wall itself.

1. Lateral pressure at active passive, and rest conditions

$$P_a = K_{as}(\sum \gamma h + Q_a - P_{wa}) - 2C\sqrt{K_{as}} \qquad (2)$$

$$P_p = K_p\left(\sum \gamma h + P_{wp}\right) + 2C\sqrt{K_p} \qquad (3)$$

$$P_0 = K_0\left(\sum \gamma h - P_{wp}\right) \qquad (4)$$

Where ;

P_a : active lateral pressure (kN/m^2)

P_p : passive lateral pressure (kN/ m^2)

P_0 : Lateral pressure at rest (kN/ m^2)

K_{as} : Coefficient of active pressure

K_p : Coefficient of passive pressure

K_0 : Coefficient at rest

γ: Unit Weight of soil (kN/ m^2)

h : Thickness of soil

Pwa : Pore water pressure at the wall side (kN/ m^2)

Pwp ; Pore water pressure at excavation side (kN/ m^2)

C : Cohesion of soil (kN/ m^2)

Qa : Wall side uniform load (kN/ m^2)

2. Coefficient of support system

H beam

$$K_b = \alpha \quad \frac{E.A}{L.B}\, x\ number \qquad (5)$$

Anchor

$$K_b = \alpha \quad \frac{E.A.cos^2\emptyset}{L.B} \qquad (6)$$

Spring

$$K_b = \alpha \quad \frac{E.A}{L.B} \qquad (7)$$

Where ;

K_b : Spring constant (kN/m/m/)

L : Length (m)

B : Lateral interval (m)

α : Constant

θ : Anchor angle (°)

E : Young modulus (N/mm^2)

A : Area (cm^2/number)

III. Soil Properties and Site Conditions

Geotechnically, until depths of approximately 9 meters, soil and rocks in the study area consists of silt and sandy soil with high plasticity, grades stiff consistency and more than 8 meters consisting of silty sandstone and very dense compactness.

Table 1: Soil paramaters of analyses

No	Depth (m)	Location	Type	N	γ (kN/m^3)	φ (^{o})	Co (kN/m^2)
1	5	Backside	Sandy	3	17	10	20
		Excavate side	Sandy	3	17	10	20
2	9	Backside	Sandy	5	17	10	25
		Excavate side	Sandy	5	17	10	25
3	20	Backside	Sandy	60	17	19	30
		Excavate side	Sandy	60	17	19	30

Where

Depth : Depth of soil from the top of earth retaining wall

N : N value

γ : Wet unit weight

φ : Internal friction angle

Co : Cohesion coefficient

Figure 1 shows the excavated cross section and ground conditions, etc., for which comparison calculations were performed. In this excavation site, H beam strut and steel sheet pile are applied to the retaining wall. Excavation was performed in 5 stages, and each excavation was performed at the reinforcing material installation position with depth is decided based on the calculation results.

Material used for the support system that holds lateral pressure from the ground. The selection of types, dimensions and intervals is decided based on the results of calculations that take into account the safety factor. Other determinations also consider the efficiency and effectiveness of construction works such as how this support system does not prevent the construction and casting and so forth.

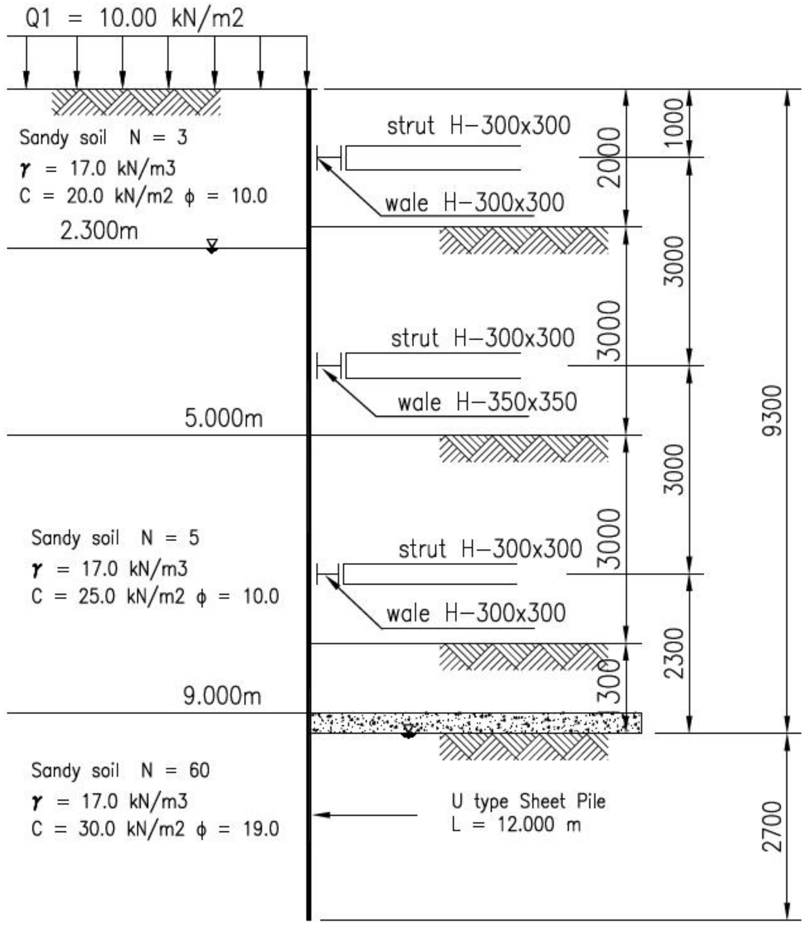


Figure 1. Cross section of excavation and ground conditions

IV. Results

Different support systems can be used for deep excavations depending on soil and water conditions land and size (width, length and depth) of excavation. The position of the support can be horizontal or tilted. On deep but narrow excavation work, horizontal support is often used, while in wide excavations and the support is often made tilted. The slope of the support is generally supported at the tip of the excavation by concrete slabs or concrete footings separately. This must be observed in slope cantilevers where anchors will cause axial forces on the emergency pole which can affect wall stability.

Below is the stage of the analyses:

Step 1: Analyze the first excavation with free support until 2.0 depth

Step 2: Analyze the anchor installation on the first layer with a depth of 1.00 m and second excavation until depth of 5.0 m

Step 3: Analyze the second layer of support by installing strut at depth of 4.0 m and third excavation until depth of 8.0 m

Step 4: Analyze the third layer of support by installing strut at depth of 7.0 m and fourth excavation until depth of 9.3 m

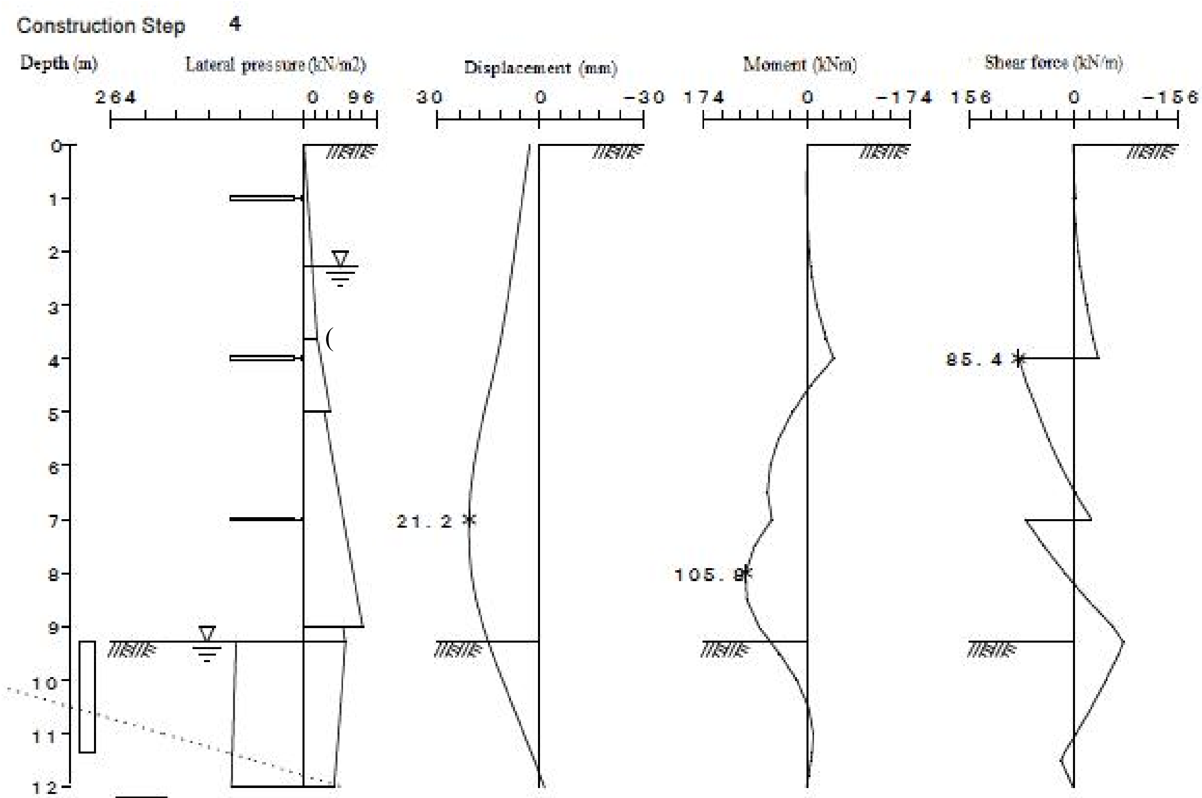
Step 5: Pouring concrete with thickness 0.3 m and remove the third layer of support

Sectional force and displacement

Lateral movement due to shifting of the soil around the deep excavation has a destructive effect buildings that are nearby. The lateral movement depends on the stiffness of the plaster wall, therefore can be reduced by increasing the stiffness of the plaster wall structure or reducing spacing of the anchor soil. Ground anchors are more effective because they can be placed near the bottom of the excavation and be given a load beforehand (preloading). Therefore strutting or temporary have the best possible avoidance.

Lateral pressure that occurs between the active state and at rest. Conversely on the face the wall of the land will be between at rest to passive state.

Figure 2 shows the results of the calculation of each step described above and table 2 is the summary of the maximum value of displacement, moment and shear force resulting from the forces acting on the retaining wall. Maximum displacement occurs in the fifth step where there is a displacement of 25,702 mm as well as the bending moment happening in step 5 which is 146,818. This occurs during the third strut replacement.



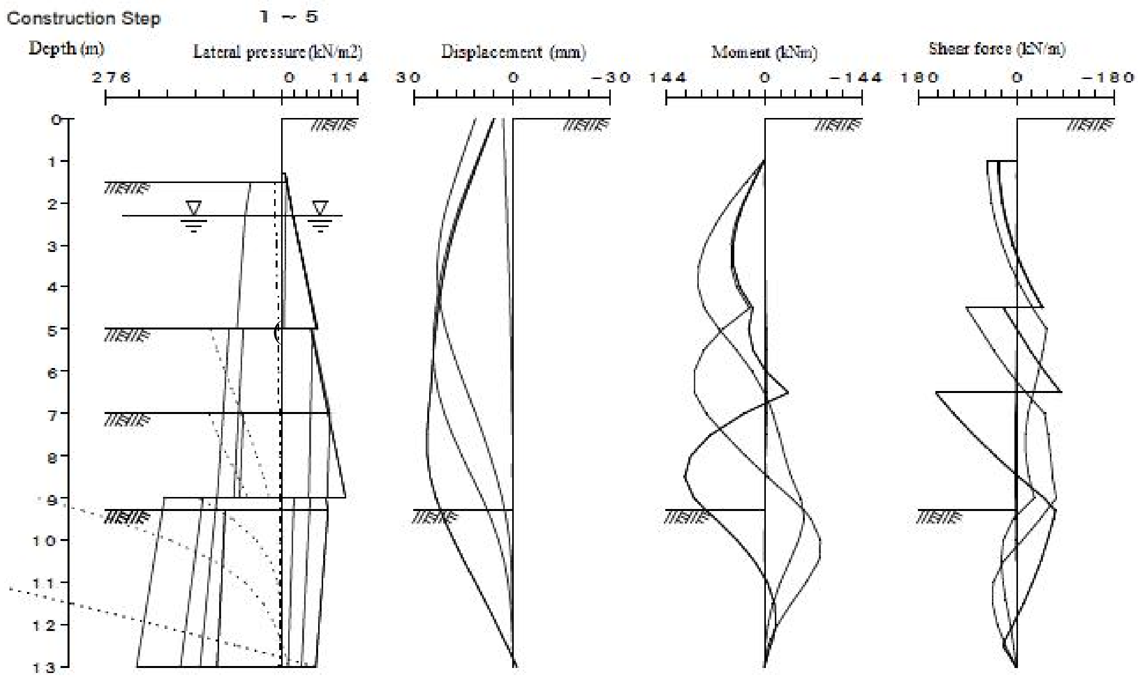


Figure 2: Cross sectional force and displacement of retaining wall due to lateral pressure at final stage (a) and plot of each stage of construction step (b)

Table 2: Maximum value of displacement, bending moment and shear force of excavation wall

Construction step		Displacement		Bending Moment		Section shear force	
		depth (m)	δ max (mm)	depth (m)	Mmax (kNm)	depth (m)	Smax (kN/m)
1	Free support	0.000	6.887	3.500	-15.463	2.000	-10.200
2	2nd excavation	4.000	11.429	4.000	57.969	5.000	-37.483
3	3rd excavation	6.500	20.424	7.000	118.843	4.000	108.321
4	Last excavation	7.000	21.205	8.000	105.801	4.000	85.356
5	Support replacement	7.000	25.702	7.000	146.818	9.000	-133.180
	MAX	7.000	25.702	7.000	146.818	9.000	-133.180

Excavation elastic modulus

Table 3: Elastic modulus of excavation side

Construction step		Total thickness of Elastic region (m)	Penetration length (m)	Elastic Modulus (%)
1	Free support	10.000	10.000	100.00
2	2nd excavation	7.000	7.000	100.00
3	3rd excavation	1.467	4.000	36.70
4	Last excavation	0.631	2.700	23.40
5	Support replacement	0.755	2.700	28.70

Since elastic modulus is defined as ratio excavation side elastic region to penetration depth, the depth of pile penetration is decided on the value of elastic modulus that should larger than the value as described by below table :

Table 4: Elastic region for kind of soil

	Foundation	Percentage of elastic modulus region
Excavation side Soil	Sandy soil	10%
	Clayey soil	10%
	Improved soil	50%

Calculation results show that each step of construction has elastic modulus region > 10 %, then the design is safe.

Stress Intensity

Table 5: Bending moment and shear force for each step

Construction step		Bending Moment (kNm)	Shear force (kN)
1	Free support	-15.463	-10.200
2	2nd excavation	57.969	-37.483
3	3rd excavation	118.843	108.321
4	Last excavation	105.801	85.356
5	Support replacement	146.818	-133.180

Maximum bending moment M = 146.818 kNm

Maximum shear force S = -133.18 kN

Sheet pile U type SP-IV

Section coefficient Z = 2270 cm3/m

Modulus of rigidity (z) αz= 60%

Allowable intensity of bending moment : 270 N/mm2

$$\alpha = \frac{M}{\alpha . z\, x\, Z} = \frac{146.818\, x\, 10^6}{0.600\, x\, 2270\, x\, 10^3} = 107.8 \leq 270.0$$

Since allowable intensity of bending moment is 270 N/mm², then the design is safe

Support frame calculation results

Strut

Table 6: Reaction force of struts

No	Depth	Reaction R (kN/m)	Material	Buckling Length L (m)	Section coeff. Z (cm^3)	Section Area A (cm^2)	Axis Force N (kN)	Bending Moment M (kNm)
1	1.000	37.54	H300X300	6.00	1150.00	104.80	300.18	22.50
2	4.000	158.12	H300X300	6.00	1150.00	104.80	782.47	22.50
3	7.000	103.22	H300X300	6.00	1150.00	104.80	562.87	22.50

No	σc N/mm^2	σ bcy N/mm^2	σ c+σ bcy +σ bcz N/mm^2	σbcz N/mm^2	L/r	Buckling ①	Buckling ②
1	28.600	19.60	48.2	133.90	46.51	0.33	49.30
2	74.700	19.60	94.2	133.90	46.51	0.68	97.30
3	53.700	19.60	73.3	133.90	46.51	0.52	75.40

Wales

Table 7: Reaction force of wales

No	Depth	Reaction R (kN/m)	Material	Buckling Length L (m)	Section coeff. Z (cm^3)	Section Area A (cm^2)	Axis Force N (kN)	Bending Moment M (kNm)	Shear force S (kN)
1	1.000	37.54	H300X300	3.00	1150.00	104.80	292.67	42.24	56.32
2	4.000	158.12	H350X350	3.00	2000.00	154.90	750.21	177.88	237.18
3	7.000	103.22	H300X300	3.00	1150.00	104.80	542.23	116.12	154.83

No	σc N/mm^2	σ bcy N/mm^2	σ c+σ bcy +σ bcz N/mm^2	σbcz N/mm^2	τ N/mm^2	τ a N/mm^2	L/r	Buckling ①	Buckling ②
1	27.90	36.70	64.7	183.00	20.90	120.00	23.26	0.34	65.10
2	48.50	88.90	137.4	191.10	63.30	120.00	19.87	0.69	138.90
3	51.70	101.00	152.7	183.00	57.30	120.00	23.26	0.79	155.10

For the retaining wall displacement, the order of the displacement amount in primary excavation is the final excavation. This greatly affects the amount of displacement up to the time of cutting. In the surface and ground conditions, the passive ground. The displacement of the ground is at most about 5 mm or less, Considerably larger than the spring value shown in the design standard

It was estimated that the spring value is large. As a result of the analysis of the stiffener springs. When shifting, the spring value of the upper three stages is reduced by half, Could be reproduced. This is due to the increase in displacement.

Figure 3 shows a comparison of the results of calculations and monitoring wall dispalcement in the field. The results show that the calculation value is slightly larger than the monitoring result. But for depths to more than 2 meters, it appears that displacement in the field is greater than the calculation results for each step, this is likely due to live load that moves around the wall and other loads that were not previously estimated and were not included in the calculation

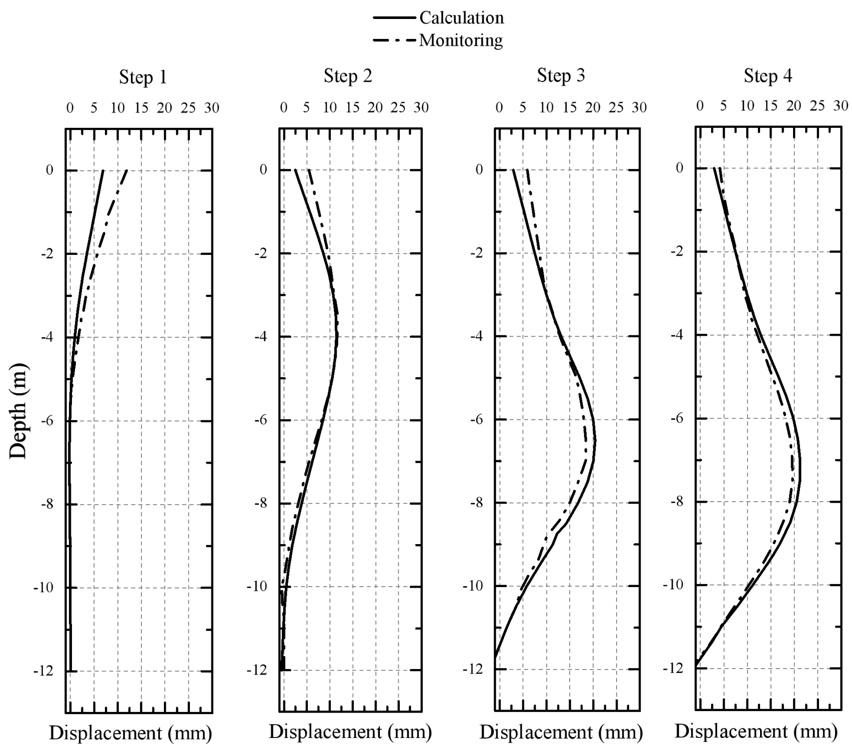


Figure 3: Wall displacement comparison between calculation results and monitoring from the site

V. Conclusions

In this study, ground spring and reinforcement spring were used as parameters. Nonlinear analysis was performed to determine the spring value of the passive ground and the spring value of the reinforcement. By properly setting the level according to the excavation level, confirm that it is possible to reproduce the behavior of the retaining wall displacement.

There is a good correlation between calculations with the methods used and the results of monitoring displacements in the field. There is a slight difference where the calculation result is slightly smaller than the monitoring result. This is likely a result of loading that was not previously calculated. Because the value is not too large this difference can be ignored.

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