APPLICATION OF STEEL SHEET PILE EMBEDDED RETAINING WALL AS A BRIDGE ABUTMENT

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ABSTRACT: This paper presents a case study of the use of sheet pile retaining wall as a bridge abutment. The U type steel sheet pile abutment is investigated to determine their stability and behavior from numerical model study. The case study gives the effective application program, design method, and guide of a steel sheet pile abutment.

INTRODUCTION

Steel sheet piles have been widely used in the construction of retaining walls or cut-off walls. Commonly, the steel sheet pile is designed to support lateral loads only. When both axial and lateral loads apply, the steel sheet pile is typically reinforced using H-pileand th e H-pile is assumed to resist the axial load. In reality, however, steel sheet pile itself can support axial load in some extent by its end bearing and skin friction resistance. In this study, a design of steel sheet pile bridge abutment is presented and the capacity of the sheet pile subject to both axial and lateral loads are investigated. Analyses of stress, displacement, and resistance of the sheet pile were performed and the results were checked whether complying with Korea Design

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Guide for Road Bridge and Design Guide for Structure Foundation. Also, the influences of bridge span length and abutment height on the embedment depth and the combined axial and bending stresses of sheet pile are investigated in details.

DESIGN OF STEEL SHEET PILE BRIDGE ABUTMENT

Design Outline

FIG. 1 shows the schematic of the steel sheet pile bride abutment used in analysis. Steel sheet piles were used as abutments for the bridge with 21m in span length. Soil type and properties used in the design of the abutment are displayed in TABLE 1. The length of steel sheet pile was 8.2m (embedment depth: 3.7m). The axial load from the bridge deck superstructure was assumed to directly act on pile cap. Analysis of the sheet pile wall was done using the free-earth method for anchored wall. The bending moment of the pile by lateral earth pressure and the axial load from bridge superstructure were considered together in the analysis. The end bearing and shaft friction resistance of pile was calculated using Meyerhof's method (1976).

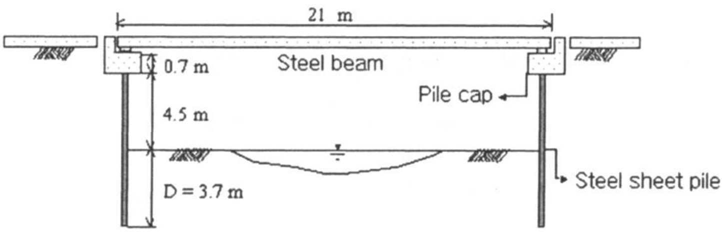


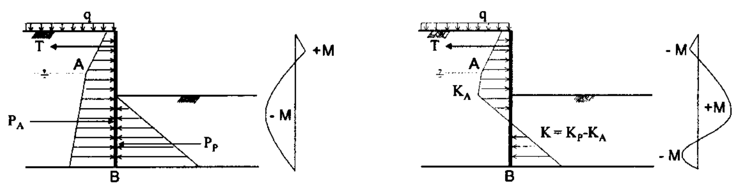
FIG. 1. Steel sheet pile bridge abutment

TABLE 1. Soil Condition and Properties at the Abutment

Soil	G_s	γ_t	ϕ	c	SPT N-value
SP (USCS Classification)	2.65	2.0t/m^3	35°	0	30 - 40

Design Method of Steel Sheet Pile

There are two basic methods of designing anchored sheet pile walls: a) the free earth support method and b) the fixed earth support method. As shown in FIG. 2, the free earth support method is based on the assumption that the active and passive pressures in the retained soil are in equilibrium and in the embedded part of the pile, no pivot point exists for the static system, whereas in the fixed earth support method, it is assumed that the earth pressure equal to the difference between the active and passive pressure in the retained soil acts on the embedded part of the pile, where a pivot point exists for the static system. Compared to the fixed earth support method, the free earth support method is more widely used because of its simplicity and economy in design.



a) Free earth support method b) Fixed earth support method

FIG. 2. Earth pressure and bending moment acting on anchored sheet pile wall

ANALYSIS OF STEEL SHEET PILE BRIDGE ABUTMENT

Loads Acting on Bridge Deck Superstructure

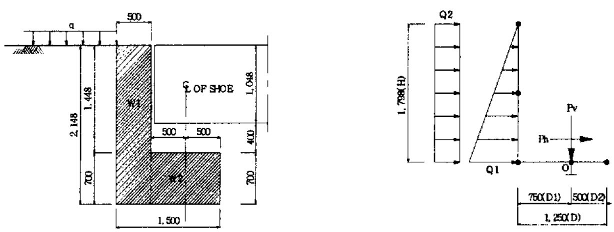
The loads acting on the short span steel bridge with 21m in span length and 7.9m in width are shown in TABLE 2. The calculated dead and live loads were 11.387 tonf and 15.922 tonf, respectively.

TABLE 2. Loads on Bridge Superstructure (Standard design for short span steel bridge, Pohang Industrial Science Institute)

Dead load (tonf)	Live load (tonf)	Total (tonf)
11.387	15.922	27.309

Design of Bride Seat

FIG. 3 displays the elevation view of bridge seat structure and the assumed distribution of loads acting on it. It was considered that the loads from the bridge superstructure are applied on the bottom of bridge seat structure and the horizontal loads acting on the bridge seat structure is Rankine's active earth pressure. As tabulated in TABLE 3, the calculated horizontal load, vertical load, and moment acting on the bridge seat structure were 1.530 tonf(/m), 30.970 tonf(/m), and 0.740 tonf·m(/m), respectively.



(unit: mm)

a) Elevation view of bride seat b) Applied load distribution

FIG. 3. Bridge seat design

TABLE 3. Loads and Moment Acting on Bridge Seat Structure

Horizon load (tonf)	Vertical load (tonf)	Moment (tonf·m)
1.530	30.970	0.740

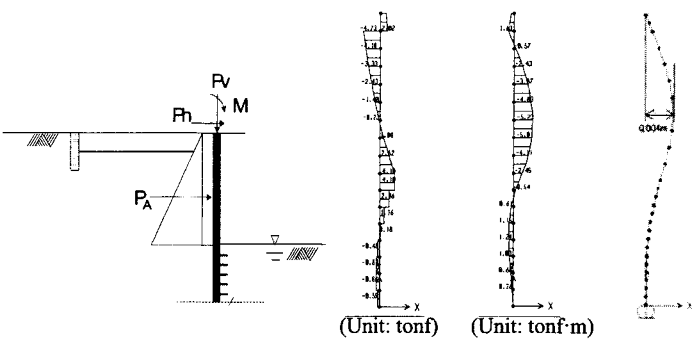
Design of Bridge Abutment

The required depth of embedment for the sheet pile bridge abutment was determined by using the free earth support method for anchored wall. The calculated embedment depth was 3.7m. The factor of safety for the sheet pile wall stability can be increased by either increasing embedment depth of pile or decreasing the friction angle of retained soil. Both methods were considered in the design calculation. Also, since the sheet pile bridge abutment is subject to both axial and lateral loads, the analysis for secondary deflection and stress of the sheet pile under axial load and bending moment were performed by using commercial structural program SAP2000.

Resistance of pile was obtained by applying Meyerhof's method (1976). In the calculation of skin friction resistance, only the resistance from the soil below dredge line was considered (FIG. 4. a).

FIG. 4 shows the sheet pile abutment modeled for the analysis using SAP2000 program and the analysis results. It was assumed that all loads from the bridge superstructure are transferred directly to the pile abutment through the bridge seat. Therefore, the vertical load of 30.970 tonf (P_v), the horizontal load of 1.530 tonf (P_h) and the moment of 0.740 tonf·m (M) were assumed to act on top of the pile in the analysis. The earth pressure acting on sheet pile was assumed to be Rankine's active pressure (P_A). The moduli of rigidity and horizontal subgrade reaction used in the analysis were 1,842 tonf/m^2 and 1,271 tonf/m^2, respectively.

As shown in TABLE 4, the obtained maximum shear force, moment, and displacement were 4.73 tonf, 5.23 tonf·m, and 0.4cm, respectively.



a) Sheet pile abutment modeled for analysis

b) Shear force diagram

c) Moment digram

d) Displacement diagram

FIG. 4. Sheet pile abutment modeled for analysis and results

TABLE 4. Maximum Shear Force, Moment, and Displacement

Shear force (tonf)	Moment (tonf·m)	Displacement (cm)
4.73	5.23	0.4

The steel sheet pile section used in stress analysis was KWSP-II, all Box-types. The axial, shear, and combined axial and bending stresses obtained from the analysis are shown in TABLE 5. Applied loads were the axial load of 30,970 kgf, shear force of 4,730 kgf, and moment of 523,000 kgf·cm. Comparison of the results with Design Guide for Structure Foundation showed that all box type steel sheet piles are applicable for use as bridge abutment. TABLE 6. displays the results of pile resistance obtained.

TABLE 5. Results of Stress Analysis

Axial stress (f_c/f_{ca})	Shear stress (τ/τ_a)	Bending stress (f_b/f_{bca})	Axial+Bending stress ($f_c/f_{ca} + f_b/f_{bca}(1-f_c/f_{Ez})$)
0.064	0.041	0.149	0.215

TABLE 6. Results of Pile Resistance

End beaing resistance $Q_p = m^*N'A_p$ (Tonf)	Shaft resistance $n^*N_{ave}A_s$ (Tonf)	Allowable resistance $(Q_P + Q_S)/3$ (Tonf)	Resistance ratio Q/Q_A
121.6	0.493	40.7	0.761

* $m = 3L_b/B \leq 30$ for driving pile (L_b: embedment depth, B: pile width)

$n = 0.2$ when $nN \leq 10t/m^2$

INFLUENCE OF BRIDGE SPAN LENGTH AND ABUTMENT HEIGHT

In the design of steel sheet pile bridge abutment, bridge span length and abutment height may be important factors affecting the capacity of the sheet pile. In this study, the influences of the bridge span length and abutment height on the capacity of steel sheet pile were investigated.

Influence of Bridge Span Length on Pile Embedment Depth and Stress Ratio

In order to examine the influence of bridge span length on the embedment depth and stress ratio of sheet pile, the analyses were performed on sheet pile abutment with 4.5m in height by varying the length of bridge span from 10m to 24m. FIG. 5 shows the results of analysis. As shown in the figure, the depth of embedment shows no change with the change in bridge span, whereas the ratio of axial and bending stress increases gradually as the length of span increases due to increase in axial load.

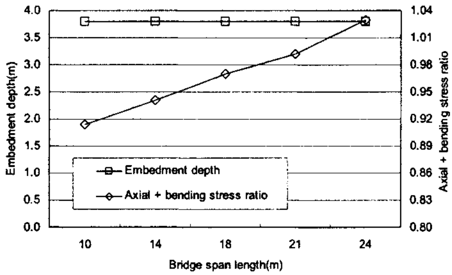


FIG. 5. Bridge span length versus embedment depth and axial +bending stress ratio

Secondary Deflection and Stress of Steel Sheet Pile

To investigate the effects of secondary deflection and stress of steel sheet pile under vertical and horizontal loads, P-Δ analysis was performed using SAP2000 program for the steel pile bridge abutment with 24m in bridge span and 10m in abutment. In this analysis, deflection was calculated by considering the moments occurred by both horizontal and vertical loads. The deflection by horizontal load was first calculated and then, as the pile becomes deflected, additional deflections occurred on the deflected pile by the vertical load were added.

The results are shown in TABLE 7. For comparison, the results of the analysis, where no secondary deflection and stress were considered, are also presented in the table. The differences in the results between both analyses were 0.05tonf for maximum shear force, 0.41tonf·m for maximum moment, and 0.017cm for displacement, respectively. Based on the results, it appears that for the steel sheet pile bridge abutment with bridge span length less than 24m and abutment height less than 10m, the effects of secondary deflection and stress are negligible.

TABLE 7. Influence of Secondary Deflection and Stress

	Vmax (tonf)	Mmax (tonf·m)	δ max (cm)
No secondary	23.60	43.11	1.837
Secondary	23.65	43.52	1.854

CONCLUSIONS

1) For the steel sheet pile bridge abutment with the bridge span of 21m length, the obtained maximum vertical displacement was 0.4 cm, which was less than the allowable displacement of 1.5 cm.

2) All stresses acting on the steel sheet pile under both axial and lateral loads were in allowable range. All-Box type steel sheet pile was found to be applicable for use as bridge abutment.

3) With the increase in bridge span length, the ratio of axial and bending stress increased gradually, while there was no change in the embedment depth of pile. Also, as the abutment height increased, both the embedment depth and the anchor force increased gradually.

4) For the steel sheet pile bridge abutment with bridge span length less than 24m and the abutment height less than 10m, the influences of secondary deflection and stress were negligibly small.

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