A horizontal test and its simulation analysis of the abutment model with backfill soil

Y. Kajita, H. Otsuka & Y. Fujiyoshi
Kyushu University, Japan

SUMMARY
In this study, a horizontal static loading test is carried out to understand the resistance characteristic of an abutment. In the test, we focus on the effect of the backfill soil on the resistance characteristic. Furthermore, we confirm the difference of the fracture behavior in two specimens. From the test results, it is understood that the maximum strength becomes larger in the case of the specimen with the backfill soil. However, the weakest part of the abutment is the basement of the vertical wall regardless of the backfill soil. Furthermore, as the results of the numerical simulation, we can estimate the load-displacement relation curve until the cracks on the vertical wall are generated.

Keywords: abutment, backfill soil, characteristic of the horizontal resistance

1. INTRODUCTION

In general, when the seismic performance of bridges is assessed, it does not take into consideration the abutments even if a bridge has the abutments at both girder ends. In this case, we anticipate that the girder of the bridge will move to greater than the real phenomenon and the inertia force acting on the pier is thought to be larger. For this reason, the bridge manager determines that the seismic strengthening of piers and foundations is needed. However, if we consider the horizontal resistance of the abutment, the displacement of the girder is restricted and the inertia force acting on the pier is reduced. Therefore, the needless seismic strengthening of the piers is removed. Therefore, the seismic response analysis considered the abutment should be conducted when the seismic performance of piers is evaluated properly.
When the seismic response analysis considered the abutment is carried out, the restoring force characteristic of the abutment is needed. Experimental studies on the resistance characteristic of the abutment have not been conducted so far. Therefore, we do not understand to what extent the vertical wall (the breast wall) is damaged and how the existence of the wing wall affects the resistance characteristic of the abutment. Therefore, it is vital to reveal the resistance characteristic of the abutment in order to assess the seismic performance of the bridges which have an abutment. The objective of this research work is to assess the seismic performance of the bridges which have abutments. First, in order to achieve this objective, we need to carry out a static loading test using two 500kN-oil jacks. In particular, we have to make the 1/6 scale abutment specimen which is 1.45(m) height 1.5(m) wide and 0.75(m) length as shown in Photo 1.1. Secondly, it is necessary to carry out its numerical simulation by using the general-purpose finite element method code, called LS-DYNA, which is specialized for the structural fracture analyses. In this paper, we describe the results of the static horizontal loading test and its numerical simulation.

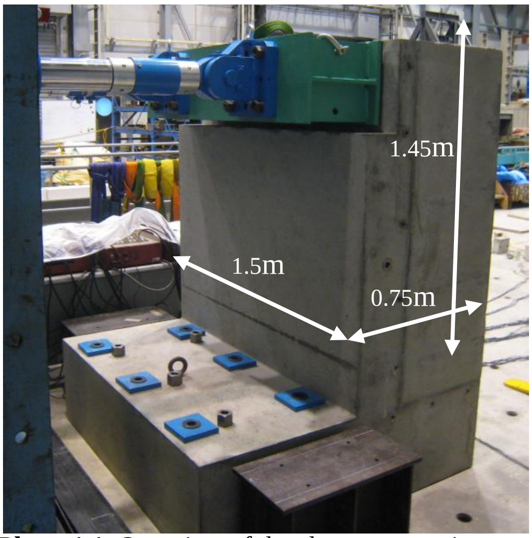


Photo 1.1. Overview of the abutment specimen

2. STATIC HORIZONTAL LOADING TEST

2.1 Outline of The Test

Figure 2.1 shows the target bridge in this research. Figure 2.2 shows the cross section of the superstructure. This bridge is the two spans PC (prestressed concrete) girder bridge. The abutment specimen is the 1/6 scale of the abutment of this real bridge. Two types of specimen are prepared. One is the abutment which has no backfill soil and the other is the real abutment which has the backfill

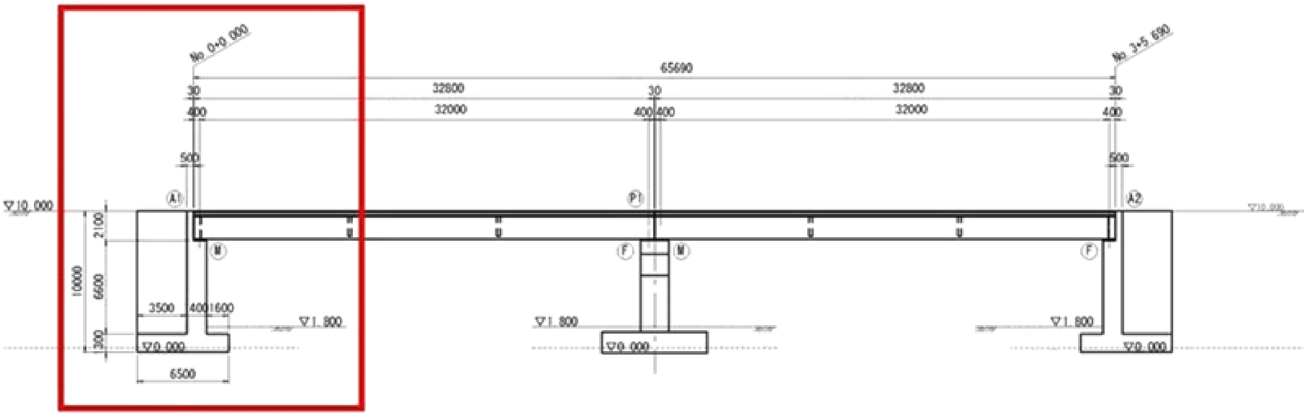


Figure 2.1. Side view of the target bridge

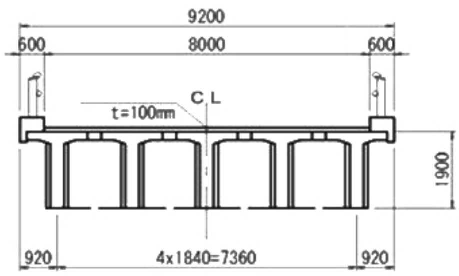
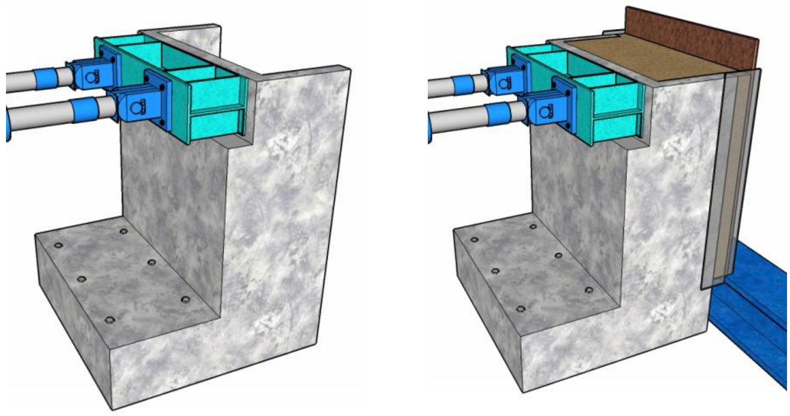


Figure 2.2. Cross section of superstructure



(a) Specimen without backfill soil (b) Specimen with backfill soil

Figure 2.3. Overview of the abutment specimen

soil as shown in Figure 2.3. Since then, two types of specimens are called the specimen without backfill soil and the specimen with backfill soil, respectively. The quartz sand is used for making the backfill soil and the N-value of the backfill soil in this test is from 10 to 15 obtained from the density test of the backfill soil. The horizontal load is applied through contact with the steel H-beam by the two hydraulic jacks as shown in Figure 2.3. Table 2.1 shows the material properties on this test.

Table 2.1. Material properties

		Density	Young's Modulus	Com. Strength	Ten. Strength
	unit	g/cm3	MPa	MPa	MPa
Without backfill soil	Concrete	2.23	$2.71E10^{4}$	31.5	3.0
	Steel Bar(D6)	7.85	$1.92E10^{5}$	500 (yield stress)	
	Steel Bar(D10)	7.85	$1.82E10^{5}$	372 (yield stress)	
With backfill soil	Concrete	2.24	$2.31E10^{4}$	21.5	2.1
	Steel Bar(D6)	7.85	$2.05E10^{5}$	478 (yield stress)	
	Steel Bar(D10)	7.85	$1.94E10^{5}$	354 (yield stress)	

2.2 Test Results

Figure 2.4 shows the load-displacement curve and Table 2.2 shows the load and the displacement of the dynamic events of the specimens. The displacement is measured at the horizontal direction of the top of the parapet wall. From the test results, the initial stiffness is the same regardless of the presence of the backfill soil. However, as for the stiffness after the main reinforcement steel bars yield, the stiffness of the specimen with the backfill soil is a little larger than the one of the specimen without the backfill soil. The backfill soil has an influence on the horizontal resistance after the main reinforcement steel bars yield. The

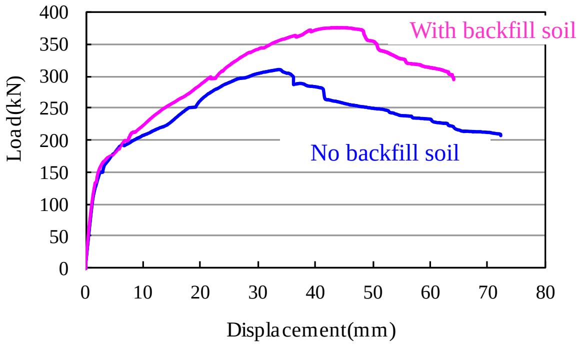


Figure 2.4. Load-Displacement curve

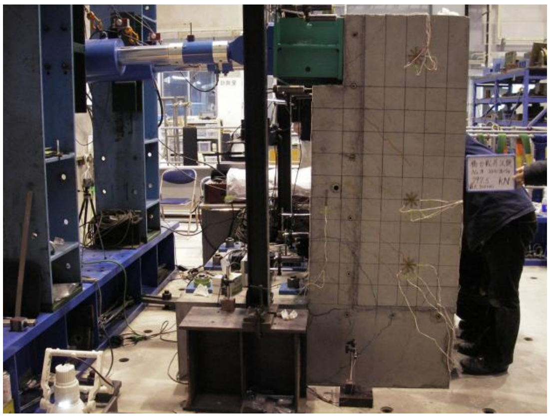
Tabel 2.2. Dynamics events

	No backfill soil	With backfill soil
Yield Load of the main reinforcement steel bar at in the vertical wall	184 kN	177KN
Maximum Load	310kN	377kN

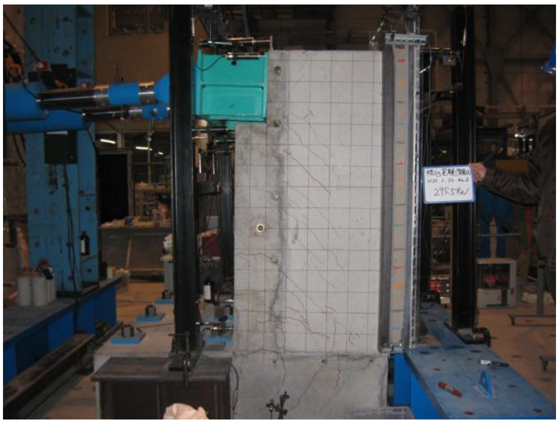
(a) Specimen without backfill soil

(b) Specimen with backfill soil

Photo 2.1. Fracture situation of the parapet wall after the test



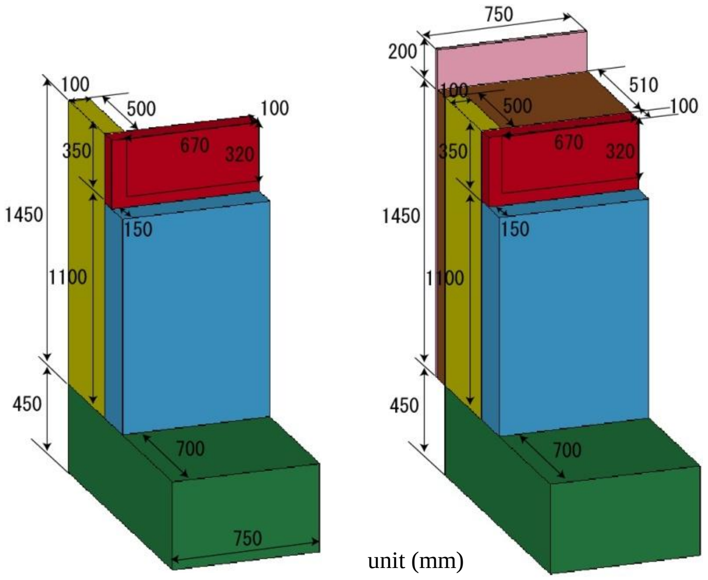
(a) Specimen without backfill soil



(b) Specimen with backfill soil

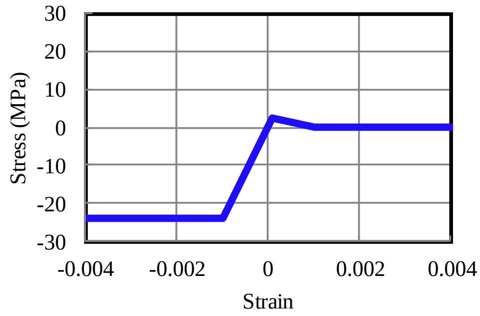
Photo 2.2. Deformation of the specimen under the maximum load

maximum load of the specimen with the backfill soil is about 20 % larger. Photo 2.1 shows the parapet wall of the specimens after finishing the test. It is found from these photos that the punching shear cracks are generated in the case of the specimen with soil. In the case of the specimen without backfill soil, the load degrades gradually due to the tensile fracture of the basement of the vertical wall and the compression failure of the corner of the wing wall. On the other hand, in the case of the specimen with soil, the horizontal deformation of the vertical wall is suppressed by the backfill soil. Therefore, the relative displacement between the vertical wall and the parapet wall becomes large and then the punching shear cracks are generated. However, the punching shear cracks are not the reason why the resistance load decreases. Photo 2.2 shows the side view of the specimen under the maximum load. From the test results, it is confirmed that the tensile fracture at the basement of the vertical wall cause the decrease of the proof strength regardless of the backfill soil.

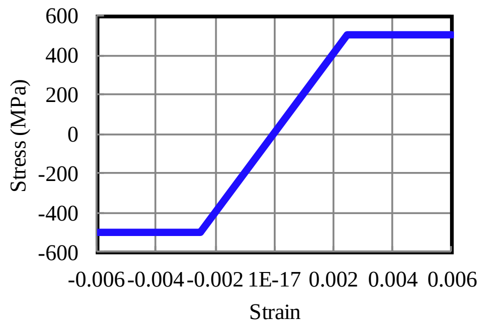


(a) Model without backfill soil (b) Model with backfill soil

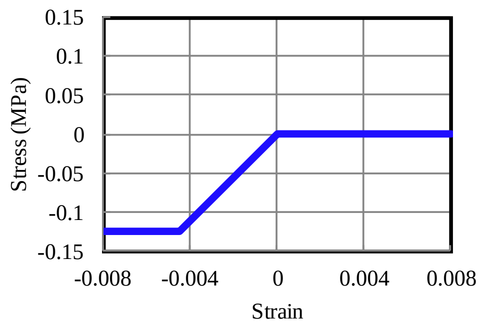
Figure 3.1. Overview of the Analytical model



(a) Concrete



(b) Steel bar



(c) Backfill soil

Figure3.2. Stress-strain curves of each material

3. NUMERICAL SIMULATION ANALYSIS

3.1 Outline of The Numerical Analysis

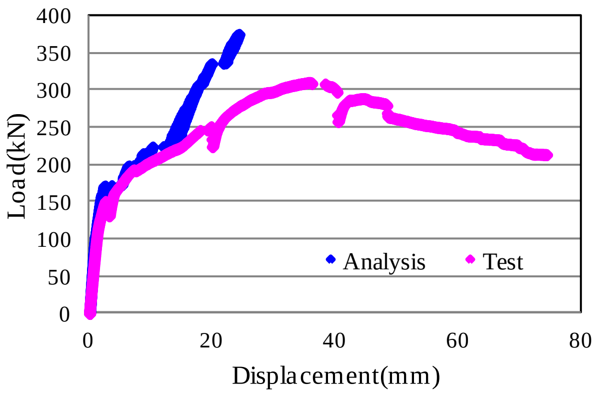
Figure 3.1 shows the analytical model. The analytical model is the half size model considered with the symmetry. The concrete and the backfill soil are modeled by the 8-node solid element and the steel bar is modeled by the 2-node truss element. The nodes of both the concrete and steel bar elements are shared, that is, the steel bars perfectly adhere to the concrete. Figure 3.2 shows the stress-strain curves of each material. In the case of the steel bars, the constitutive law is defined as the bi-linear model satisfied with the von Mises yield criterion. The stiffness after the yielding is 0.01 times as the initial stiffness. In the case of the concrete, the compressive stress after the maximum stress is set to be a constant value. In the case of the soil, the stress is not generated in the tensile region. The Young's modulus of the soil is calculated from Eq.(3.1) as below.

$$E = 2.8N \tag{3.1}$$

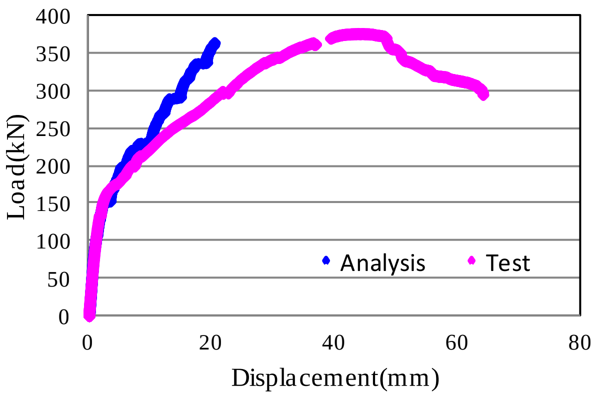
E is the Young's modulus (unit: MPa) and N is the N-value of the backfill soil. In this analysis, N-value is set to be 10. The maximum compressive stress is obtained from the equation of Terzaghi and Peck as below.

$$q_u = \frac{N}{80} \tag{3.2}$$

q_u is the maximum compressive stress (unit: MPa) and N is the N-value of the backfill soil. The material properties of the steel bar and the concrete are used the values obtained from the horizontal test as shown in Table 2.1. In this numerical simulation, not the displacement but the monotonically increasing load is applied to the analytical model.



(a) Load-displacement curve without backfill soil



(b) Load-displacement curve with backfill soil

Figure3.3. Load-displacement curve

3.2 Numerical Results

Figure 3.3 shows the load-displacement curve. The analytical result in this figure shows until the main reinforcement steel bars yield. It is found that the initial stiffness is well simulated and the changing point of the stiffness is also simulated due to the tensile crack at the basement of the vertical wall. However, the yield point of the steel bar is quite different. This is because the compressive stress doesn't decrease in this analytical model. So, the stiffness after the tensile crack in the analytical result is larger.

4. CONCLUSIONS

In this study, a horizontal static loading test is carried out to understand the resistance characteristic of an abutment. The results of this study were obtained as explained below.

From the test results, the initial stiffness is the same regardless of the presence of the backfill soil. However, as for the stiffness after the main reinforcement steel bars yield, the stiffness of the specimen with the backfill soil is a little larger than the one of the specimen without the backfill soil.

It is found that the punching shear cracks are generated only in the case of the specimen with the backfill soil.

It is confirmed that the tensile fracture at the basement of the vertical wall cause the decrease of the proof strength regardless of the backfill soil.

From the analytical results, the initial stiffness is well simulated and the changing point of the stiffness is also simulated due to the tensile crack at the basement of the vertical wall. However, the yield point of the steel bar is quite different at this stage.

ACKNOWLEDGEMENT

This work was supported by JSPS KAKENHI (Grand-in-Aid for Young Scientists (A), 21686041).

REFERENCES

Japan Road Association (2002), Specifications for Highway Bridges (Part V seismic design), Maruzen.
Japan Road Association (2002), Specifications for Highway Bridges (Part IV substructures), Maruzen.
Karl Terzaghi, Ralph B. Peck and Gholamreza Mesri (1996), Soil Mechanics in Engineering Practice (Third Edition), Wiley-Interscience.