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Evaluation of Limit State for Pier According to Scour and Peak Ground Acceleration

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Abstract. Recently, materials and structure analysis techniques used in various structures have been developed and have made remarkable progress. As the design method for reinforced concrete structures is shifting to the limit state design method, it is necessary to conduct the limit state assessment. So far, several researchers have evaluated the safety of many structures covered by the civil engineering field by introducing the limit state assessment. However, there is a lack of research on bridge piers considering the level of scour. Therefore, in this study, T-shaped bridge piers with a height of 11.5 m and a width of 2.8 m installed in underwater ground were selected and the critical condition of bridge pier for 20 seismic waves was evaluated using LS-DYNA. The presence or absence of scouring was also set as a variable and the level of scour is changed from 0 to 5 meter. As a result of the analysis, the main fracture was tensile failure at the maximum ground acceleration of 0.2g to 0.4g, and the maximum ground acceleration after the earthquake was found to be weak as a whole except compression. Finally, as a result of comparing analysis results according to the presence or absence of scour, the limit state reaching ratio showed a similar pattern without significant change.

1. Introduction

In addition to material and structure analysis techniques, design methods have been developed for high-rise and large-scale structures. Recently, a design method for reinforced-concrete structures has been shifted by the limit state design method, and several researchers have evaluated the safety by introducing the limit state evaluation for many structures. However, the evaluations of structures and study on bridges, which play a large role as social infrastructures, remain insufficient. Because the bridge structure is designed for various conditions, the structure is safe under normal extreme conditions. Generally the structure, which is designed with seismic load, is safe to the targeted earthquake. However, since the frequency and magnitude of earthquakes are increasing every year, the risk of earthquakes is also increasing. Therefore, it is necessary to evaluate the marginal condition of bridge structures for earthquakes. In this study, the limit states of bridge structures for various seismic loads and PGA were evaluated. To evaluate the limit state of the bridge structure according to the scour, the pier is analysed with the difference level of scour.

2. Analysis and evaluation plan

The bridge pier in the evaluation is T-shaped bridge pier with pit bases, 11.5 m in column height, and 2.8 m in width. A structural analysis was performed using infinite ground conditions. LS-DYNA which is a finite-element analysis program to simulate the dynamic behaviour of three-dimensional inelastic structures, reinforced-concrete and soil material model and contact boundary condition model in the analysis code, is used in the analyses. When the seismic waves were applied, infinite ground was implemented using the PML model to absorb the energy and control the reflected wave. The modelling results and real structural analysis model results using PML are shown in Fig. 2. Table 1 summarizes the finite-element analysis model.

Table 1. Finite element analysis plan.

Material model			Contact condition	Damping	Element	
concrete	soil	Unbounded Soil	2D-AUTOMATIC _NODE_TO_SURFACE	FREQUENCY _RANGE	3-NODE BEAM	4-NODE SHELL
159-CSCM	147-FHWA_SOIL	230-PML				
FPC=24MPa	K=65MPa, G=186MPa	E=1.32GPa	Soil-concrete(FS=0.5)	CDAMP=5%	Number of = 752	Number of = 5609

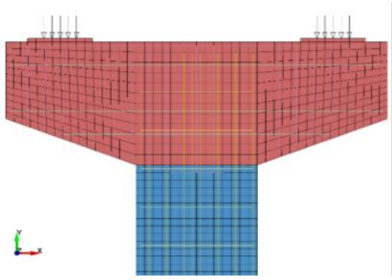

Figure 1. Load condition.

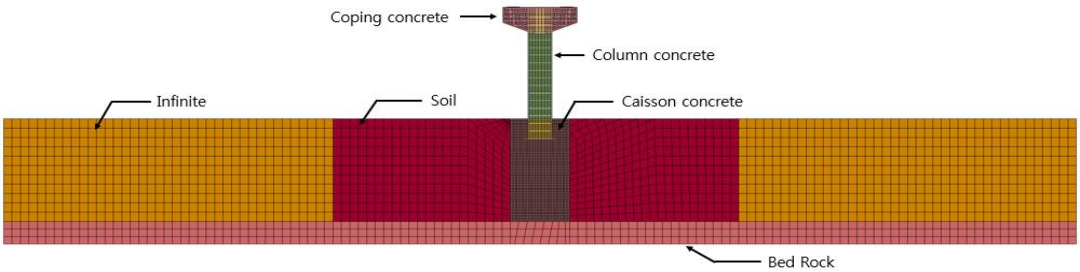

Figure 2. Whole model (scour 0m).

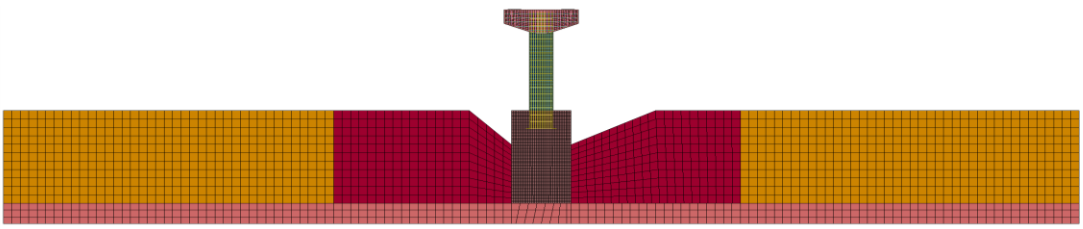

Figure 3. Scour 5m model.

Natural waves were selected to account for the uncertainty of seismic waves. Due to that, 20 natural seismic waves are selected from the seismic records in the recent 20 years worldwide. The natural wave enables one to derive the effects of different characteristics of seismic waves. Among various factors that can characterize seismic waves, the peak ground acceleration is used the main characteristic of the seismic since it is widely used in practice. As another variable, scour was created

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at 1-m intervals from 0 m to 5 m around the pier in different conditions. The upper load is shown in Fig. As shown in Fig. 1, the dead load of 7.5 kN/m^2 was applied to both bearing supports. The limit state of the concrete structure was set to the tensile and compressive failure of the concrete. The maximum relative displacement between the right top of the pier and the bottom of the column is set to displacement limit state, and the von-Mises stress is used as the limit stat of reinforcing bar.

3. Results and discussion

The Tables 2-7 show the probability of the bridge failure to the maximum ground acceleration with difference level of scour. First, Table 2 shows the analysis results with the 0m of scour. It indicates that there is no concrete compression failure at 0.2g and the probability of failure in reinforcement and drift ratio is 5%, but the probability of failure about concrete tension failure is relatively high as 40%. At 0.4 g, the failure probability for the tensile, rebar and maximum displacements increased to 100%, 60% and 75%, respectively, which can be treated as tensile failure. However, after reaching the ground acceleration of 0.6 g to 1.5 g, the probability of failure for the tensile, reinforcing bar, and maximum displacements exceeded 90% except for concrete compression. Second, Table 3 shows the analysis results with the 1m of scour. It indicates that the probability of concrete compression failure, reinforcement failure and drift failure are very similar with the case of scour with 0 m and the probability of concrete tension failure is increased as 45% at PGA 0.2g. At 0.4g, all limit state reaches to the failure except concrete compression failure. The probability of concrete tensile, reinforcement, and drift failure are sharply increased to 95%, 65%, and 75% respectively.

The main failure can be considered a tensile failure. Next, from 0.6 g to 1.5 g, the probability of failure for the tensile, reinforcing bar, and maximum displacements exceeded 90% except for concrete compression. The scouring range of 2-5 m was similar. Therefore, there is no large change in tendency of failure probability depending on the presence and depth of the scour since the bridge pier possesses the strong caisson concrete foundation. Fig. 4 shows the results of the tensile stress and compressive stress of bridge pier subject to PGA 1.5g seismic load with change of the scour level.

Table 2. Probability of failure with maximum ground acceleration (scour 0m).

PGA	Limit state			
	Tension of Concrete	Compression of Concrete	Steel	Drift
0.2g	40%	0%	5%	5%
0.4g	100%	0%	60%	75%
0.6g	100%	0%	90%	90%
0.8g	100%	0%	95%	100%
1.0g	100%	0%	100%	100%
1.5g	100%	0%	100%	100%

Table 3. Probability of failure with maximum ground acceleration (scour 1m).

PGA	Limit state			
	Tension of Concrete	Compression of Concrete	Steel	Drift
0.2g	45%	0%	5%	5%
0.4g	95%	0%	65%	75%
0.6g	100%	0%	90%	90%
0.8g	100%	0%	95%	100%
1.0g	100%	0%	100%	100%
1.5g	100%	0%	100%	100%

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Table 4. Probability of failure with maximum ground acceleration (scour 2m).

PGA	Limit state			
	Tension of Concrete	Compression of Concrete	Steel	Drift
0.2g	40%	0%	5%	10%
0.4g	90%	0%	75%	75%
0.6g	100%	0%	90%	85%
0.8g	100%	0%	95%	100%
1.0g	100%	0%	95%	100%
1.5g	100%	0%	100%	100%

Table 5. Probability of failure with maximum ground acceleration (scour 3m).

PGA	Limit state			
	Tension of Concrete	Compression of Concrete	Steel	Drift
0.2g	35%	0%	0%	0%
0.4g	95%	0%	65%	70%
0.6g	100%	0%	90%	90%
0.8g	100%	0%	100%	95%
1.0g	100%	0%	100%	100%
1.5g	100%	0%	100%	100%

Table 6. Probability of failure with maximum ground acceleration (scour 4m).

PGA	Limit state			
	Tension of Concrete	Compression of Concrete	Steel	Drift
0.2g	25%	0%	0%	0%
0.4g	95%	0%	60%	95%
0.6g	100%	0%	90%	95%
0.8g	100%	0%	95%	100%
1.0g	100%	0%	100%	100%
1.5g	100%	0%	100%	100%

Table 7. Limit state arrival rate with maximum ground acceleration (scour 5m).

PGA	Limit state			
	Tension of Concrete	Compression of Concrete	Steel	Drift
0.2g	35%	0%	0%	0%
0.4g	85%	0%	50%	60%
0.6g	100%	0%	90%	90%
0.8g	100%	0%	95%	95%
1.0g	100%	0%	95%	100%
1.5g	100%	0%	100%	100%

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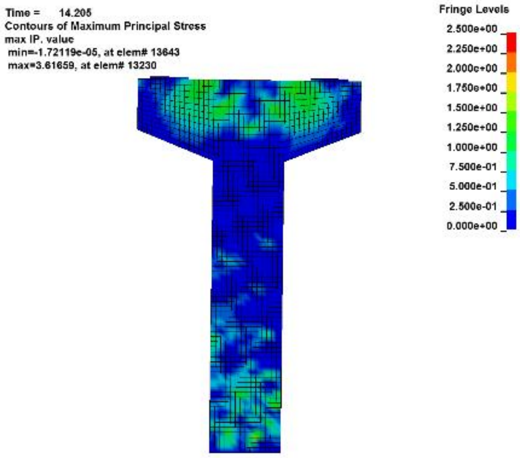
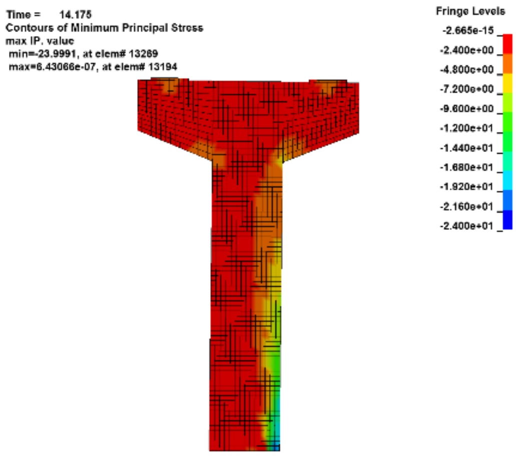
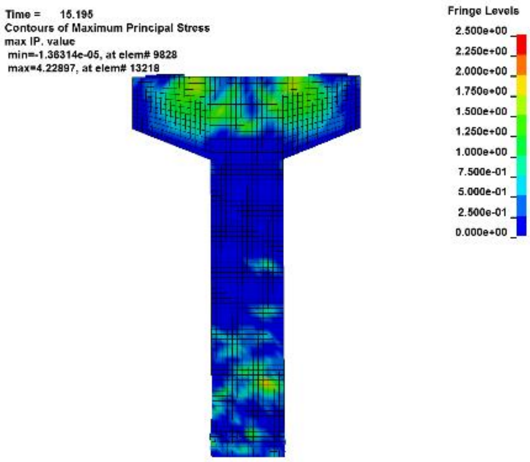


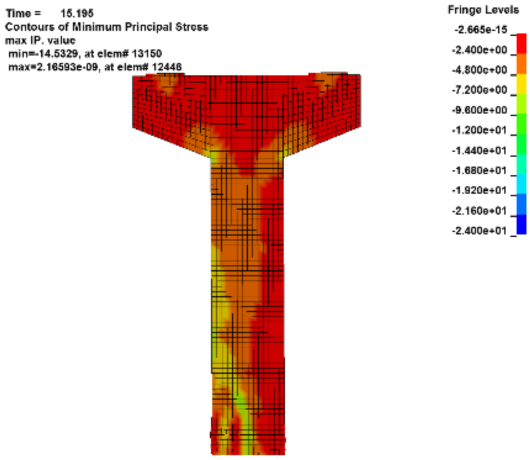
(a) 1.5g Tension of concrete (scour 0m)



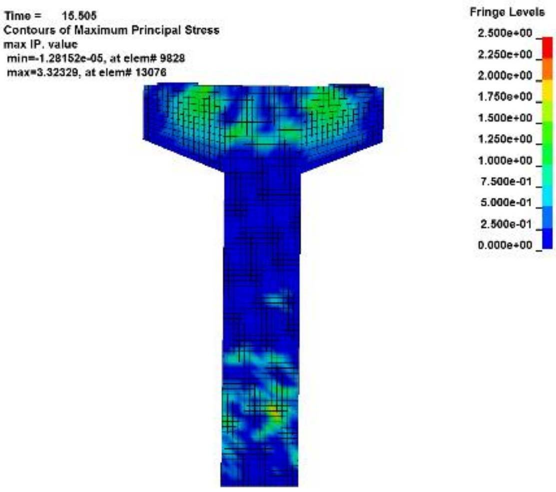
(b) 1.5g Compression of concrete (scour 0m)



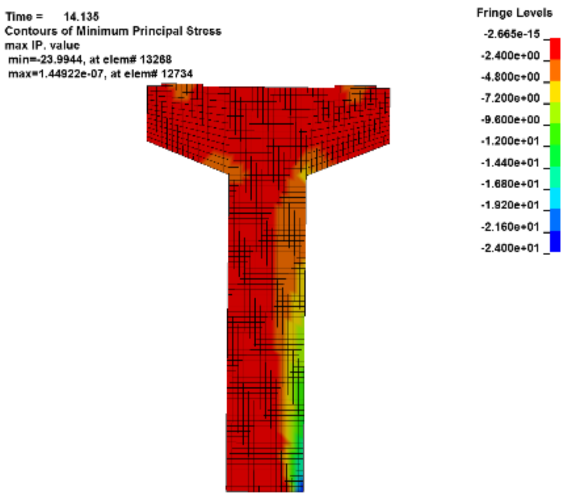
(c) 1.5g tension of concrete (scour 1m)



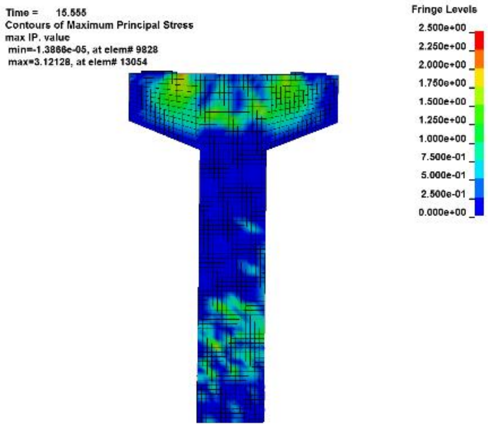
(d) 1.5g compression of concrete (scour 1m**)**



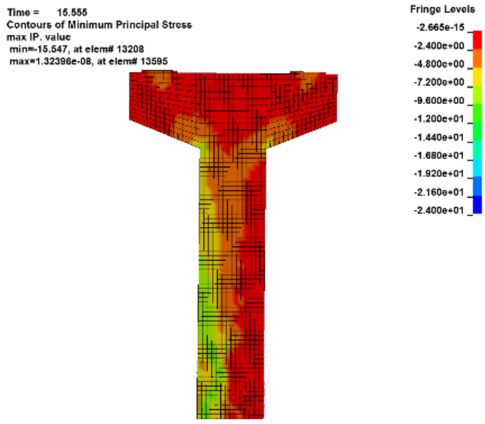
(e) 1.5g tension of concrete (scour 2m)



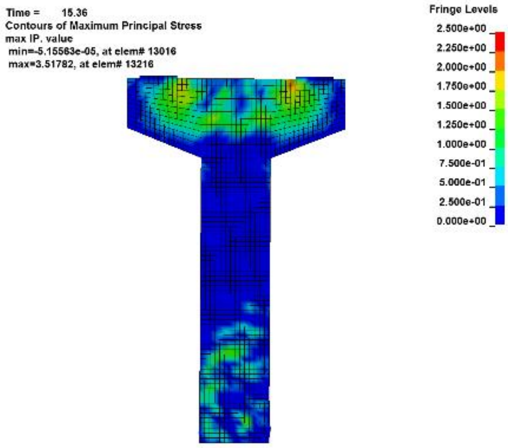
(f) 1.5g compression of concrete (scour 2m)



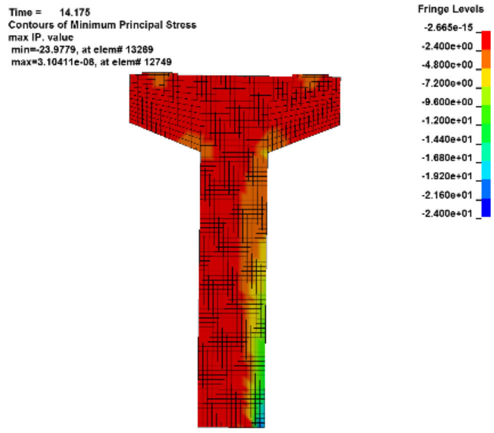
(g) 1.5g tension of concrete (scour 3m)



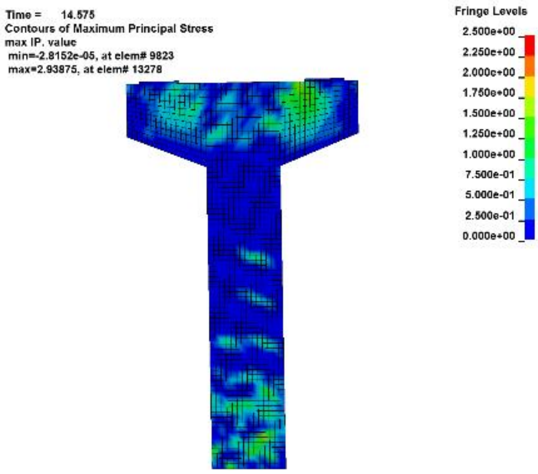
(h) **1.5g compression of concrete (scour 3m)**



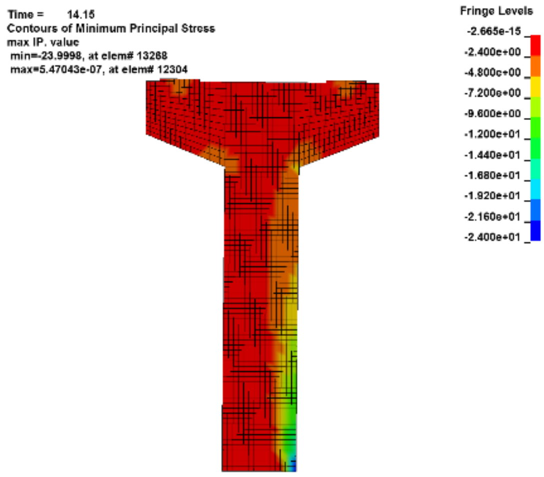
(i) 1.5g tension of concrete (scour 4m)



(j) 1.5g compression of concrete (scour 4m)



(k) 1.5g tension of concrete (scour 5m)



(l) 1.5g compression of concrete (scour 5m)

Figure 4. Results (tension, compression).

4. Conclusion

The evaluation results of the limit state of the bridge with variety natural seismic loads are as follows. When PGA is 0.2 g, the failure probability of reinforcement and drift condition is 0~5% and the probability of concrete tension failure is 25~45%. With PGA 0.4 g, the probability of failure for all limit states are increased by 50% more. When PGA is greater than 0.4g, probability of failure is more than 90%, which indicates that the usability is weak as a whole such as tension and compression limit state. In addition, it is observed that the failure probability of the pier is not effected much as the increasing the level of scour due to the strong caisson concrete foundation.

5. References

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