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“Technical Research and Development for Road Policy Quality Improvement”
Study Summary

No.	Title	Principal Researcher
No.22-4	Evaluation of Design Concept on Multi-Arch Culvert Embankment through Dynamic Experiments and Numerical Simulations	Kyoto Univ. Prof. Makoto Kimura

The multi-arch culvert embankment is a new type of filling structure proposed to solve some social issues, namely, the stress felt by the residents of a neighborhood where such an embankment is located, the fragmentation of a local society, and construction costs. In this research, dynamic experiments and numerical simulations have been conducted in order to clarify the damage conditions and the seismic performance of the multi-arch culvert embankment. In addition, the design concept for the multi-arch culvert embankment has been discussed.

1. Backgrounds and Objects

When an arterial high-standard road or expressway is built, it is necessary to construct a fill or an elevated bridge to pass over other roads and railways. However, if a fill structure is chosen, it acts as a wall that partitions one area from another. And if an elevated bridge is chosen, the construction and maintenance costs of the elevated bridge are more expensive that those of the fill structure. In order to solve these issues, it has been proposed that precast arch culverts be installed in the fill structure in the direction of the road extension.

The proposed structure is arranged as continuous flexible arch culverts in the embankment. One problem to its practical use is the evaluation of the interactive dynamic behavior between the culvert and the embankment. In this research, two types of dynamic experiments and their numerical simulations have been carried out. Field measurements at an actual construction site have been also conducted. Based on these works, damage shapes for the proposed structures and the seismic performance during an earthquake have been evaluated, and a design concept considering the seismic behavior has also been proposed.

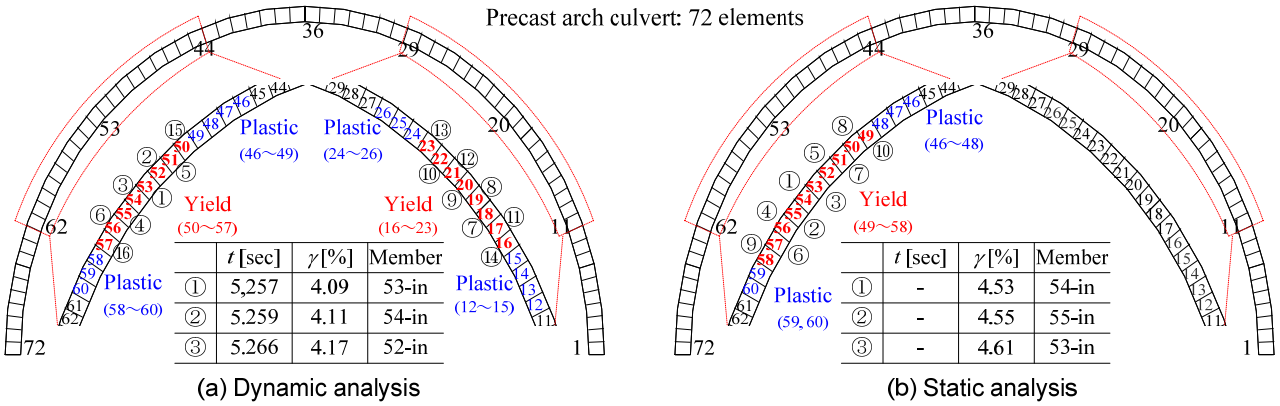
2. Activities in Research Period

The following activities were conducted during this research so as to discuss a design concept for the multi-arch culvert embankment.

(1) Dynamic centrifuge model tests were carried out to evaluate the seismic performance, and a numerical simulation was performed. (The shaking directions were both culvert cross section and culvert longitudinal direction.)
(2) Real-size model tests were conducted at Kyoto University using their strong earthquake response simulator, and a numerical simulation was performed.
(3) The response of the precast arch culvert was discussed through performance tests of splice models and field measurements of actual construction work
(4) The seismic resistance of the precast arch culvert was evaluated, and a design concept for the multi-arch culvert embankment was discussed.

3. Study Results

- As for the seismic performance in the culvert longitudinal direction, the connection style of the culvert’s jointing had a strong effect on preventing the opening of the culvert’s jointing and the total deformation of the continuous culvert arrangement structure. In the case of a high overburden above the culvert, high seismic resistance could be confirmed under these research conditions. Therefore, it is thought that certain overburden conditions are desirable for application at the entrance of an arch culvert structure.
- As for the seismic performance of the arch culvert in the cross section, dynamic centrifuge model tests and numerical simulations were carried out to clarify the basal earthquake behavior when considering the influence of each structure style and the height of the overburden. In the case of a hinge-type arch culvert, the increment in



	t [sec]	γ [%]	Member
①	5,257	4.09	53-in
②	5.259	4.11	54-in
③	5.266	4.17	52-in

	t [sec]	γ [%]	Member
①	-	4.53	54-in
②	-	4.55	55-in
③	-	4.61	53-in

(a) Dynamic analysis (b) Static analysis

Fig. 1 Damage process of reinforcing steel

bending moment at each seismic level was constant. And, it was confirmed that the function of the hinge structure was disturbed in the case of the high overburden due to the relative high confining stress conditions.

- In the condition of more than 7% shear strain, many cracks could be found on the surface of the concrete wall. Moreover, the strain of the reinforcing bar was two times the yield strain occurring under this condition. However, the hinge structure did not fail and the arch culvert did not yield.
- From the results of the real-size model tests using the strong earthquake response simulator and a numerical simulation, it was confirmed that the process of the seismic damage of the arch culvert could be accurately simulated. In addition, from the results of the model tests, it was also confirmed that a static verification method, such as the response displacement method, could be applied to evaluate the seismic performance of the arch culvert (Fig. 1). Therefore, the design of the cross section of the precast arch culvert could be applied to the response displacement method which is usually used for the design of underground structures. However, the hinge structure should be considered as a suitable model which is developed through the performance tests.
- Some earth pressure conditions are usually applied to the hinge-type arch culvert. This culvert is a thin structure and deforms flexibly. Using the acting earth pressure, the structure of the arch culvert becomes stable. However, it is very sensitive to the surrounding ground. Therefore, it is necessary to evaluate the strength of the foundation and to verify the subsidence.
- With the multi-arch culvert embankment, a large maximum bending moment with wide unit spacing is generated in the case of narrow unit spacing. Then, it is confirmed that the seismic performance of a single arch culvert and an embankment should be addressed when the seismic performance of the multi-arch culvert embankment is discussed. However, since the multi-arch culvert embankment is a composite structure, it is recommended that the dynamic verification method be applied.

4. Papers for Presentation

1) Sawamura, Y., Arai, T., Kishida, K. and Kimura, M.: Centrifuge model test on the earthquake performance of culvert longitudinal direction in arch culvert embankment with perpendicular wall, Japanese Geotechnical Journal, 9(1), 41-57, 2014-3. doi.org/10.3208/jgs.9.41
2) Sawamura, Y., Kishida, K. and Kimura, M.: Evaluation of Dynamic behavior of culverts and embankments through centrifuge model tests and a numerical analysis, Proc. of the 14th IACMAG, pp.743-748, 2014-9.
3) Sawamura, Y., Ishihara, H., Kishida, K. and Kimura, M.: Seismic Assessment of Two-Hinge Precast Arch Culvert based on Shaking Table Test through Strong Earthquake Response Simulator, Proc. of the 27th KKHTCNN Symp. on Civil Engineering, S-8-1, 2014-11.
4) Sawamura, Y., Ishihara, H., Kishida, K. and Kimura, M.: Experiment on Three-hinge Precast Arch Culvert using Strong Earthquake Response Simulator, Proc. of 59th Geotechnical Symposium, pp.207-214, 2014-11.

5. Study Development and Future Issues

(1) Verification of three-dimensional seismic behavior

In this research, the seismic performance of an embankment, including an arch culvert, has been discussed in considering the direction of the culvert arrangement and the direction of the input seismic wave. Then, the damage process for the earthquake has been confirmed. In the next step, the three-dimensional seismic behavior should be confirmed. In particular, in the case of a shallow overburden and unbalanced earth pressure near the entrance of the culvert, it must be predicted that the seismic behavior of the culvert becomes unstable. Under these conditions, some damaged structures were found after the 2011 off the Pacific coast of Tohoku Earthquake.

(2) Discussion on seismic strengthening of existing hinge-type precast arch culvert and recovery methods

Many hinge-type precast arch culverts are already in existence. In this research, it was confirmed that the existing hinge-type precast arch culverts, constructed with the current design method, have shown seismic performance. However, the existing hinge-type precast arch culverts should be discussed in terms of the damage process against huge earthquakes, and seismic-strengthening work should be also addressed.

6. Contribution to Road Policy Quality Improvement

In this research work, the seismic performance of the hinge-type precast arch culvert has been discussed through centrifuge model tests, real-size model tests using the strong earthquake response simulator, their numerical simulations, performance tests of a splices model, and field measurements of actual construction work. Therefore, a design concept could be proposed with visual evidences and actual results. The results strongly affect their contribution to the improvement of the seismic performance of multi-arch culvert embankments. Then, the demand for the construction of multi-arch culvert embankments will surely expand and contribute to saving on the costs of road construction.

7. References, Websites, etc.

The results of this research work have already been published. The published paper list and a video of the real-size model tests, using the strong earthquake response simulator, can be seen on the following website:
http://geomechanics.kuciv.kyoto-u.ac.jp/index.html