# Development of Earthquake Resistance Check Methods for Large Box Culverts

(Research period: FY2019–FY2021)

Foundation, Tunnel, and Substructures Division, Road Structures Department

Senior researcher TANI Toshihide    Guest Research Engineer KURIHARA Yūta

Guest Research Engineer OKAZAKI Takayoshi    Head (Ph.D. in Engineering) Nanazawa Toshiaki

*(Keywords) large box culverts, earthquake resistance check, response displacement method*

## 1. Introduction

Revisions to technical standards for road and earthworks structures are being considered from the perspective of giving concrete detail to the required performance and the check methods. As part of this, NILIM is considering earthquake resistance check methods for large box culverts, which are not clearly described in the current guidelines, etc.

This article proposes an analysis model used in earthquake resistance checks for large box culverts, which fall outside the scope of the current guidelines, through previous experiments and reproduction analysis of disaster case examples, and also checks earthquake resistance under various conditions using the analysis model and presents the results of an assessment of its validity. This consideration was conducted in collaboration with the Public Works Research Institute (PWRI).

## 2. Comparative analysis with experiment results

To compute the response values in the event of an earthquake, we used the response displacement method, which is a static analysis method. When modeling the culvert body and surrounding ground, we let the body be a linear beam element and adopted a model that added joint elements between the body and ground spring elements so that we could appropriately replicate slipping and peeling phenomena between the culvert and the surrounding ground.

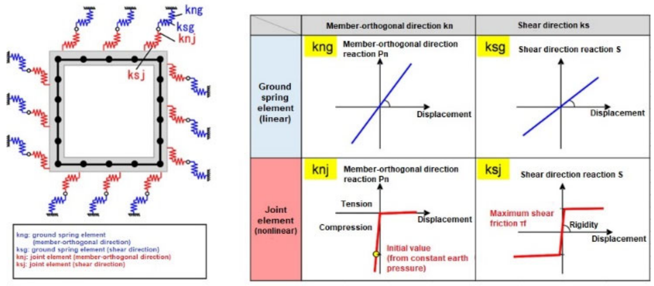



Fig. 1. Outline of body and ground modeling

Using the above analytical model, we conducted a comparative analysis with the results of two existing centrifugal model experiments shown in table 1. Given the importance of setting a maximum value for the circumferential shear on the body in creating an accurate analysis model, we changed the circumferential shear for both conditions over three cases, organized the section forces, displacements, etc. occurring in the body, and compared them to the experimental values (table 2).

Figure 2 shows the results of comparing the maximum bending moment in the experiment and the analysis for each culvert member in examination case 3 of condition 2.

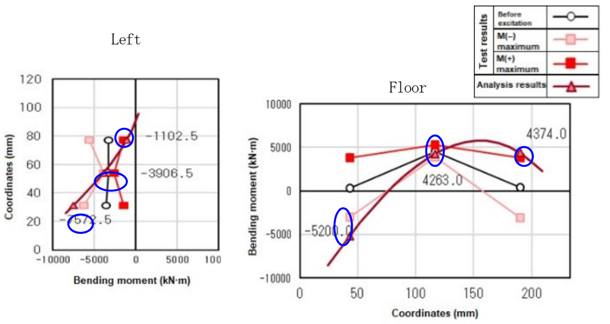
Examination case 3 was set up according to the maximum circumferential shear on a caisson foundation, which has resistance between the concrete and the ground, as with culverts, and the results show a maximum bending moment approximately aligned with that obtained for the body in the experiment (blue circles in fig. 2). Moreover, the results in condition 2, which had a smaller overburden, were similar.

Table 1. Conditions for centrifugal model experiments

| Conditions | Banking materials | Internal cross-section breadth (m) | No. of series | Overburden thickness (m) | Examination case no. |
|---|---|---|---|---|---|
| 1 | Fine-grained soil | 14 m | 1 series | 0.5 m | 3 cases |
| 2 | Fine-grained soil | 14 m | 1 series | 10 m | 3 cases |

Table 2. Examination cases

| Examination cases | Max. circumferential shear force (top slab/side walls) | Max. circumferential shear force (bottom slab) | Notes |
|---|---|---|---|
| 1 | $c + \sigma\tan\varphi$ | $c + \sigma\tan\varphi$ | *1: Set under 2012 retaining wall work guidelines *2: 2012 Road Bridge Specifications (max. circumferential friction force of caisson foundation) |
| 2 | $\sigma\tan(2/3\varphi)$ [*1] | $\sigma\tan(2/3\varphi)$ [*1] | |
| 3 | $0.5(c + \sigma\tan\varphi)$ [*2] | $\sigma\tan(2/3\varphi)$ [*1] | |




* Positive values indicate bending in the direction of internal tension,
◯Places where experimental and analysis

Fig. 2. Bending moment diagram (condition 2: examination case 3)

## 3. Comparative analysis with actual earthquake-affected culverts

Using the analysis model evaluated in section 2, we conducted an analysis of actual structures affected by earthquakes and compared the analysis with the actual damage to verify the validity of the proposed analysis model. Here, we set the maximum shear friction around the body as in examination case 3 in table 2.

### (1) Case where damage occurred (Southern Hyogo Earthquake (1995): Daikai Station[1])

The damage to Daikai Station is as shown in figure 3; the damage to the central pillars was characteristic and the upper floor slabs collapsed due to shear destruction or compression failure of most of the central pillars in sections where the damage was most severe. In the trial calculation results (fig. 4), the shear check was out around the center pillars and broadly reproduced the actual damage.

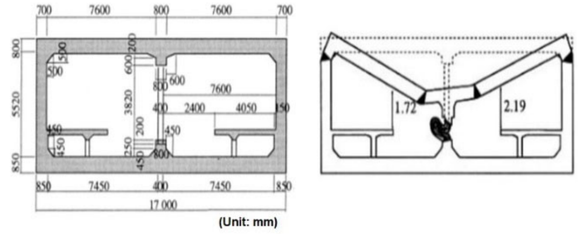



Fig. 3. Cross-section of Daikai Station (before and after disaster)

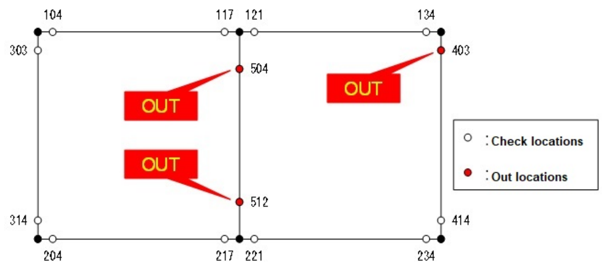



Fig. 4. Daikai Station analysis results (shear resistance check)

### (2) Case where no damage occurred (Kumamoto Earthquake (2016): culverts crossing the Kyushu Expressway[2])

In the culverts crossing the Kyushu Expressway, no noticeable damage to the body has been confirmed, other than joints spreading. In the trial calculation results, all check items were satisfied and the results reproduced the outcome of no actual damage.

## 4. Comparison with conventional design methods

We conducted an earthquake resistance evaluation of large culverts under various conditions with cross-section designs under stationary load, which has conventionally been performed as a design method for culverts, using the analysis method considered in sections 2 and 3. The examination cases are as shown in table 3 and were conducted with level 2 earthquake tremors of types I and II.

In the bending check results, the generated curvature did not reach the yield curvature in any case, and the allowable values for drift angle established based on previous research outcomes[3] were satisfied.

On the other hand, in the shear check, while it was necessary to expect shear reinforcement roughly equivalent to erection bars in some culverts exceeding the scope of application of the conventional form, we confirmed that changes to member width would not occur.

Table 3. Examination cases

| Internal breadth | Internal height | Overburden thickness | Member thickness | Ground condition | Notes |
|---|---|---|---|---|---|
| 6.5 m | 5.0 m | 0.5 m | Thin | Class I ground to class III ground | Conventional culvert |
| | | | Thick | Class II ground | |
| | | 1.5 m | Thin | Class II ground | |
| | | | Thick | Class II ground | |
| 6.5 m | 6.0 m | 0.5 m | Thin | Class I ground to class III ground | Culvert exceeding scope of application of conventional culverts |
| | | | Thick | Class II ground | |
| | | 1.5 m | Thin | Class II ground | |
| | | | Thick | Class II ground | |
| 8.0 m | 6.0 m | 0.5 m | Thin | Class I ground to class III ground | |
| | | | Thick | Class II ground | |
| 14.0 m | 6.0 m | 0.5 m | Thin | Class I ground to class III ground | |

## 5. Summary

Through this study, we conducted a reproduction analysis of centrifugal model experiment results and actual case examples and proposed an analysis method for earthquake resistance checking for large box culverts. This proposal succeeded in accurately demonstrating a standard method for earthquake resistance checking for large box culverts, which had not been demonstrated previously.

Based on the results obtained here, we intend to investigate methods to reflect the earthquake resistance checking method for large box culverts in technical standards for road and earthworks structures in future.

## References


1) "Damage to Daikai Subway Station of Kobe Rapid Transit System and Estimation of Its Reason during the 1995 Hyogoken-Nanbu Earthquake." *Proceedings of the Japan Society of Civil Engineers*, no. 537, 1996.

2) "Damage analysis of box culvert locations in the Kumamoto Earthquake." *54th Proceedings of the 54th Conference of the Japanese Geotechnical Society*, 2019.

3) "Evaluation of Seismic Limit State of Single-Cell Box Culverts for Roads." *Journal of Japan Society of Civil Engineers, Ser. A1 (Structural Engineering & Earthquake Engineering)*, vol. 71, 2015.


☞See here for detailed information

"Development of a Seismic Verification Method for Large Box Culverts." *Civil Engineering Journal*, vol. 63, 2021.