# 2D FE analysis on culvert longitudinal soil-structure interaction of 2-units box culvert on liquefiable ground

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## 1. OVERVIEW

One of the major damages caused by earthquake motion is the joints separation of structures such as bridges and reinforced box culverts (RBCs) according to Ishikawa et al., (2018). There is residual loss of serviceability to the whole road embankment upon destruction of these underground road structures (Yasuda et al., 2009). Various studies have been conducted in attempt to clarify the destruction of these underground road structures by seismic activities. For instance, dynamic centrifuge model tests conducted by Ito et al., (2021) suggested that joint opening causes ground flow and RBCs lateral movement due to inertial force acting on the liquefied ground.

To understand the seismic response to spoil serviceability of RBCs, numerical 2D-FE elastoplastic dynamic analysis was conducted. The analysis model was based on and updated with the experimental model by Ito et al., (2021)

## 2. ANALYSIS OUTLINE

Fig. 1 illustrates the description of the 2D model of the 2-units RBCs on liquefiable ground. The model dimension was based on the experiment by Ito et al., (2021). However, the overburden of the RBCs was erased and the units of the RBCs changed from 4 units to 2 units. The supporting layer and liquefiable grounds were modeled by a rotating hardening elastoplastic model developed by Zhang et al., (2007).

Table 1 lists the parameters for the soil. The culvert was modeled by elastic with E of 7.00 x 107 kPa, n of 0.334, r of 2.71 and h of 0.02. The 2D elasto-plastic finite element analysis operated in DBLEAVES (Ye et al., 2007) was conducted. To predict the displacement between the culvert elements, bilinear spring elements were used. The spring parameters are as shown in Fig. 2. The seismic wave was inputted at the foundation in the culvert longitudinal direction. The applied wave as shown in Fig. 3 was the TR component on the ground around the Tsugaru Ohashi Bridge, 1983 Central Japan Sea Earthquake.

To explain the liquefaction behavior of the grounds during the analysis, the effective stress reduction ratio, -*(EDSR)* proposed by Oka et al., (2016) defined by Equation 1, was used. $\sigma'_m$ is the current mean effective stress while $\sigma'_{m0}$ is the initial mean effective stress;

$$ESDR = 1 - \frac{\sigma' m}{\sigma' m0} \tag{1}$$

## 3. RESULTS AND DISCUSSIONS

Fig. 4 exhibits the heatmap of ESDR at 90.0 seconds. The figure shows that the culvert elements experienced

**Table 1** Soil parameters (Mommae et al., 2019)

| | Ts-S | Ts-L |
|---|---|---|
| Constitutive model | CMM | CMM |
| Compression index $\lambda$ | 0.05 | 0.05 |
| Swelling index $\kappa$ | 0.0064 | 0.0064 |
| Critical stress ratio $M$ | 1.30 | 1.30 |
| Void ratio $p'$ = 98 kPa $N$ | 0.87 | 0.87 |
| Poisson's ratio $\nu$ | 0.30 | 0.30 |
| Degradation parameter of overconsolidation state $m$ | 0.01 | 0.01 |
| Degradation parameter of structure $a$ | 0.50 | 0.50 |
| Evolution parameter of anisotropy $b_r$ | 1.50 | 1.50 |
| Initial void ratio $e_0$ | 0.772 | 0.626 |
| Reference degree of structure $R^*_r$ | 0.80 | 0.80 |
| Reference anisotropy $\xi_r$ | 0.0 | 0.0 |
| Permeability $k$ | 2.35 | 1.72 |
| Elastic modulus $E$ | - | - |
| Damping ratio $h$ | 0.05 | 0.05 |

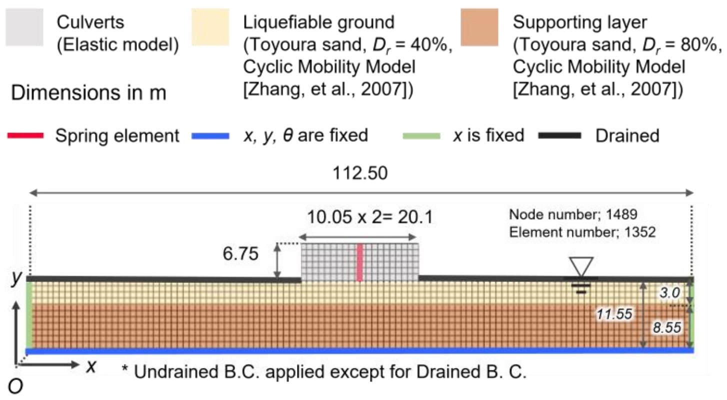


**Fig. 1** Model outline

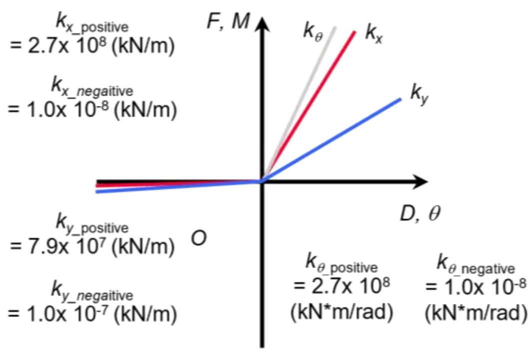


**Fig. 2** Spring models

Keywords: Liquefaction, joint opening, effective stress reduction ratio, box culvert
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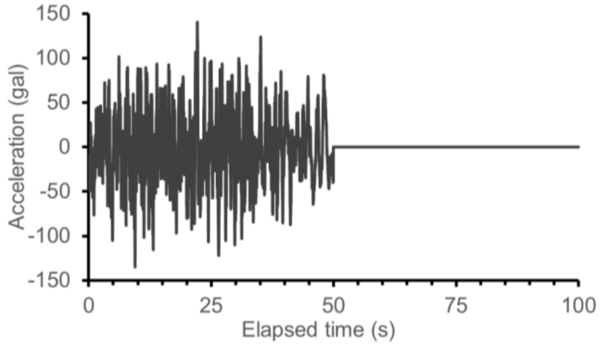


**Fig. 3** Input wave

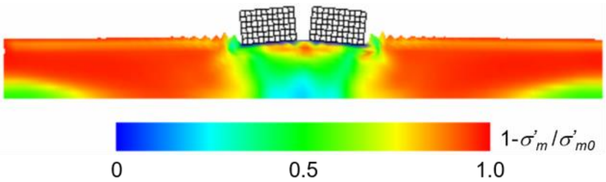


**Fig. 4** Heatmap of *ESDR* at 90.0 seconds
(5 times scale as the original)

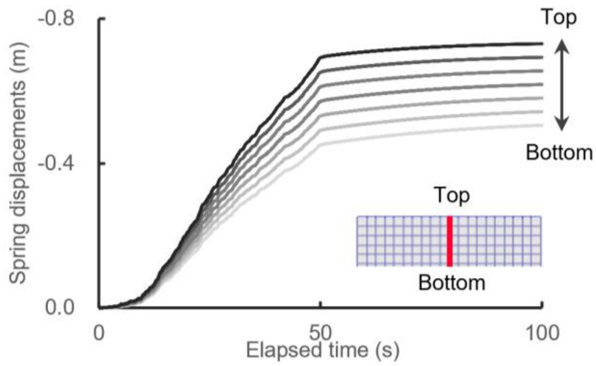


**Fig. 5** Time history for spring displacements

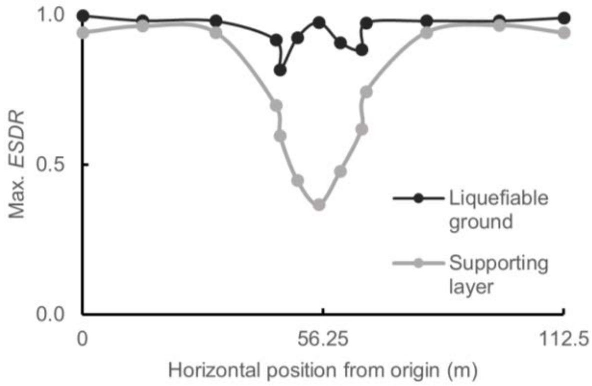


**Fig. 6** Maximum *ESDR* variations during seismic analysis in foundation ground

lateral movement inclined towards the mouths of the culverts. Characteristically, the ESDR beneath the culvert increased at the zone close to the joint section. To understand further, the time histories of the culvert displacement, the spring elements displacements in x-direction were plotted in Fig. 5. According to the figure, the top spring experienced the highest displacements, and the magnitude decreased towards the bottom of the joint.

The variation of the ESDR across the liquefiable and foundation grounds is plotted in Fig. 6. The liquefiable ground had experienced higher liquefaction as compared to the foundation ground. The ratio at the liquefiable ground was high at the end of the grounds and decreased towards the culvert mouths then increased to maximum at the middle joint of the culvert. By achieving an ESDR of one, it's clear that all the mean effective stress had been converted to excess pore water pressure. Hence the total liquefaction of the ground below the culvert joint increased the excess pore water pressure of the soil, hence the upward push of the culvert elements at the middle joint and final inclination towards the mouth of the culverts.

## 4. CONCLUSIONS

The numerical analysis results with 2-units RBCs explained the cause of culvert opening and inclination behavior of the culverts, using displacement behavior of spring elements and effective stress reduction ratio. It seems that the total liquefaction of the ground below the culvert joint increased the excess pore water pressure of the soil, hence the upward push of the culvert elements at the middle joint and final inclination towards the mouth of the culverts. Further studies can explore how the number of culvert units, the thickness of the liquefiable layer or embankment dimension will have effect on the reported results.


## ACKNOWLEDGEMENT

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