# Dynamic behavior of multi-arch culverts embankment considering the installation interval of consecutive arch culverts

## Comportement dynamique des terre-pleins à dalot multi-arche en fonction de l'intervalle entre les arches successives

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ABSTRACT: Multi-arch culverts embankment is a new type of filling structure where several precast arch culverts are installed continuously in the direction of the road extension. The shape of the embankment resembles that of a bridge structure due to the space of the precast arch culverts and it is more open than the genaral fill method. The key in design is to estimate the practical interval between each installed arch culvert and to clarify the interactive behavior of filling material between them in considering the seismic influence. In this study, dynamic FEM analysis has been carried out to investigate the influence of spacing between multi-arch culverts and mechanical behavior under seismic conditions has been discussed. From the result of numerical analysis, it is found that when the unit interval is narrow, small maximum bending moment is generated compared with the case with wide unit interval. Moreover, the amount of the subsidence at the center of the unit becomes small, hence unequal settlement becomes small.

RÉSUMÉ : Le terre-plein à dalot multi-arche est un nouveau type de structure de remplissage où plusieurs dalots arqués préfabriqués sont installés de façon continue dans la direction du prolongement de la route. La forme du terre-plein ressemble à la structure d'un pont, du fait de l'espace entre les dalots arqués préfabriqués et de la taille de ceux-ci, plus ouverts que dans la méthode de remplissage traditionnelle. La clé du design est d'estimer l'intervalle entre chaque arche ainsi que de déterminer le comportement des matériaux de remplissage dans des conditions sismiques. Dans cette étude, une analyse par la méthode des éléments finis a été réalisée pour rechercher l'influence de l'espace entre les arches et le comportement de la structure dans des conditions sismiques. D'après les résultats de l'analyse numérique, il apparaît que lorsque l'intervalle est étroit, le moment de torsion maximal est réduit. De plus, la quantité d'affaissement au milieu de la structure diminue, ce qui réduit également le tassement inégal.

KEYWORDS: Arch culvert, Enbankment,

## 1 INTRODUCTION

When an arterial high-standard highway is built, it is necessary to construct the fill or the elevated bridge to overpass other roads and railways. Most of the time, however, the fill structure acts as a wall that partitions an area. Unlike an elevated bridge, that does not partition an area into two, fill structures often create a partition, thereby obstructing the free flow of the wind and denying people direct access. Recently, multi-arch culvert embankments (Figure 1) of continuously arranged precast arch culverts in the direction of the road extension are proposed as a solution to such problems. The shape of the embankment is close to that of a bridge structure, due to the void space of the precast arch culverts, and it is more open than with the general fill method. Continuous arch culverts make the structure blend in well with the environment and beautify the scenery. The reuse of the removed soil from the cut ground is also possible, therefore being more economical than an elevated bridge. It is expected that the demand for this new type of structure will increase in the future from an economic point of view.

The design of traditional culvert structures in Japan has not considered seismic stability, because such structures have not suffered terrible damage in past earthquakes. Even now, therefore, it is thought that earthquake stability need not be considered for the range in application of traditional culverts. However, some cases which exceed the application of traditional culvert must be considered the seismic stability. In multi-arch culverts embankment, since there are several arch culverts consecutively, the behavior of arch culvert and the surrounding soil may differ from the case with single arch culvert, hence seismic stability must be investigated.

In the previous study (Sawamura et al., 2010, 2011), dynamic centrifuge model test and its FEM analysis have been carried out to confirm the difference of dynamic behavior according to the unit interval. In the experiment, two units of arch culverts were modeled due to the restriction of soil chamber. From the result, experiment can be simulated accurately by using the constitutive model and clear difference was not confirmed because of unit interval.

In this study, the full-scale numerical analysis has been executed to clarify the influence of the installation intervals between consecutive arch culverts on the structures as a whole and the surrounding soil during earthquake.

## 1 NUMERICAL ANALYSIS

### 1.1 *Model of simulation*

In this study, 3-dimensional elasto-plasticity FEM is conducted using static and dynamic FEM code (DBLEAVES) developed

Figure 1. Multi-arch culverts embankment

by Ye et. al (2007). Analytical model represented a fill of 5.0 m to be constructed on a 7.5 m thick sandy ground with overburden height of 0.7 m above the arch culvert as shown in Figure 2. Light fill material can be used as shown in Figure 1 for the reduction of earth pressure during earthquakes and the load alleviation of the foundation ground. This results into the unit interval being smaller than the case where usual fill material is used. Though, the purpose of this study is to examine the difference of the dynamic behavior by unit interval, usual sandy material is used for fill ground. Unit interval L between the precast arches was expressed as a function of the culvert height H. Results of the case with consecutive arch culverts were compared to cases of single arch culvert setting alone. The examination cases are shown in Table 1. In the cases of multi-arch culverts embankment, since several precast arch culverts are set up continuously in the in-situ construction, 1 unit of arch culvert was modeled and both sides of analytical domain were configured equal displacement condition of horizontal and vertical direction. Moreover, the boundary on the bottom area is fixed on all directions. The analysis mesh of Case-1,3 and boundary condition were as shown in Figure 3. On the other hand, in the case of single arch culvert, the width of analytical domain is wide enough (100 m) and boundary condition is same as other cases. The input ground motions used in this study is the time history of acceleration measured in the centrifuge model test when 1 Hz sin wave was inputted by controlling the displacement of vibration table. The input ground motions shown in Figure 4 are applied at the bottom boundary. The time interval of calculation is 0.01 seconds.

1.2 *Modeling of ground*

The constitutive model for foundation ground and filling adopted in the present study is subloading $t_{ij}$ model (Nakai and Hinokio, 2004). This model was proposed based on the concept

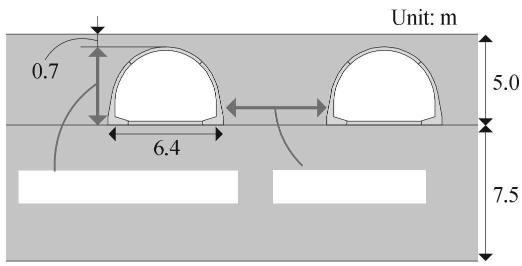



Figure 2. Dimension of multi-arch culverts

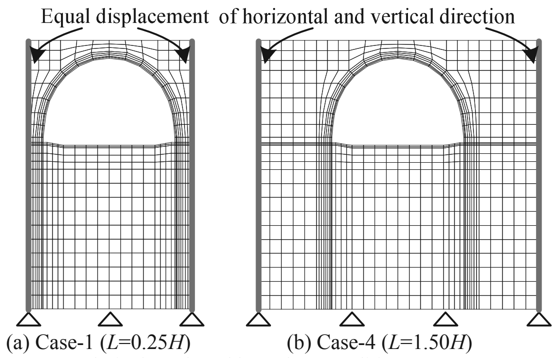



Figure 3. Analytical mesh and boundary condition

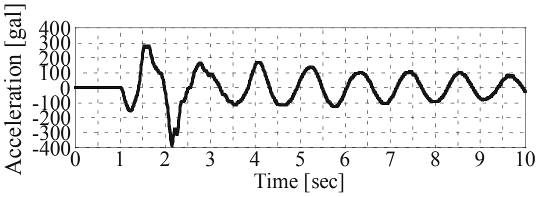



Figure 4. Input wave

of SMP (Spatially Mobilized Plane (Matsuoka and Nakai, 1974)), in which the influence of the intermediate principal stress can be properly evaluated. Furthermore this model can describe the dependence of the direction of plastic flow on the stress paths, density and confining pressure on the deformation and strength of soils. Same Properties was used for foundation ground and filling as shown in Table 2. The damping coefficient of both ground are assumed as 5%.

1.3 *Modeling of arch culvert*

In-situ precast arch culverts are made by joining several precast sections and its joints are connected using pre-stressed concrete wire. The joints stiffness is somewhere between rigid and hinge. However, the arch culvert model in this study was made as an all-in-one design structure. While modeling of structure, nonlinearity of concrete was also considered. For culvert concrete, nonlinear moment-curvature relation was simulated using the AFD model (Zhang and Kimura, 2002), which considered the axial-force dependency according to variable axial force of the structure. The parameter of arch culvert is

Table 1. Examination cases

| Case | *Unit interval (Number of node: N, Number of element: E)* |
|---|---|
| Case-1 | *L=0.25H (N:1478 , E:642)* |
| Case-2 | *L=0.50H (N: 1578, E:690)* |
| Case-3 | *L=1.00H (N: 1778, E:786)* |
| Case-4 | *L=1.50H (N: 1978, E:882)* |
| Case-Single | *∞ (N:6278 , E:2946)* |

Table 2. Property of embankment and foundation ground

| Constitutive model | *Subloading $t_{ij}$ model* |
|---|---|
| Unit weight $\gamma$ (kN/m$^3$) | 15.76 |
| Principal stress ratio at critical sate $R_{cs}$ | 3.20 |
| Poisson's ratio $\nu$ | 0.30 |
| Coefficient of earth pressure at rest $K_0$ | 0.42 |
| Void ratio $e_0$ | 0.65 |
| $\beta$ (stress-dilatancy) | 2.00 |
| a (ANN) parameter | 500 |
| OCR | 1.20 |
| Compression index $\lambda$ | 0.012 |
| Swelling index $\kappa$ | 0.0025 |
| Damping coefficient h | 0.05 |

Table 3. Parameter of concrete

| Constitutive model | *AFD model* |
|---|---|
| Unit weight $\gamma$ (kN/m$^3$) | 19.35 |
| Young's modulus E (kN/m$^2$) | $2.07\times10^7$ |
| Compressive strength $f_c$ (kN/m$^2$) | $4.92\times10^4$ |
| Tensile strength $f_t$ (kN/m$^2$) | $5.76\times10^3$ |
| Poisson's ratio $\nu$ | 0.18 |
| Damping coefficient h | 0.02 |

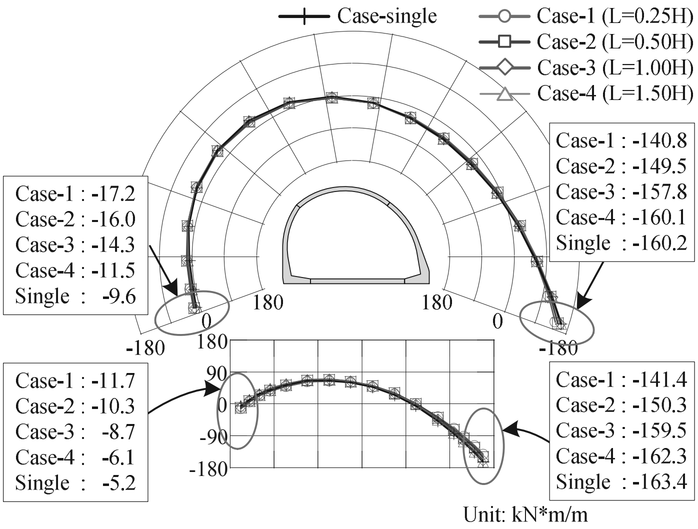



Figure 5. Maximum bending moment occurring at the right foot.

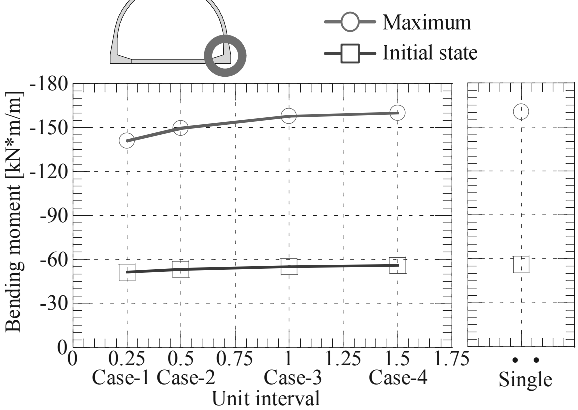



Figure 6. Initial and maximum bending moment at right foot .

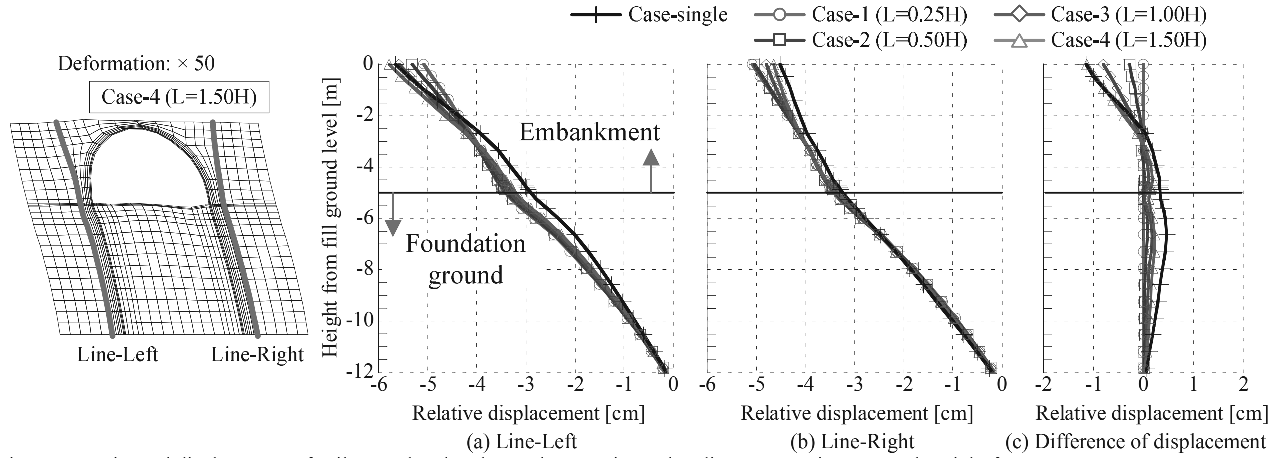



Figure 7. Horizontal displacement of soil around arch culvert when maximum bending moment is generated at right foot.

shown in Table 3, and the damping coefficient of arch culvert is assumed as 2%. Moreover, the joint element was arranged on the boundary division of the culverts and the ground to represent the influence of friction. The parameters of the joint were defined from box shear tests between Toyoura sand and the concrete element.

## 3 NUMERICAL RESULT

When the stability of concrete structure against earthquake is evaluated, the point that should be noted most is generation of excessive bending moment. Figure 5 shows the distribution of maximum bending moment occurring at right foot, and Figure 6 shows the initial and maximum bending moment at the right foot. Positive bending moment is defined for the case where tension is generated inside arc culvert. From these figures, it can be seen that the influence of the installation interval on the fill between arch culverts was remarkable in the right foot and the right end part of invert. The maximum bending moment in Case-4 increased by about 14 % compared with Case-1. Moreover, when unit interval is wide, large bending moment is already generated in the initial state because of the self-weight of the surrounding soil.

Figure 7 shows the horizontal displacement of soil around arch culvert when the maximum bending moment is generated at right foot. In this figure, two lines which is left and right side of arch culvert are pick up. In Case-1, the difference of displacement hardly occurs. It is because arch culvert and

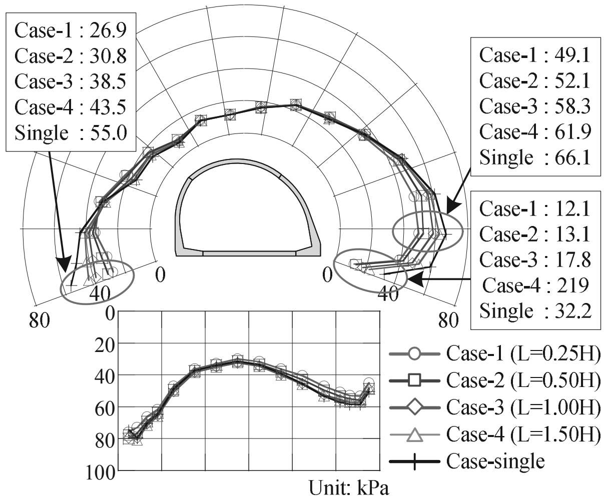
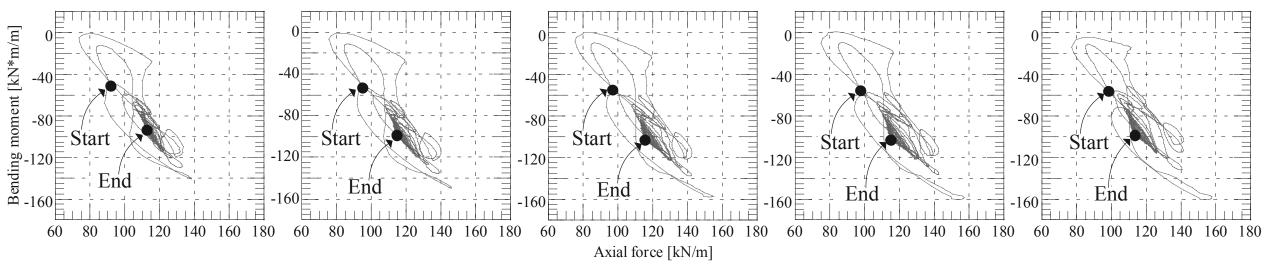



Figure 8. Earth pressure distribution of normal direction which acts on the boundary portions of the ground and arch culvert when maximum bending moment is generated at right foot.

surrounding soil behave monolithically. On the other hand, it can be seen that the difference of displacement has occurred on the left-line and right-line in other cases. The difference of




(a) Case-1 ($L$=0.25$H$) (b) Case-2 ($L$=0.50$H$) (c) Case-3 ($L$=1.00$H$) (d) Case-4 ($L$=1.50$H$) (e) Case-Single

Figure 9. Variation of axial force with bending moment at the right foot.

displacement is large at the boundary between fill and foundation ground and ground surface. Moreover, when unit interval is wide, the difference of displacement increases and comes to the behavior of Case-single.

Figure 8 shows the earth pressure distribution of normal direction which acts on the boundary portions of the ground and arch culvert when maximum bending moment is generated at right foot. When the arch culvert bends to the left, as a result of seismic force, it turns out that a large earth pressure acts on the right-hand side of arch culvert. Compared all cases, earth pressure also becomes large as a unit interval become large. This could be ascribable to the difference of horizontal displacement of soil around arch culvert as shown in Figure 7. On the other hand, near the top part of the arch culvert, a difference is not seen between cases.

Figure 9 shows the variation of axial force with bending moment at the right foot. During earthquake, the bending moment for all cases increase accompanied by increase in axial force. When all cases are compared, the more unit interval is wide, the more both axial force and bending moment increase, and there are few differences between Case-4 and Case-Single. It can be concluded that arch culverts and surround soil shake greatly because the volume in the fill part where the rigidity is comparatively small increases when unit interval is wide.

Figure 10 shows the settlement of ground surface and Figure 11 shows the grade of settlement. The grade of settlement is defined as unequal settlement $\Delta S$ divided by distance from the top part of arch culvert to the center of the unit $l$. At the top part of arch culvert, settlement is almost same in all the cases. However, when the installation interval is wide, the amount of the subsidence at the center of the unit becomes large. It is because that the volume in the fill part where the weight is comparatively large increases when unit interval is wide. Therefore, Unequal settlement becomes large. But the grade of settlement is only 0.3% in Case-4 and it does not become a serious traffic hindrance. Furthermore, surface geometry is continuity and local discontinuous subsidence like the case of box culvert does not occur.

## 4 CONCLUSIONS

In this study, the full-scale numerical analysis has been executed to clarify the influence of the installation intervals between consecutive arch culverts on the structures as a whole and the surrounding soil during earthquake. The following conclusions can be drawn from the results of this study:

1) When earthquake-proof stability of culvert is examined, the generation of bending moment at the foot is especially important, and the influence of the installation interval on the fill between arch culverts was remarkable at the foot.
2) In case with wide unit interval, large maximum bending moment is generated compared with the case with narrow unit interval.
3) For case with wide unit interval, bending moment increases accompanied by an increase in the axial force. It is thought that arch culverts shake widely because the volume in the fill part where the rigidity is small increases comparatively when the unit interval is wide.
4) When the installation interval is wide, the amount of the subsidence at the center of the unit becomes large, hence unequal settlement becomes large. However, the grade of settlement is very small and it does not become a serious traffic hindrance.

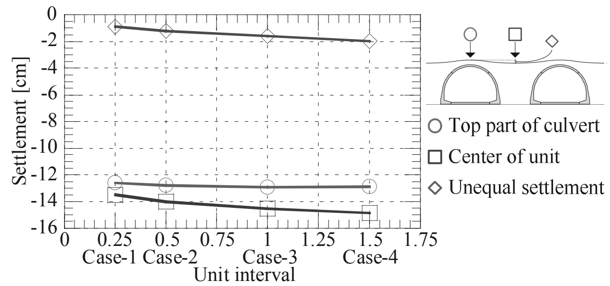



Figure 10. Final ground level displacement and unequal settlement.

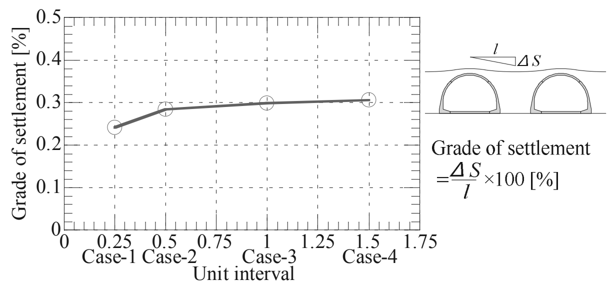



Figure 11. Grade of settlement.

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