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Behavior of Large Precast Box Culverts with Prestressing in Longitudinal Slope

*Shinya SUKEGAWA[1)], Yuki SAKOI[2)] and Takuma GOTO[3)]

[1), 2)] *Hachinohe Institute of Technology, 88-1 Myo, Ohbiraki, Hachinohe-city,Aomori,031-8501,Japan*

Abstract. In recent years, precast products have been increasingly adopted at construction-sites as part of efforts to improve productivity. In the construction of precast products at actual sites, it is necessary to install and construct the products according to the site conditions, but there is insufficient study on the effects of various site conditions on the installation and construction of precast products. Especially, when the precast box-culvert was adopted to the construction-site with longitudinal slope, occurring cracks to axis direction on top face of the culvert and/or to cause falling forward of the culvert have been reported.

In this study, the experimentally investigation of the influence of the longitudinal slope on the load resistance and/or of the deformation performance of precast products was performed. Additionally, the difference of the influence of longitudinal slope for the load resistance or the deformation performance of precast box-culvert and on-site casting box-culvert was examined with structural analysis.

From the result of this study, it was confirmed that the stress occurring in box-culvert constructed on longitudinal slope was different with the longitudinal slope and/or loading. However, it was confirmed that the shearing stress caused to each element of precast culvert was similar to that caused to on-site casting culvert by experiment and analysis.

The structural integrity of precast culvert made improve due to introduce PC tension force and due to adjust it, and it was cleared that the behavior of the precast box-culvert can be made similar to that of an on-site casting box-culvert.

Keywords: Longitudinal slope, Precast box- culvert, PC tension

1. Introduction

They have been widely used in cold regions where the construction period is limited and in reconstruction roads where rapid construction is required, because the precast box culverts are superior to on-site casting ones in terms of quality and construction period. In addition, it will be possible to use high-quality products for a long period of time by using the precast products, and it will play an important role in the sustainable development goals of the SDGs.

From these background of above, many researches about the increase of the demand for precast products and the expansion of utilization of it have conducted.

Large precast box culverts function as a series of structures by connecting many elements of a certain

Fig.1 Water leakage from joint gap

1) Graduate Student
E-mail:s.sukegawa@giken-pat.com
2) Associate Professor
E-mail:sakoi@hi-tech.ac.jp
3) General Engineering Manager of GIKEN Corp.

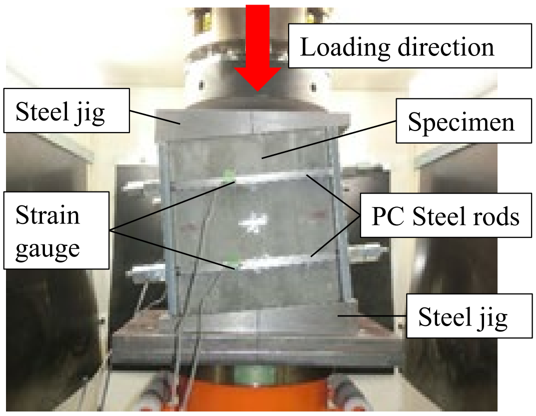


Fig.2 Tilting fixture and steel placement situation

length in the longitudinal direction, but the case of adopt a precast box culvert at a location of a large longitudinal slope, there are some reports occurring the water leaking at a joint part of elements and/or occurring cracks toward to longitudinally direction on top face of culvert were reported (Fig.1).

According to the relevant specifications [(1)], the installation of box culvert on the longitudinal slope is permitted up to the longitudinal grade is 10%, however, the design and construction methods have not been clarified, and the influence of the longitudinal grade on the mechanical behavior of precast box culverts has not yet been clarified.

In this study, the influence of longitudinal slope on the mechanical properties and the stability of large-scale divided precast box culverts is investigated.

In a previous study [(2)], the authors confirmed that it is possible to replicate the behavior occurring in the connected culverts under the longitudinal gradient, such as occurring a gap in connected culverts, by the experiment with five elements connection. And it was suggested that inducing a PC tension force was effective to improve the integrity of divided culvert elements.

There are a number of parameters and/or conditions related a tipping behavior of a precast box-culvert. In this study, the relationship between the longitudinal slope and the PC tension used for the connection toward to extension direction was focused on and examined.

There was reported[(3)] that a rotational moments was occurred to top of a precast arch culvert that with hinges and without PC tension due to stresses caused by circumferential shear forces from the embankment portion, during an earthquake.

However, the stress state for connected the box

Table 1 Test case

	PC Tension □ □ □	Longitudinal slope□ □ □		
		0	5	10
Assume on-site casting box- culvert				
	0	1_00_t0	—	1_10_t0
	100	—	—	1_10_t100
Assume precast box- culvert				
	0	5_00_t0	5_05_t0	5_10_t0
	8	5_00_t8	5_05_t8	5_10_t8
	17	5_00_t17	5_05_t17	5_10_t17
	32	5_00_t32	5_05_t32	5_10_t32
	50	5_00_t50	5_05_t50	5_10_t50
	75	5_00_t75	5_05_t75	5_10_t75
	100	5_00_t100	5_05_t100	5_10_t100
	150	5_00_t150	5_05_t150	5_10_t150

culvert on the longitudinal gradient and/or the effective of PC tension force for joining of divided box-culvert have not been sufficiently investigated. The purpose of this study is to examine the relationship between PC tension force and longitudinal gradient in order to improve the stability of divided precast box- culvert on longitudinal slope.

2. Load test

2.1 Outline

Because of it has confirmed that the behavior of actual box-culvert could be replicate by a specimen model in laboratory, this experiment was examined the influence of PC tension force on the load-bearing capacity of the box-culvert by the specimen model. In the experiments, a load- bearing capacity of the divided precast box-culvert that a PC tension force was varied on was compared with that of on-site casting box- culvert that was given same level PC tension force.

2.2 Specimen Outline

The specimen that assumed a divided precast culvert used the mortar specimen joining five elements of (B) 200 mm × (H) 200 mm × (L) 40 mm. The size of specimen that assumes on-site casting culvert was (B) 200 mm × (H) 200 mm × (L) 200 mm, that was same length with joining precast culvert of five elements.

The specimens were conducted the steam curing, as same as the normally precast products, and the experiments were done after confirming the strength development.

The mortar used in this experiment was W/C = 36.4 % and f 'ck = 40 N/mm^2.

2.3 Test method

In order to examine the load capacity and the behavior of the box- culvert on slope with longitudinal grade, a loading test with uniformly distributed load was conducted on a loading test apparatus with inclined fixtures of 0%, 5% and 10% (Fig. 2). The PC tension force applied on a box-culvert decided a based on the previous study[(2)]. Applied tension force was defined a tension force used in an actual construction site as

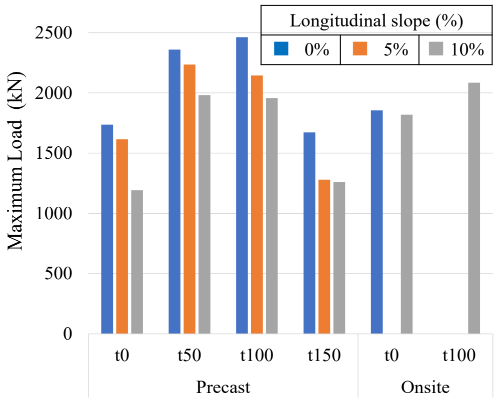


Fig.3 Change in maximum load (stress) due to longitudinal slope and PC tension

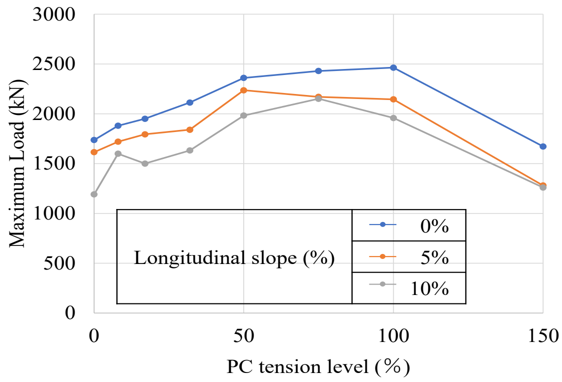
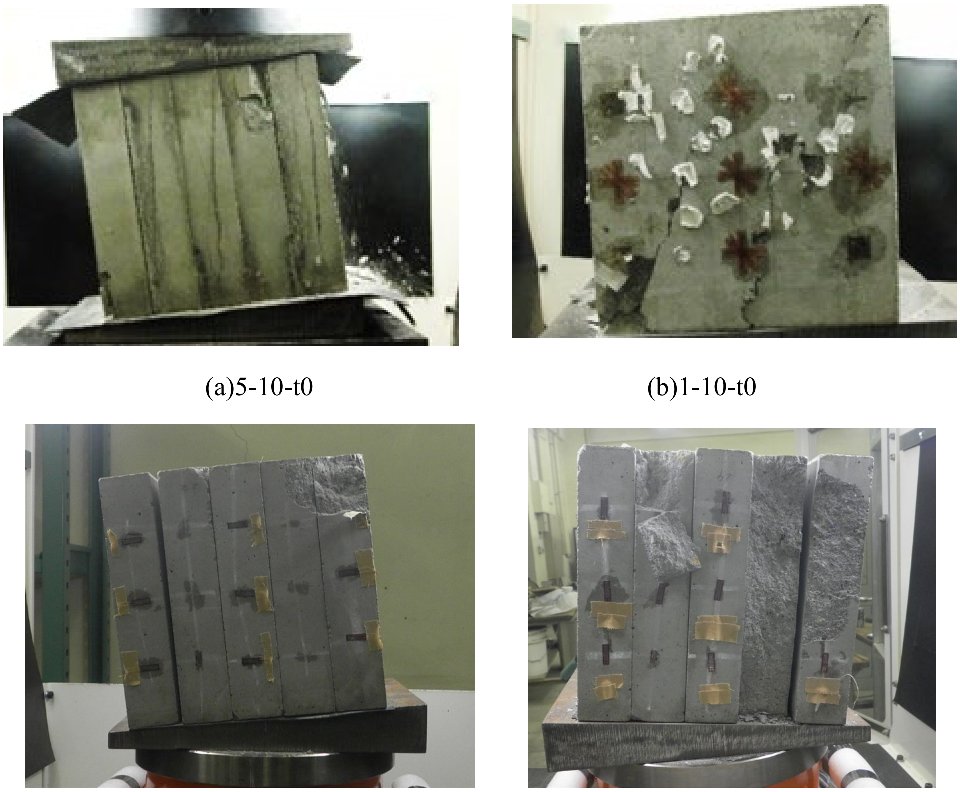


Fig.4 Maximum load (stress) and transition of PC tension with longitudinal slope



(a)5-10-t0

(b)1-10-t0

(c)5-10-t150(front side)

(d)5-10-t150(back side)

Fig.5 Specimen after completion of loading test

100%, the PC tension force varied in the range of 0 ~ 150% of it.

Table 1 shows the experimental condition. Symbols of an experimental condition in Table 1 indicates the combination of number of box- culvert (the specimen assumed on-site casting denotes as 1 and the specimen assumed divided precast box- culvert denotes as 2), slope gradient and PC tension force (e.g.; the case of the precast culvert, the slope gradient of 5% and the PC tension force of 75%, it denotes as "5_05_t75").

The PC tension force was controlled by the strain of 4 steel bars (each 2 bars were installed to top and bottom of specimen) used for working the PC tension to culvert.

2.4 Results and Discussion

The relationship between the maximum load and the gradience of longitudinal slope by the case of applied the each tension force is shown in Fig 3. The vertical axis is the maximum compressive load and the horizontal axis is the longitudinal slope. From the result in Fig.3, although the maximum load of the specimen that assumed on- site casting culvert indicated almost same vale regardless of the slope gradient, the maximum load of the precast culvert decreased with the increase of the slope gradient. However, there is seem like a trend that the maximum load of the precast culvert increased due to applying PC tension force.

Fig.4 shows the relationship between the maximum load and the PC tension force

From the Fig.4, it was confirmed that the maximum load increased with the increase of PC tension force for all gradient of slope. The increase amount of the maximum load indicated peak value at a certain tension force, and after this, the maximum load decreased with the increase of PC tension force. Especially, the maximum load with the tension force of 150% indicated almost same or less load at the case of no-tension force.

These results indicate that the structural integrity of the divided precast box-culvert is improved due to applying PC tension force to precast elements, and their load-bearing capacity is almost equal to or better than that of on-site casting box-culvert. The similar result have been also indicated in a previous study (2) that was examined the load-bearing capacity and the axially displacement of the precast box-culvert applying PC tension force of 100%. However, according to the results of this study, it is thought that the PC tension force to ensure the structural integrity of precast box- culvert was enough on the order of 50%, not need to 100%. The peak of tension force that indicated a largest load- bearing capacity was varied depend on the gradient of longitudinal slope. In other words, it was inferred that an optimum tension force for enhancing the structural integrity was existed for each gradient of longitudinal slope.

When the gradient of slope increased, it was thought that the component-force of the extension direction increased and, as a result of this, the displacement (rotate) to extension direction increased and the maximum load of culvert on the longitudinal slope decreased. on the other hand, the case of applying tension force for the culvert on the longitudinal slope, it was inferred that restraining the displacement of extension direction due to the tension force load to increase the load bearing capacity, even though the component force worked.

Fig.6 shows the specimen after experiment. The case of no- tension force (see in Fig.5 (a) and (b)), it was confirmed that the shear crack was occurred toward from upstream side to downstream side of the slope with the longitudinal gradient. On the other hand, the case of

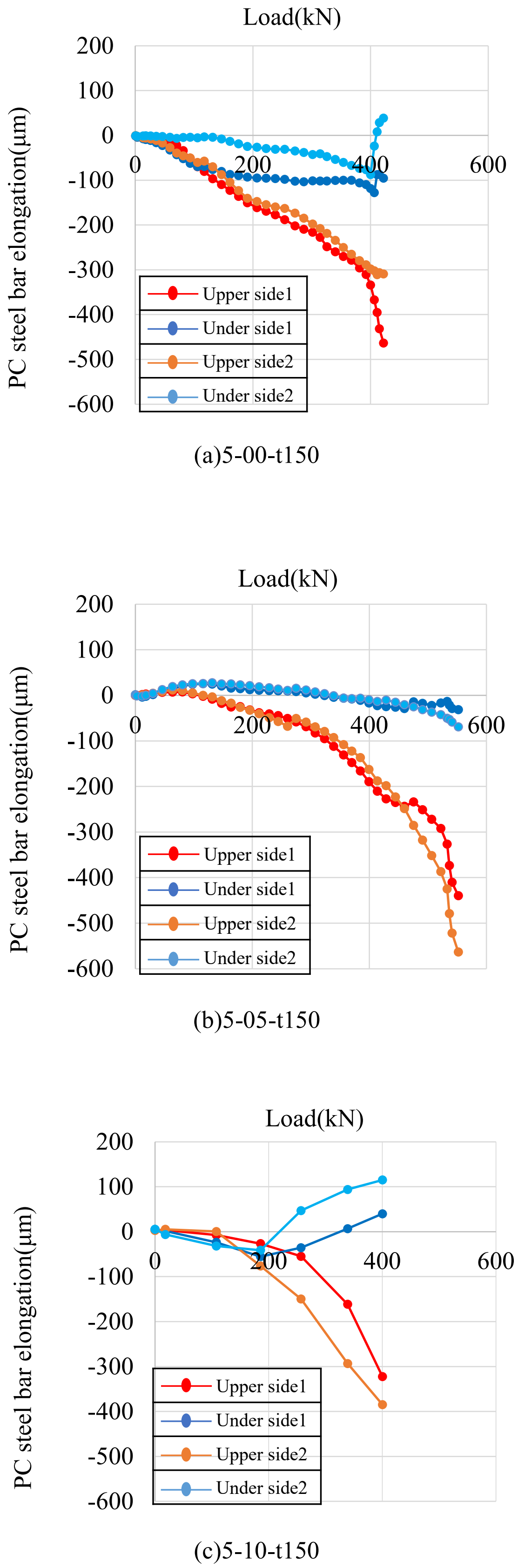


Fig.6 Relationship between elongation of PC steel bar and load carrying capacity

applied the tension force to divided precast culvert, although there was not observe the occurrence of the shear crack in the specimens, exfoliation was occurred on side face of specimen.

This phenomenon was due to work the stress with loading toward to antiplane (right angle to extension direction) direction, due to restraining the displacement of extension direction with tension force.

Fig.6 shows the relationship between the strain of PC steel bar for introducing tension force and the load. The vertical axis indicates a strain of PC steel bars, and (-) means the expansion and (+) means the shrinkage.

From the Fig.6, it was confirmed that the change of strain with load was different with the gradient. The strain of PC steel bar installed to top side increased with the load, regardless of the gradient. Especially, its value significantly increased just before the reaching a maximum load. The strain of PC steel bars installed to bottom side was almost no-changed or a little increased for the case of the gradient of 0 and 5%. However, the case of the 10% gradient, the strain installed to bottom side was shifted to shrinkage after expansion at initial stage.

it was thought that the increasing strain of top side was resulted from the shear stress which was induced by load to specimen on the slope and front the restraining the displacement with the shear stress.

In this study, loading experiment was conducted with steel jigs placed above and below the specimen, but an overturning of box-culvert was not observed. On the other hand, in actual field, jointed box culverts have been observed to displace and overturn significantly, and to occur gaps at connection part of between culvert elements with overturning of it. This phenomenon is considered to be due to the influence of the embankment and foundation soil as well as the tensile force and longitudinal slope.

In here, the result of the experiment in which rubber plates simulating the ground were placed above and below the specimen is shown in Fig.7. Fig.7 is the side view of specimen under loading, and the red line in Fig.8 indicates the initial angle, before loading, of specimen installed on slope.

From this figure, the overturning of the specimen toward to downstream side and the occurring the gap in between the each elements of divided precast culvert can be decidedly confirmed. This result suggests that the ground conditions (embankment and foundation ground) of a place to install the divide precast box

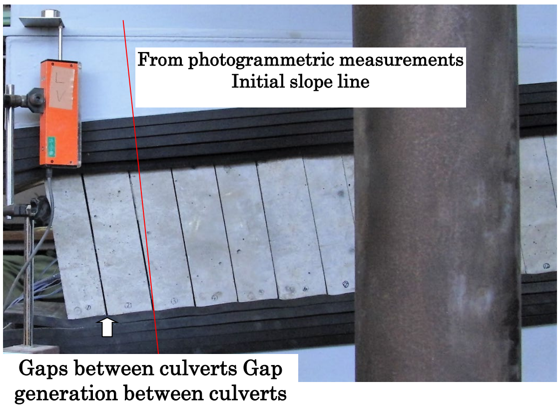


Fig.7 Displacement situation

culvert also have a significant effect on the behavior of it.

3 . Structural analysis

3. 1 Outline

In order to confirm the stress state of the specimen, installed to the slope with the longitudinal gradient, under loading, the structural analysis used 3D model was conducted. Two types of models, divided precast box-culvert and on-site casting box-culvert, were made, and the stress state of these models that was installed to the longitudinal slopes of 0%, 5%, and 10% were analyzed. The analysis results were compared and discussed with the result of loading experiment.

3. 2 Analysis model Outline

The 3D model for box- culvert was used (B) 200 mm × (H) 200 mm × (L) 200 mm. The model for the precast box- culvert created connecting five elements, (B) 200 mm × (H) 200 mm × (L) 40 mm. Parameters for analysis were set same values for each models, Young's modulus was 2.35e+10N/m^2 , Poisson's ratio was 0.17, the maximum and minimum mesh size were 0.07 mm and 0.04 mm respectively. In order to simulate the loading experiment in the analysis, the model of jig for loading experiment also created.

3．3 Analysis Method

In this study, “SALOME-MECA”, a structural analysis software that integrates the pre-post "SALOME" and the structural analysis solver "Code Aster" among open source CAE software, was used as the analysis software.

The analysis were conducted for 6 cases representing in Table 2.The analysis was performed with a maximum load of 1000 kN as the loading condition, the distribution of the maximum shear stress was examined and compared with the specimen damaging after loading experiment.

Incidentally, the influence of PC tension force was not considered in this analysis, because of the main purpose of this analysis was to clearly understand the influence of the longitudinal gradient of slope on load bearing capacity of box- culvert.

3．4 Results and Discussion

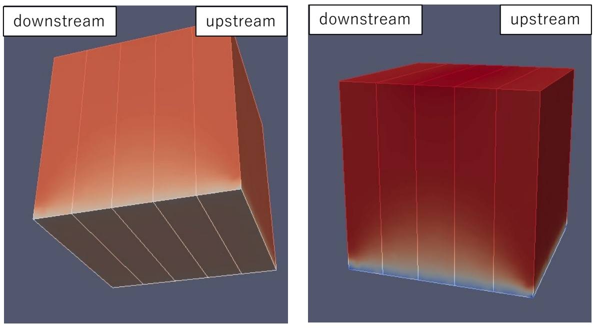
Fig. 8 and Fig.9 show the analysis results of the precast and onsite-casting box-culvert models, respectively. Left column of Fig.8 and Fig.9 is the view from bottom, and the right column of Fig.8 and Fig.9 is the side view. And the right and left side of the model in each figures shows the upstream (upside of the slope) and downstream (downside of the slope) of the slope, respectively.

According to overview of the results, in the case of no-gradient, it was confirmed that the load was uniformly worked to whole of culvert despite the difference in precast or on-site casting culvert. And the case of slope, it was confirmed that the shear stress occured at the direction from top of upstream side element to bottom of downstream side element. In addition, it was found that its stress increased with the increase of longitudinal gradient, and a greater load worked on top of upstream side with the increase of the longitudinal gradient. For the joined precast box-culvert, its phenomenon was observed in each element consisted the box-culvert.

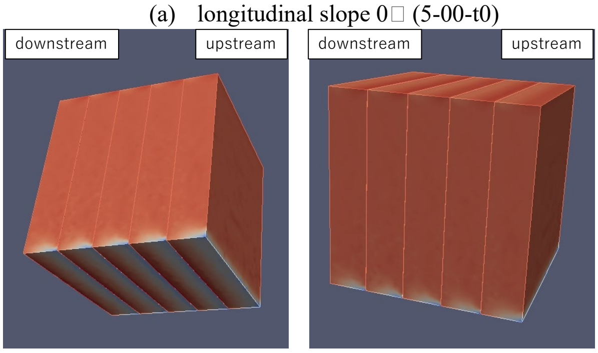
Table.2 Analysis Case

	Longitudinal slope（％）		
	0	5	10
model of on-site casting box- culvert	1_00_t0	1_05_t0	1_10_t0
model of precast box-culvert	5_00_t0	5_05_t0	5_10_t0

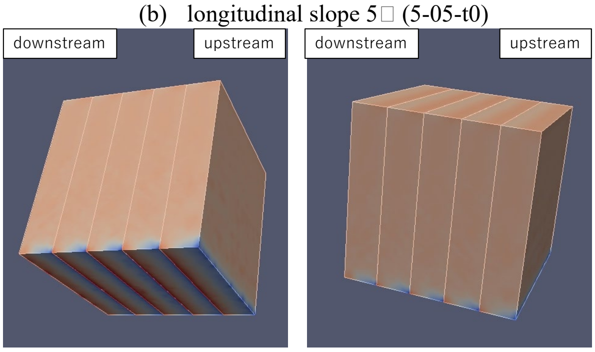
e.g.: Number of specimen _Longitudinal slope _PC tension



(a) longitudinal slope 0□ (5-00-t0)

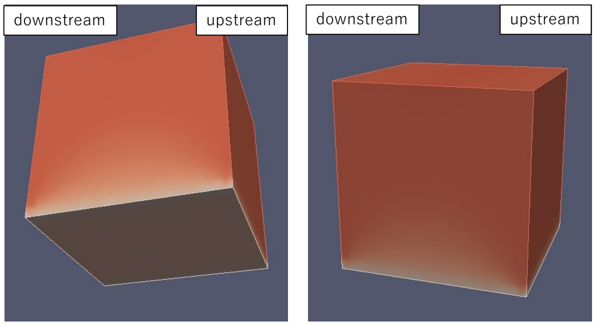


(b) longitudinal slope 5□ (5-05-t0)

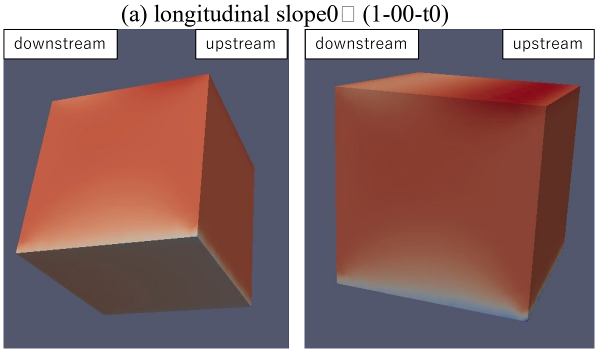


(c) longitudinal slope 10□ (5-10-t0)

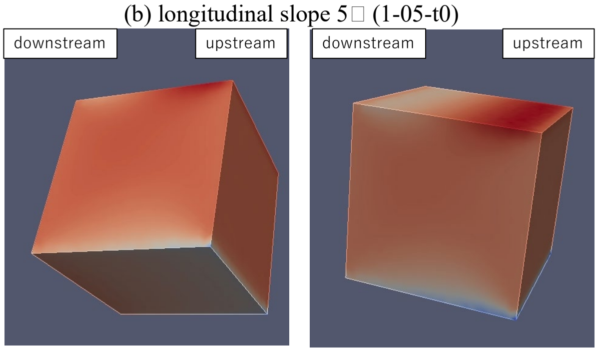
Fig.8 assume models precast box- culvert



(a) longitudinal slope0□ (1-00-t0)



(b) longitudinal slope 5□ (1-05-t0)



(c) longitudinal slope 10□ (1-10-t0)

Fig.9 assume models on-site casting box- culvert

According to compare with the result of Fig.5 (a) and Fig.8 (c), and the result of Fig.5 (b) and Fig.10 (c), it was found that the direction of occurrence crack of the specimen observed by a load experiment corresponded approximately with the distribution of the shear stress analyzed by structural analysis. Hence, it was judged that this structural analysis model reflected the load experiment.

For the on-site casting box-culvert, even though on the slope with incline, it was not observed that the displacement like an observed for the precast box-culvert. That is, it can be inferred that even when precast is used, it is possible to suppress the deformation peculiar to precast by making it approach the stress state of on-site casting box-culvert.

4 Conclusions

The results obtained from this study are summarized below.

(1) The load-bearing capacity of the box-culvert decreased with the increase of the longitudinal slope.

(2) The structural integrity of divided precast box-culvert is improved by applying PC tension force.

(3) However, the load bearing capacity of the box-culvert with the tension force of 150% indicates almost same or less load at the case of no-tension force.

(4) the case of applied the tension force to divided precast culvert on the slope of the longitudinal

gradient, the exfoliation was occurred on side face of specimen, due to working the stress toward to antiplane direction.

(5) For the box-culvert on the slope of the longitudinal gradient, the shear stress due to loading works from the top of the upstream side to bottom of downstream side. This phenomenon was confirmed comparing the experimental result and the result of the structural analysis (without PC tension force).

(6) The case of using the divide precast box-culvert on the slope with the longitudinal gradient, it can be dealed with the same as on-site box-culvert by the introducing appropriate PC tension force depend on the gradient of slope.

In this study, it was examined the behavior of the precast box-culvert applying PC tension at three types of longitudinal slopes, 0%, 5% and 10%.

In the future, it is necessary the examination about the optimum PC tension force, required to enhance the stability and the load bearing capacity of the split precast box-culvert at the slope with the longitudinal gradient.

In addition, it is considered necessary to examine a structural analysis method for taking an axial force due to PC tension force into account.

In actual construction site that install the large- scale slit precast box-culvert to the slope with the longitudinal gradient, there are many parameter to affect of the stability and the load bearing capacity on other than the tension force and the gradient of slope.

It is necessary to consider and establish a design method including the influence of the construction condition, such as a foundation condition, a backfilling of box-culvert, an embankment and so on.

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