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Field test of embankment constructed by column-net method

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ABSTRACT: This report describes a column-net design method for a railway embankment investigated on basis of comparison and evaluation of the loading test result concerning two types of embankment. For construction of railway embankment on soft ground, both the deep mixing soil stabilization method and geogrid application were employed to suppress settlement as much as possible after the start of business operation of a new railway line. However, for the construction it was required to understand differences in behavior of the embankment between the two different conditions under static and dynamic load state; namely, strain in the geogrid, stress between non-improved and improved areas, uneven settlement suppression effectiveness and such depending upon the relationship between the interval of soil-cement piles and the embankment height. Consequently, test embankments with two different types of height were constructed on site and the dynamic loading test was conducted through simulation of train running using various types of measuring instruments installed in the field to verify effects of the embankment structure employed at the site.

1 INTRODUCTION

The roadbed section of the Hachinohe car storage track on the Tohoku Shinkansen will be an embankment with a soft organic soil layer as supporting ground and will be provided with comparatively lower embankment with variable height conditions (planned embankment height: 1.5 m to 3.2 m). For construction of railway embankment, when the supporting ground is soft, it is essential to reduce as much as possible the amount of plastic settlement caused by the embankment and/or train load after opening the concerned line. In order to resolve the problem, a method combining the deep mixing soil stabilization method and the use of geogrid was applied as the countermeasure at the concerned site: this method is referred to as the column-net method in this report.

Since the column-net method has been applied to and designed for railways based on the "Handbook of Design and Construction of Soil-cement Foundation (Mechanical Mixing Method)" issued by the Railway Technical Research Institute on July 1, 1987) (hereinafter referred to as the "current standard"), investigation was implemented at the concerned site based on this "current standard". The "current standard" defines the condition that "stabilizing pile center interval D must not exceed embankment height H," which is the important prerequisite for applying the column-net method from the viewpoint of preventing embankment panting caused by train running. However, when an attempt was made to apply this to the embankment at the concerned site, some problems occurred including complicated design and construction for ground amelioration since it was required to design the embankment with variable stabilizing pile arrangement intervals and pile radiuses due to embankments with lower height variations. Thus, it was decided to employ a more reasonable and economic structure for applying the column-net method at the concerned site. The applied structure has stabilizing pile center interval D = 2.5 m for embankment height H = 1.5 to 3.2 m, which includes a portion contrary to the condition of "$D < H$" in the "current standard." Although there is concern that panting may be caused, it was decided to work around the panting by changing the types and/or arrangement of the geogrid. In addition, it was decided to design the embankment with two layers of high-strength geogrid though the "current standard" provides for single layer arrangement of geogrid. Based on the above background, for the purpose of verifying the performance and validity of the embankment structure at the concerned site through comparison with the performance of the structure conforming to the "current standard," the on-site loading test was conducted for two different cases. This report describes the results of on-site loading test.

2 ON-SITE DYNAMIC CYCLIC LOADING TEST

2.1 *Overview of on-site dynamic cyclic loading test*

The on-site loading test was conducted with a total of two embankment cases: Case 1 used the embankment of height 3.206 m conforming to the application condition "D < H" of the "current standard" and Case 2 used the embankment of height 1.96 m ("D ≥ H") not conforming to the application condition of the "current standard." The test embankment construction, loading test summary and such are summarized in the following.

2.1.1 *Overview of test embankments*

The test embankment shape and the arrangement of measuring instruments are summarized in Fig. 1. For the ground amelioration method, the Cement Deep Mixing (CDM) method was employed with the pile arrangement interval of 2.5 m in the direction of crossing the railroad and 3.0 m in the direction of the railroad (2.5 m × 3.0 m). The process flow of test embankment construction and loading test is shown in Fig. 2. The test was conducted at the same location in a series of process. Upon completion of Case 1 embankment construction and loading test, Case 1

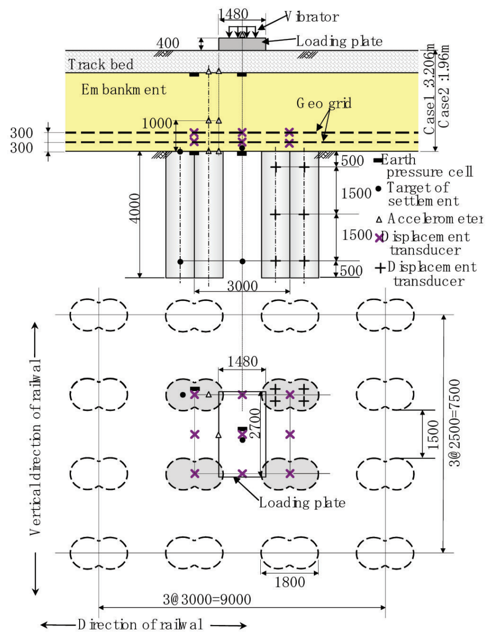

Figure 1. Schematic figure of embankment.

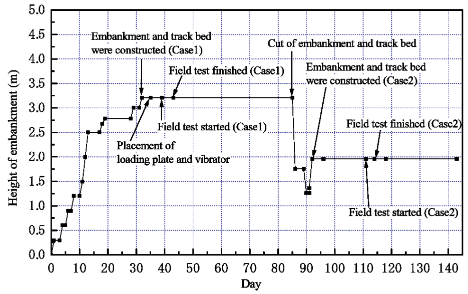

Figure 2. Plan of construction and loading.

embankment was cut, Case 2 embankment roadbed was constructed and Case 2 embankment loading test was conducted in that order. The embankment and roadbed materials and the compaction management values were the same as those for the embankments on the main line. With the finish thickness of a single embankment layer set to 30 cm, the measuring instruments were installed as shown in Fig. 1 in the embankment construction process to implement static measurement during the embankment construction and the dynamic measurement during the loading test.

2.1.2 *Setting of dynamic cyclic loading conditions*

The dynamic cyclic load equivalent to train running load was simulated with roadbed pressure of 30 kN/m^2 assuming Shinkansen car running of P16 load (wheelbase 2.5 m) at V = 200 km/h. Loading was implemented by use of a vibration generator with performance of tare 60 kN and vibration load +/–60 kN (maximum load 120 kN, minimum load 0 kN). From the viewpoint of the performance of the vibration generator, the loading plate was set to the size (2.7 m in the direction of crossing the railroad × 1.48 m in the direction of the railroad) equivalent to the roadbed pressure generated by an actual train load. In addition, since the loading plate simulates track load, such as ballast, the thickness of the concrete plate was determined to be 0.4 m to generate track load of 10 kN/m^2. Table 1 shows the load conditions for the loading test.

Table 1. Loading condition.

Dynamic load	60 kN ± 60 kN
Area of loading plate	2.7 × 1.48 = 4.0 m^2
Earth pressure on the track bed	30 kN/m^2
Loading frequency cycles	22 Hz
Number of loading	2 million

2.2 *Comparison of on-site dynamic cyclic loading test results*

2.2.1 *Static measurement during embankment construction*

Static measurement was conducted in series from the start of Case 1 embankment construction to the completion of Case 2 embankment loading test. The following shows the result of the static measurements with the installed measuring instruments. The measuring instruments were installed as shown in Fig. 3.

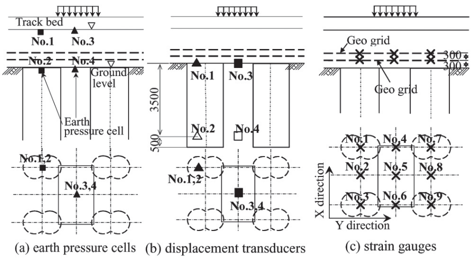

Figure 3. Location of earth pressure cells, displacement transducers and strain gauges.

Figure 4 illustrates the changes of the vertical earth pressure on the ground level throughout the entire process. From this illustration, it is found that the earth pressure increased in both the pile head section and the inter-pile section by following along the calculated effective overburden pressure up to Case 1 embankment height of 0.9 m or so; subsequently the stress started to converge on the pile head section. Although the earth pressure decreased in accordance with dismantlement of Case 1 embankment, both earth pressure gauges No. 2 and No. 4 showed a value approximate to the calculated effective overburden pressure when the embankment height was 1.26 m. In addition, Fig. 4 also shows that the stress tends to converge again on the pile head section in accordance with construction of Case 2 embankment. From these measurement results, it is believed that the arching effect of the embankment is exerted beginning from the embankment height of 1.0 m or so when the stabilization piles are installed at the same intervals as used in this test.

Next, when attention is focused on the measurement result before and after each loading test, the following is found: each earth pressure gauge indicated a slight

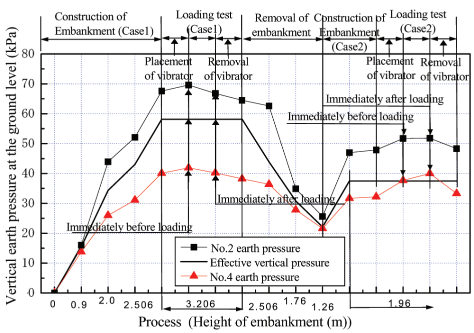

Figure 4. Vertical earth pressure on the ground.

reduction of the earth pressure before and after the Case 1 loading test; the earth pressure did not change in the pile head section (No. 2) before and after the Case 2 loading test; and the vertical earth pressure increased in the inter-pile section (No. 4) after loading. From here onwards, it is believed that the arching effect of Case 2 embankment lower than Case 1 was damaged by dynamic loading, thus increasing the earth pressure in the inter-pile section. Figure 5 illustrates the changes of geogrid strain observed throughout the entire process. Strain measurement of the geogrid was conducted at a total of 18 points in X and Y directions for the upper and lower layers, respectively, as shown in Fig. 3(c). However, the following describes the geogrid strain in the Y direction of the upper layer as the typical measurement result. From this illustration, it is found that the geogrid strain caused by embankment construction changed as follows: large strain was caused in the inter-pile section during surface compaction of the first layer after completion of laying of the geogrid, and the subsequent strain caused by embankment construction reduced the changes and tended to change toward the compression side. The maximum tensile strain in the measurements was approximately 1200μ in the Y direction of the upper layer at the No. 4 measurement point, and can be converted to tensile strength of approximately 15 kN/m based on the relationship of tensile load and strain obtained from the tension test of a simple geogrid. In addition, the residual strain of the geogrid before and after the loading test was as small as about 50μ or less in both Case 1 and Case 2 loading tests, and the compression side tended to have residual strain.

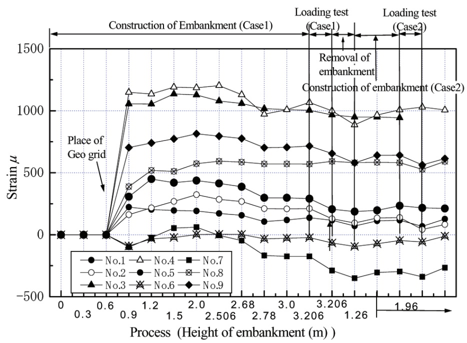

Figure 5. Tensile strain of Geo grid during construction.

Figure 6 shows the settlement changes of the ameliorated ground throughout the entire process. Measurement was carried out at the locations shown in Fig. 3 by levelling with a settlement plate installed underground. This diagram allows determining that the settlement at all measurement positions shows nearly the same progress. It was also determined that the ameliorated ground layer was in the even settlement

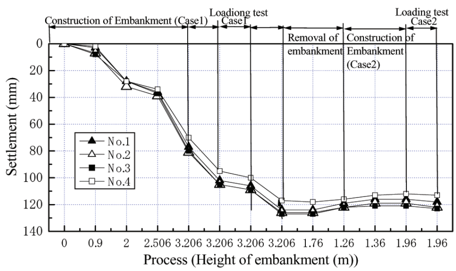

Figure 6. Settlement of improved ground.

state as the integrated composite ground in both the stabilizing pile positions and the inter-pile ground areas. In addition, the ameliorated ground layer showed 1 to 2 mm of compression settlement before and after Case 1 and Case 2 loading tests. Therefore, it was determined that the embankment in both cases sufficiently performed the function as the column net from the viewpoint of preventing uneven settlement.

2.2.2 *Dynamic measurement in loading test*

Figure 7 shows a comparison of the double amplitudes of the dynamic earth pressure generated during vibration loading. The comparison between Case 1 with a higher embankment conforming to the "current standard" and Case 2 with a lower embankment not conforming to the "current standard" based on this diagram shows the following: the double amplitudes of the dynamic earth pressure on the ground level in Case 1 are nearly the same and are equally dispersed in both the pile head section and the inter-pile section or show the distribution of slightly larger earth pressure in the pile head section with high rigidity. On the other hand, the double amplitudes of the dynamic earth pressure on the ground level in Case 2 are larger in the inter-pile section than in the pile head section, indicating that the inter-pile ground section is more affected by the train load. Thus, the double amplitudes in the inter-pile section on the level under the roadbed are accordingly larger than those in Case 1.

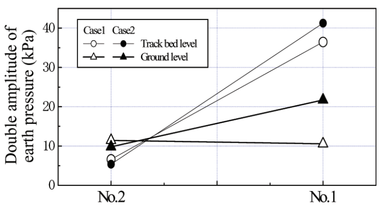

Figure 7. Comparison double amplitude of dynamic earth pressure.

2.3 *Performance evaluation of the column-net structure*

In order to verify the performance and validity of the column-net structure which does not conform to the condition of "D < H" in the "current standard" but which was applied at the concerned site, the on-site loading test was conducted to implement performance comparison with the structure conforming to the "current standard."

As a result, since two layers of high-strength geogrid were arranged to support a larger earth pressure affecting the inter-pile ground, the Case 2 embankment defined as being non-applicable in the "current standard" showed nearly the same behavior of the Case 1 embankment within the application range of the "current standard" concerning the vertical dynamic displacement amplitude on the embankment surface and the settlement of the ameliorated ground layer. Therefore, it can be determined that Case 2 embankment has sufficient functions and performance of the column-net structure. However, since the test result showed that a train load largely affects the inter-pile ground section in the case of a low embankment, it was also verified that the conventional single-layer geogrid arrangement has a danger of occurrence of panting within the embankment.

3 CONCLUSIONS

In connection with application of the column-net method in the low-embankment section, a more reasonable and economic structure was employed and its performance was verified by the on-site loading test. Based on these results, a study is planned to review the "current standard."

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