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Evaluation Criteria and Results of Full Scale Testing of Bridge Abutment Made from Reinforced Soil

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Abstract. Structures made of reinforced soil can be evaluated for their safety based on a load testing. Measurement results are essentially evaluated by displacements of surcharge (mainly in vertical direction) and facing elements (mainly in horizontal direction). Displacements are within several tenths to several millimetres and they can be taken by common geodetic equipment. Due to slow soil consolidation (progress of displacements) under constant load, observations should be made over several days or even weeks or months. A standard procedure of heating of geotextiles, used in laboratory conditions to simulate long term behaviour cannot be used in a natural scale. When the load is removed, the soil unloading occurs. Both the progress of displacements and soil unloading after unloading of the structure are the key presumptions for evaluating its safety (stability). Assessment of measuring results must be preceded by assuming even the simplest model of the structure, so as it could be possible to estimate the expected displacements under controlled load. In view of clearly random nature of soil parameters of retaining structure composed of reinforced soil and due to specific erection technology of reinforced soil structure, the assessment of its condition is largely based on expert’s judgment. It is an essential and difficult task to interpret very small displacements which are often enough disturbed by numerous factors like temperature, insolation, precipitation, vehicles, etc. In the presented paper, the authors tried to establish and juxtapose some criteria for a load test of a bridge abutment and evaluate their suitability for decision making. Final remarks are based on authors experience from a real full scale load test.

1. Introduction – genesis of the problem and description of tested structure

The presented case was unique, because it is not frequent to test the entire structure and the instrumentation must be individually adopted [1,2]. Some references concerning instrumentation may be found in the works [3,4] and examples of numerical modelling in work [5]. A single-span overpass (viaduct) was constructed to eliminate level crossing as a part of Central Railway Main Line upgrading. The facility is situated along a local road of very low traffic intensity, used by nearby farms. The overpass was built in 2013 to ensure safe crossing over railroad rails. The access embankments of the overpass about 11 m high were provided with reinforced soil structures with concrete facing panels. Following the project closeout, some deformations of vertical surfaces of retaining structure, appearing as mutual displacements of protective prefabricated elements and a bulge of walls composed of these elements, were noticed. As there were some doubts about the structure stability, it was decided to make expert opinions [6-8] and proposed testing method [9] including some specific long-term loading test of the structure described in [10].
The static system consists of a single-span simply supported beam. The span is made of steel/concrete structure with main steel girders and reinforced concrete deck slab. Theoretical length of unsupported span is 36 m. Each support includes, inter alia, 3 columns, transom back member and back wall. Wing walls and headwalls of abutments are made as a reinforced soil structure with facing shields made out of concrete prefabricated elements. Polyester strips were used as soil reinforcing elements.

![Figure 1. General view of the overpass](image1)

![Figure 2. View of span and retaining structure](image2)

The overpass span imposes no load on reinforced soil retaining structure and the embankment, embraced by retaining structure, transfers no load to the overpass supports. These elements contact each other via a transition plate which is based on the back wall of the support and, on the other side – on a block of reinforced soil, (Figures 1 and 2).

2. Preliminary recommendations and reasons for further testing

The following findings were made during inspecting the facility at construction completion and before putting it into use:

- concrete shielding elements do not create smooth and flat surfaces; elevation bulges, offsets between elements and deviations from vertical were found;
- some shielding elements have their plane turned, so the gaps between them are uneven;
- the highest number of defects of elevation shape in retaining headwall were in top parts of the structure and in wing walls;
- visual inspection found no deformations of cornice prefabricated elements on coping of wings, and no visible deformations of paved surfaces located near the face of retaining structure, and no deformations of balustrades on coping of wings;
- no deformations of carriageway pavement at access ways were found;
- no atypical relocations in expansion joints were detected.

Regarding the existing situation, a decision was made to test the condition of soil built into the reinforced soil structure [6-8]. Results of testing showed possible inconsistency of the condition and features of soil with technical specifications (incorrect compaction). Consequently, an individually designed load test was performed [9,10] which was aimed at taking decision of treating.

3. Long term static load test

Testing was performed as outlined below:

- the surcharge was loaded with concrete road slabs placed on a roadway pavement at access to the overpass (over the reinforced soil abutment); the load was of uniformly distributed;
- following the static test, dynamic testing was carried out by carrying a part of accumulated slabs with a truck;
• the test load was close to that assumed for the surcharge in static analysis of the structure [8];
• measurements during the test were taken for displacements of designated points on shielding panels, dislocations of support columns, and also displacements of roadway pavement; the relative positions of panels were also observed;
• the load was left for 17 days on the structure;
• evaluation of testing results was mainly based on analysing the dislocations found for the measuring points.

The test load was made using reinforced concrete road plates stacked in 7 layers with total thickness of 1.1 m approximately. The plates were placed in layers over almost the whole width of the roadway, i.e. 6 m in width and 9 m in length (Figures 3 and 4). In total 84 plates were used weighing about 135 Mg. The loaded surface area was $9 \times 6 = 54 \text{ m}^2$. The value of uniformly distributed load was equal to 25.0 kN/m$^2$. Road plates were placed in two stages. The plates were not placed over the whole transition plate so as the load to be transmitted to the embankment soil instead to the support via the transition plate. The scheme of pressure distribution on the retaining structure is shown in Figure 5.

![Figure 3. Placing the first layer of loading plates](image1)

![Figure 4. Full load on the structure (7 layers of road plates)](image2)

![Figure 5. Longitudinal profile of embankment structure and positions of loading plates. Measuring points (P1 \(\rightarrow\) P4) on the columns are shown](image3)
While determining the load position and pressure distribution, the internal friction angle for the soil built into the reinforced structure was assumed $\Phi=40^\circ$, according to the soil testing [6,7]. Locations of measuring points are shown in Figures 6 through 7.

Figure 6. Locations of measuring points (S1 ÷ S18) on head wall and wings. Dimensions are given along the wall surface.

Figure 7. Arrangement of loading plates and locations of measuring points on roadway pavement (N1 ÷ N6)
Immediately before placing the road plates, gypsum fillings (see Figure 8) were put in gaps between protecting prefabricated elements in selected points of the reinforced soil head wall.

The load test was started on 17 May 2016. At 9:00 a.m. the “zero” geodetic measurements were taken. Placing the first layer of plates was started at 10:15. The first stage of plate placement (3 layers of plates) was completed at 12:00. Control measurements were then taken. Upon analyzing the results and visual inspection of gypsum fillings the next stage of road plates was initiated (13:45 hour). Placing the plates was terminated at 16:00. Control measurements and visual inspections of gypsum fillings (following the full load was applied) were carried out on the following days: 17.05.2016, 18.05.2016, 21.05.2016, 24.05.2016, 27.05.2016, 3.06.2016.

The loading was removed on 3 June 2016, from 9:15 to 13:15. Following removal of the loading plates and after completing geodetic measurements and inspecting the gypsum fillings, decision was taken to make dynamic load testing which was carried out from 14:30 to 15:00 of that day, i.e. 3.06.2016. The geodetic survey upon finishing the test load was made on 3.06.2016 and 6.06.2016.

A heavy truck (Figure 9) laden with 16 road plates was used to apply loads of dynamic nature. The magnitude of load put on the facility under testing (the weight of truck with load) was about 420 kN. The control drives were as follows:

- 6 drives at the speed of 30 km/h
- 14 rides at the speed of 50 km/h.

Control measurements were taken after each two series of drives. The conditions of gypsum fillings were also controlled. The geodetic measurements, having been the main component of the testing, were carried out under the following conditions:

- measurement points were arranged on protective panels, on column supports and on roadway pavement;
- target plates were used to ensure precise location of measurement points;
- the measuring method and the instrumentation were chosen so as to get the accuracy down to ±0.3 mm and to 0.2 mm in horizontal and vertical directions, respectively.

4. Evaluation criteria and results of testing
The assessment of testing results is shown in Table 1 below, prepared on the basis of Table 1 included in the test load design [10] and on the grounds of measurements. It must be stressed that most of the evaluation criteria relate to the measured, not-modified values. Only in some cases the relative values (quotients) are taken into consideration. Moreover, sometimes measured values are of the same range as the accuracy of the instrumentation.
| Pos. | Criterion                                                                 | Value    | Evaluation        |
|------|---------------------------------------------------------------------------|----------|-------------------|
| 1.   | Measuring points S1 \(\rightarrow\) S18; total horizontal displacement under static load | \(\leq 10\) mm | Correct status     |
|      |                                                                           | \(> 10\) mm | Incorrect status   |
|      | Assessment of results                                                     |          |                   |
|      | Total horizontal displacements of facing elements were different and amounted from 0 to 2.6 mm. The displacement criterion was met as: **2.6 mm < 10 mm** |          |                   |
| 2.   | Measuring points N1 \(\rightarrow\) N6; total vertical displacement under static load | \(\leq 3\) mm | Correct status     |
|      |                                                                           | \(> 3\) mm | Incorrect status   |
|      | Assessment of results                                                     |          |                   |
|      | Total vertical displacements for the measuring points N1 \(\rightarrow\) N6 were different, from 2.7 mm to 3.2 mm. The average displacement was 2.92 mm. The settlement criterion was met. |          |                   |
| 3.   | Measuring points N1 \(\rightarrow\) N6; The quotient of permanent and total vertical displacements – after static load is removed | \(\leq 70\) % | Correct status     |
|      |                                                                           | \(> 70\) % | Incorrect status   |
|      | Assessment of results                                                     |          |                   |
|      | The average permanent vertical displacement for the points N1 \(\rightarrow\) N6 as measured after three days from removing the load was 2.4 mm. The average total displacement as measured directly before load removal was 2.9 mm. Hence, the quotient is \((2.4 / 2.9) \times 100\% = 82\%\). The quotient is higher than that declared for the criterion: \(82\% > 70\%\). However, the following should be taken into account: (i) soil distressing proceeds very slowly; considering that over time the soil distressing will be continued, the results achieved were accepted; (ii) during dynamic tests, the truck drove over some benchmarks in the roadway pavement, so they were driven into the pavement, thus the results were disturbed. |          |                   |
| 4.   | Damages of edges and corners of panels resulted from test load             | None     | Correct status     |
|      |                                                                           | Occurring | Incorrect status   |
|      | Assessment of results                                                     |          |                   |
|      | **No damages were found** in facing panels caused by test load            |          |                   |
| 5.   | Relative positions of facing panels due to test load effects              | Admissible, provided no backfill, geotextile, etc. is coming out |          |                   |
|      | Assessment of results                                                     |          |                   |
| 6.   | Additional horizontal displacements after completing the dynamic loads    | \(\leq 1\) mm | Correct status     |
|      |                                                                           | \(> 1\) mm | Incorrect status   |
|      | Assessment of results                                                     |          |                   |
|      | **No meaningful displacements were found** after completing the dynamic loads |          |                   |
| 7.   | Grow of displacements over time (no important progress of displacements)  | Stabilization | Correct status     |
|      |                                                                           | Grow of displacements | Incorrect status   |
|      | Assessment of results                                                     |          |                   |

**Table 1. Evaluation of testing results (see Table 1 in [9])**
5. Results and discussions
The testing can be illustrated by the measurement results for benchmarks in pavement loaded with road plates (Figures 10, 11). The processes of continued settlement following load placement and of distressing following load removal are clearly visible.

Figure 10. Settlement of N1 point. Restraining the settlement process is visible since 24 May. The loading plates were removed on 3 June.

Figure 11. Settlement of N5 point. Restraining the settlement process is visible since 21 May. The loading plates were removed on 3 June.

The following conclusions were drawn from the results.

- As an average settlement of N1 ÷ N6 benchmarks is about 3 mm, it let us estimate that the average stiffness modulus of the embankment is c. 60÷70 MPa, which is not much different from the values occurring in other civil engineering structures. It should be noted that over the years of using the structure, this modulus will favourably increase.

- The assessment criteria based on quotients of selected values (i.e. on relative values, like criterion No. 3 in Table 1) cannot be of priority meaning as the values of measured displacements are very low while, at the same time, the measurement errors are relatively high (relatively low accuracy of results).

- Uncertainty of measurements significantly affects the uncertainty of the final result. For this reason, these criteria were not considered to be the key ones while the testing results are evaluated whereas the criteria based on absolute values were met.

- Repeatable drives of the truck (dynamic loads) did not result in any phenomena indicating improper behaviour of the structure.

- The structure appeared to have expected figures of settlement which stabilized in several days. Hence, it demonstrates some reserves of load-bearing capacity.

- Retaining structures of the overpass did not subject to any alarming deformations or damages during actions undertaken. The structure demonstrated correct properties under load.
6. Conclusions and final remarks
Structures of reinforced soil can be evaluated for their safety based on a load testing. Measurement results are essentially evaluated by displacements of surcharge (mainly in vertical direction) and facing elements (mainly in horizontal direction). Displacements are within several tenths to several millimetres and they can be taken by common geodetic equipment. Due to slow soil consolidation (progress of displacements) under constant load, observations should be made over several days or even weeks. When the load is removed, the soil distressing occurs. Both, the progress of displacements and soil distressing after unloading the structure are the key presumptions for evaluating its safety (stability). Assessment of measuring results must be preceded by assuming even the simplest model of the structure, so as it could be possible to estimate the expected displacements under controlled load. In view of clearly random nature of soil parameters of retaining structure composed of reinforced soil and due to specific erection technology of reinforced soil structure, the assessment of its condition is largely based on expert’s judgment. It is an essential and difficult task to interpret very small displacements which are often enough disturbed by numerous factors like temperature, insolation, precipitation, vehicles driven close to testing site, etc.

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