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The first permanent road-bridge abutment in Germany built of geosynthetic-reinforced earth

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ABSTRACT: In the course of replacing a bridge carrying the road K1355 over the river Ilse, a single-span bridge was to be erected near the town of Ilsenburg. A alternative bid suggested not using piles but instead basing the structure on geosynthetic-reinforced earth. Since there is no information concerning the long term deformation behaviour of this sort of construction, a selection of instruments was built into both abutments. The instrumentation consists of deformation-measurement points, inclinometers, and earth-pressure sensors. The instrumentation was designed to monitor spatial deformation for at least the next 5 years. In addition to this, rolling tests with HGVs were carried out on the bridge. For these tests, additional sensors (acceleration sensors and oscillation sensors) were used. After the information had been gathered, the GRE abutment was recalculated using an FEM model which provided a new quasi-static model and a new dynamic model. Using the acceleration measurements and the earth pressure measurement, the values used for the calculation were calibrated. The following article presents the structure and deals with the evaluation of the measurement results, and details the designing process with the FEM. The deformation measurements, the rolling tests and the recalculation correlate well, and show that the current design approach, as found in EBGEO, offers a realistic design method. The construction method itself, as can be seen at the end of the article in a comparison of construction time and cost, offers enormous advantages opposite conventional construction methods.

1 INTRODUCTION

In 2000, the administrative district of Wernigerode applied for tenders to replace the K1355 road bridge over the River Ilse at Ilsenburg. During the construction, an existing arched bridge was to be demolished and a new bridge built at the same place. The official design, as seen in fig. 1, called for a solid superstructure supported on concrete piles with a diameter of 1.0m. The concrete piles were required to support the planned rigid-frame construction . The abutments were conceived as a leaning gabion construction. According to the official design, the load was to be carried by the concrete piles. An alternative offer suggested building the abutments out of geosynthetic-reinforced earth. The aim of this bid was a noticeably cheaper variant. For this tender, as seen in fig. 2, the entire design system of the bridge was changed. The superstructure was made of single-span precast girders in pre-stressed concrete with a clear span of 21.0m. The precast girders rested on load distributing reinforced-concrete beams with small wings. Underneath the reinforced-concrete beams was a construction made of geosynthetic-reinforced earth of approximately 2.7m in height. The alternative bid was accepted by the client because of the inherent advantages in cost and time. The design and construction started in May 2000 and was finished in November. The bridge was opened to traffic on December 7, 2000.

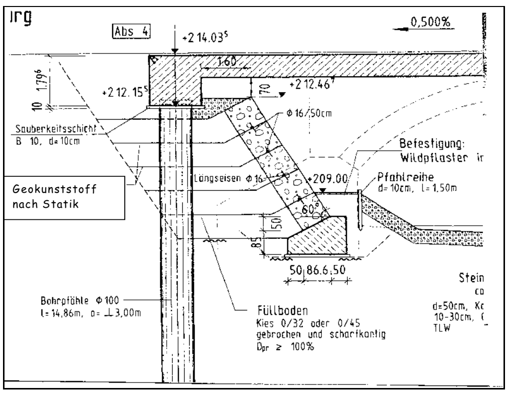
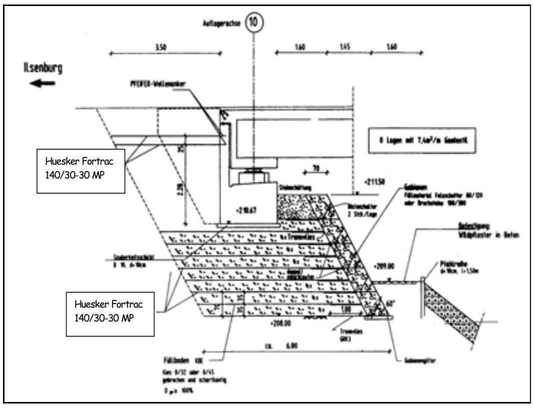


Figure 1. Official design

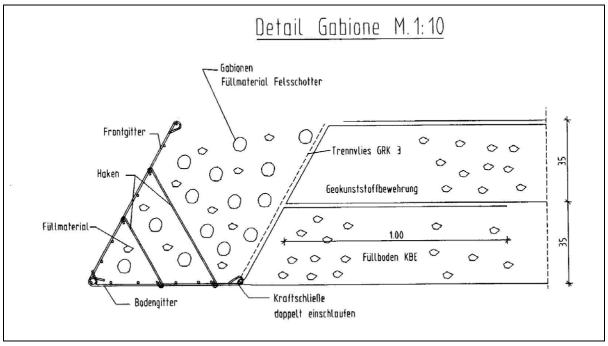
Figure 2. Alternative bid



2 EXPLANATION OF THE CONSTRUCTION/SPECIFIC FEATURES

The abutment was constructed in accordance with the principle of reinforced earth. Geosynthetic grids were laid between layers of fill. The resulting construction was capable of supporting the load of the superstructure. The load from the superstructure was tranferred at each end through a monolithic cill beam into the reinforced earth. The abutment was cemented directly onto the GRE-structure (see fig. 2). The GRE structure was built directly on the remains of the old bridge and the subgrade. On site, there are layers of stones at the subgrade level, quite capable of supporting the structure, supported by clay formations. The groundwater level at the site corresponds with the level of the outfall drain, about 0,50m below the lowest point of the GRE-abutment. The facing was constructed from galvanized gabion mesh at the bottom and at the front, that is to say, not built into sealed boxes, and filled with grade II rip-rap stones (see fig. 3). To keep the mesh in place and help stabilize the whole structure, two metal rods were added to connect the two mesh elements. These rods were mounted 25 cm apart at an angle of 45°. The geosynthetic grid was threaded twice into the galvanized mesh and additionally turned back to cover the filling soil. Using this method, a self-supporting GRE-construction was built with a separate facing. This allows the facing to be repaired separately should this be necessary. Design calculations yielded a vertical grid spacing of 0.35m , and a wrap-round length of 1 m. The length of the geosynthetic reinforcement was calculated to be 6.0m. A separator was added between the facing and the GRE-construction to ensure that in the event of a flood, none of the filling soil would be washed away.

Figure 3. Detail of the facing of the GRE abutment



3 DESIGN CALCULATION/DESIGN/MATERIAL

GRE constructions are designed and verified using static modelling. The current code of practice is the EBGEO (Recommendations for Reinforcement using Geosynthetics) /1/. The design is based on the partial-safety concept . The basis for this is DIN V 1054-100 and the norms found within. Overall and internal stability must be verified according to /1/. The design results for the determining cross-section for load case 1 are listed in table 1.

Table 1. Design results for load case

Stability	Resistance	Failure Mode	Calculated safety margin	Required Safety Margin
External	Global stability	GZ 1C	≥ 1,01	≥ 1,00
External	Bearing capacity	GZ 1C	4,77	≥ 1,00
External	Sliding	GZ 1C	3,03	≥ 1,00
External	Overturning	GZ 2	0,48 m	< b/6 = 0,88 m
External	Settlement	GZ 2	ca. 1,5 cm	< 2,0 cm
Internal	Required strength of reinforcement	GZ 1B	42,7 kN/m	42,6 kN/m
Internal	Grid Rupture	GZ 1B	1,11	≥ 1,00
Internal	Connection between gabions and GRE	GZ 1B	2,50	≥ 1,00

The materials for the reinforcement were chosen for cost reasons and in compliance with the design model. Flexible geogrids were used for the structure. These allow it to be properly connected to the gabion mesh and to be turned back on itself at the front of the GRE structure. The fill soil was recycled concrete of grain size 0/56 mm. This was won in the demolition of the old bridge. Because of the high pH value, a geogrid made of PVA was used to prevent hydrolysis. The geogrid was doubly threaded into the gabion mesh and secured using pins. The following materials were used in the design calculation:

Fill Soil:
Recycled concrete 0/56 pH value = 10-11
$\varphi_k = 35{,}0\,°$, $c'_k = 0$ kN/m²,
$\gamma_k/\gamma'_k = 21/11$ kN/m³,
$D_{Pr} \geq 100$ % angular

Geosynthetic:
Type Huesker Fortrac® 140/30-30 MP
Material PVA/PA
Nominal Strength: $F_{B,k0} = 140{,}0$ kN/m (MD)
Design Strength: $F_{B,d} = 42{,}7$ kN/m (MD)
$[F_{B,d} = F_{B,k0} / (A_1*A_2*A_3*A_4*\gamma_B)]$

Gabion Mesh:
Connection: Eye and Pin
Dimensions: L x B : 1,00 x 0,70 m
Bar size: Front Frame/Base: 5,00 mm
Pins: 6,00 mm
Stabilizing Rods: 5,00 mm
Nominal Strength: > 450...600 N/mm²
Corrosion Protection: Zn-Al Coating >350-450 g/m²
Mesh size: 10 x 10 cm

Coefficient of Friction: $f_{sg,k} = 0{,}70$ $f_{sg,k} = \lambda * \tan \varphi k = 1{,}00 * \tan 35{,}0°$ ($\lambda = 1{,}00$ for the Geosynthetic used)

The specific reduction factors of the different products A1 to A4 and the coefficient of friction had been experimentally verified by the producer. The partial-safety factor for the geosynthetic reinforcement of $\gamma_B = 1.40$ was used in the calculation /1/. The result of the design verified the adequate stability of the construction.

Figure 4. Preparation for abutment

Figure 5. Gabion grid underlay

Figure 6. North Abutment during Construction

Figure 7. North Abutment with cill beam

Figure 8. North Abutment – Complete

Figure 9. North Abutment

Figure 10. South Abutment – Complete

Figure 11. Full View

4 CONSTRUCTION

The entire construction was effected between April 2000 and November 2000. No problems arose during construction. Since the construction process used in an abutment made of GRE is inherently simple, the construction time could be noticeably reduced. Monitoring instrumentation was installed during bridge construction. The layers of fill soil and geogrids were checked as part of the regular construction monitoring. The fill material, in this case recycled concrete 0/56 mm, was tested for applicability before work began. The required degree of compaction in the GRE structure was checked in layers by directly measuring the soil density. Exceeding the rulings of the ZTVE-StB 94 (1997 version), a Proctor density of $D_{pr} \geq 100\%$ was aimed for within the GRE structure, to reduce the deformation of the structure itself. The following figures show the various stages of construction, from the preparation of the ground for the GRE structure up to the finished structure.

5 MEASUREMENT AND TESTING PROGRAMME

The bridge abutments are the first of this kind in Germany. Because of this, no long-term information is available for this sort of construction. In the case of clients in the public sector, and a large number of consultants, there are still reservations about the geosynthetic-reinforced earth construction method. The are indeed a number of unanswered questions and understandable objections, some of which are listed here:

The deformation characteristics of GRE constructions can only be predicted with relative difficulty. Even in this case, the results can only be regarded as approximate. Most clients and designers still think in terms of ‘security’; conventional solutions, usually because of ignorance and a lack of experience, are still chosen in preference to innovative new possibilities. The current code of practice in Germany for the measurement of GRE construction independent of product, the EBGEO (1), is based on the partial-safety concept (DIN V 1054-100 and related norms). The concept is currently under revision. The GRE method of construction is not listed in the 'Bauregelliste' A, B and C (a collection of approved building methods). For this reason, the go-ahead sometimes needs to be given for individual constructions.

Because of the above, it can be understood that this construction method, in spite of obviously lower costs and shorter construction time, is still regarded sceptically, and can only slowly find acceptance with clients in the public sector. To clear up these reservations, a comprehensive measurement and testing program was presented to the client. This program is to provide detailed information about the supporting and deformation behaviour of the whole construction for at least the next 5 years. Information relevant to the theory of GRE constructions, of equal value to conventional reinforced concrete solutions in this field, is to be gathered through measuring the actual deformation of the abutment. It is hoped that the problems of acceptance can be successfully confronted, and a wider audience for this financially interesting method can be found, by delivering data showing that this method is in every way just as capable and reliable as those methods which have been used regularly to date. The measurement and testing program presented to the clients provides them with information about the deformation and stability of the construction at any time. The measurements are in accordance with the recommendations of DIN 1054 observational methods. The instrumentation has been designed to allow observation of the construction exceeding the planned 5 years. The measurement and testing program consists of the following:

Deformation monitoring by means of vertical inclinometer Deformation monitoring by means of settlement-measuring points Measurement of the soil pressure (static and dynamic) Rolling-load tests in combination with oscillation and acceleration measurements in order to measure the behaviour of the whole system. It is also possible to remove samples of the geogrid at points specially designed for this purpose to measure its long-term behaviour.

Fig. 12 shows the instrumentation in the cross-sectional axis #10 of the abutment. For clarity, a vertical inclinometer was built into each abutment, directly in front of the third point of the concrete superstructure. Each abutment also contains six settlement gauges in the superstructure, the cill beam, and the wings. Measurements were taken regularly. Under the superstructure of the abutment at axis 10, an earth-pressure sensor was installed at the level of the highest geogrid layer. This is to measure the vertical tension beneath the superstructure in its natural state and during rolling tests. Three rolling tests with HGVs and passenger cars are planned for the next 2 years. For these tests, additional acceleration-measurement equipment is to be added to the superstructure. The tests are to be carried out at different speeds. Extreme cases (emergency stops) are to be checked, as is the dead-load case. The bridge abutments were completed in October 2000 and the bridge was opened to traffic in December. Work began on the GRE-construction in June 2000. To date (the last measurement being on 23/02/01), one calibrating measurement and three subsequent measurements to measure the vertical deformation (settlement) and 3 subsequent measurements have been carried out on the built-in deformation measurement points.

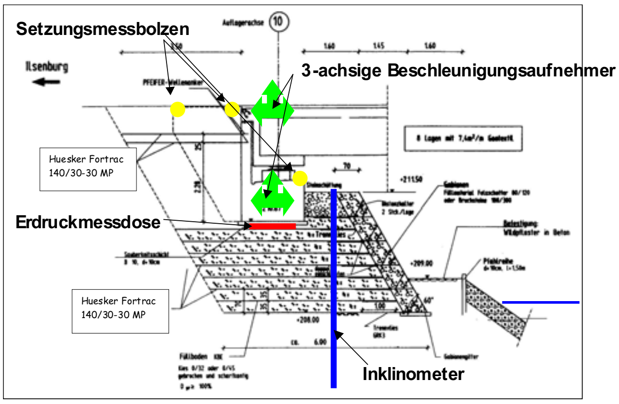


Figure 12. Instrumentation in the North Abutment

First Results of the Deformation Measurement

Fig. 13 shows the results of settlement measurements for 4 measurement points on the supporting surface abutment axis 10. The settlement to date is between 3.0 and 4.5 mm. The measurement points were installed after the cill beam had been covered in cement before the superstructure was added. The GRE-construction was completed about a week before cementing. The settlement measurement, here represented graphically, already shows a reduction in the rate of settlement. Further increases in settlement are, as suggested by these results, not to be expected. According to design calculations, a vertical deformation of $s_{max} \leq 20$ mm was predicted. The maximum allowable difference in settlement between axis 10 and axis 20 of the abutment was set at delta $s_{max} \leq 10$ mm. The measurements to date show that the actual deformation is less than 30% of the expected value and that the estimated deformation is unlikely ever to be reached.

Similar results follow through the analysis of the inclination measurements. Fig. 14 shows the measurements taken from inclinometer 1 (axis 10), here in the side facing the river. The transition from construction to service took place after the second measurement was taken. The calibrating measurement took place after the cill beam was cemented. The first and second measurements were taken during construction, the third about three months after the bridge was opened to traffic. The largest horizontal deformation to date is 0.2mm at the level of the top geogrid layer. The general deformation is in line with the predictions of the design calculations. The expected horizontal displacement towards the river can be found, but remains much smaller than expected.

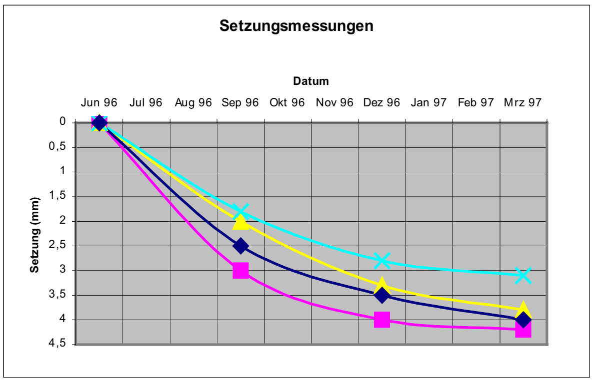


Figure 13. Results of Settlement Measurements in Abutment Axis 10

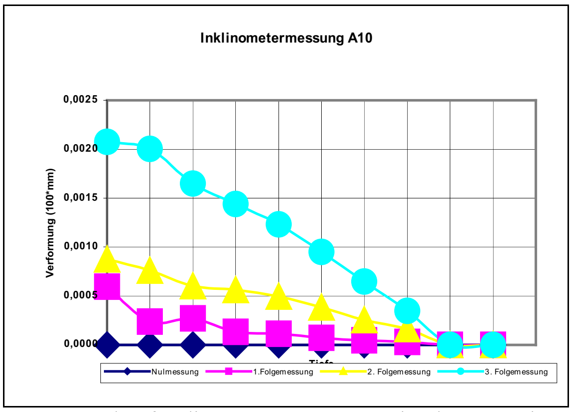


Figure 14. Results of Inclinometer Measurements in Abutment axis 10

5.2 First Results of the Rolling-Load Tests

In February 2001, three months after the bridge was opened, the first of the planned rolling-load test series took place. Fig. 15 and fig. 17 show examples of the measurements taken. The rolling tests were executed using a four-axle HGV (40t) at speeds of 20, 40 and 60 km/h. Emergency stops on the bridge and in the runoff area were also part of the measurement program. The graphs show the measurements taken at the third measurement point at axis 10. The first graph shows the earth pressure and the second the acceleration at the upper edge of the cill beam. The HGV rolling test can be clearly seen in the acceleration signal and also in the earth-pressure measurement, and is different from the results for a passenger car (fig. 17)

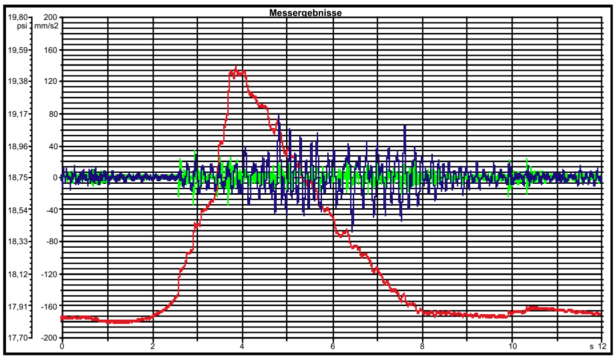


Figure 15. Rolling test with HGV (40t) at 20 km/h

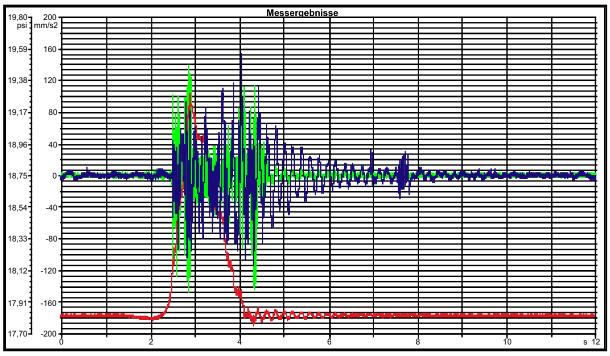


Figure 16. Rolling Test with HGV (40t) at 60 km/h

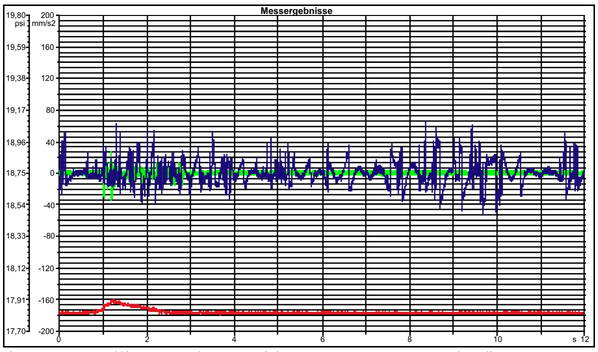


Figure 17. Rolling-Load Test with passenger car at 60 km/h

The additional contact pressure under the structure measures +10 kN/m² in the top geogrid layer during an HGV rolling test. The dynamic additional stress (change in load) resulting from the rolling test and the effect on the superstructure measures max ± 1.0 kN/m² (see fig. 16). Additional dynamic earth pressure was only measurable in the case of an HGV travelling faster than 50 km/h. The loading tests with passenger cars show a scarcely noticeable increase in tension or dynamic pressure. It could be measured that the superstructure during rolling tests with fast, heavy HGVs was effected as predicted. The measured dynamic tension in the top reinforcement layer was primarily the result of the excitation of the superstructure. However, the magnitude of this dynamic tension is so small that an effect on the frictional forces between geogrid and filling soil does not have to be considered.

6 COMPARISON

The GRE-abutment was designed in accordance with /1/. The proof of the applicability of GRE construction presents a problem. This is because the methods of design to date allow an inadequate prediction of the deformation. These methods should always be brought into alignment with the measured values. For this reason, the deformations were recalculated with the program Plaxis Version 7.2 after the first deformation measurements and rolling tests had been made. Fig. 18 shows the geometry used in the calculations. The calculations were based, firstly, on the load on the upper surface of the GRE-structure according to the original design (quasi-static model), and, secondly, the dynamic results. For this part, the acceleration resulting at the top of the cill beam surface during rolling tests was used in the calculation. The results of the design calculation are given below. The dynamic recalculations are complicated and will be published separately. Fig. 19 shows the horizontal displacement calculated using the quasi-static model. As a result of the recalculations, the following displacements for the construction were found:

Maximum horizontal displacement:

$S_{\text{horizontal calculated}} = 0.24\text{ mm} \approx s_{\text{measured}} = 0.20\text{ mm}$

Maximum vertical displacement:

$S_{\text{vertical calculated}} = 5.20\text{ mm} \approx s_{\text{measured}} = 3.0\text{-}4.5\text{ mm}$

The results of the finite-element calculation show good correlation. The progression of the horizontal displacement as well as the vertical and horizontal deformation were given with great accuracy. For these reasons, the deformation of the GRE-structure can be found relatively accurately. Precisely the verification of the operational condition (GZ 2 according to DIN 1054) can be dealt with. In every case however, it is recommended that the calculations be checked against the actual deformations.

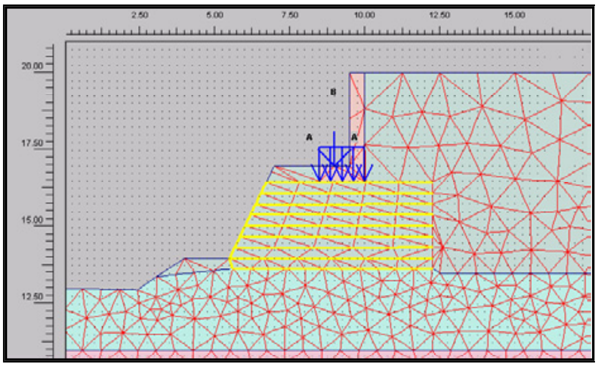


Figure 18. Finite element model of the abutment

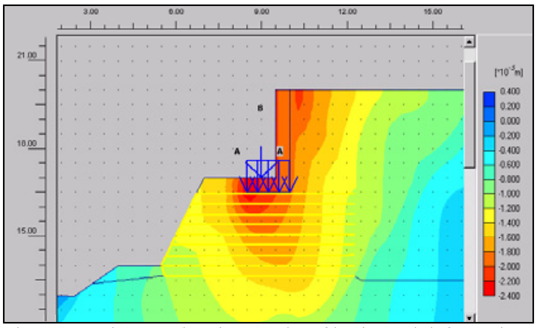


Figure 19. Diagram showing results of horizontal deformation

7 COMPARISON OF CONSTRUCTION TIME AND COSTS

After completion of the construction, a comparison of costs and construction times between three different construction methods was made. The actual values (cost and construction time) could be used for these calculations. The three different methods were firstly the original design, secondly, the alternative bid (GRE) and thirdly a conventional solution (reinforced-concrete abutments). For the comparisons, the values of the original design are set at 100%. The costs and the construction time are shown in fig. 20 and 21.

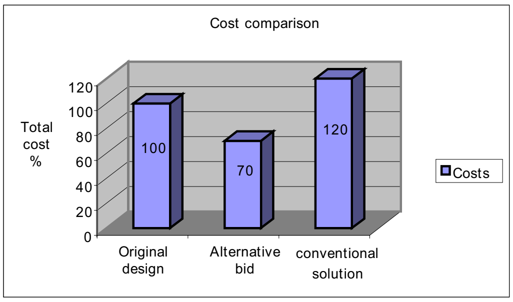


Figure 20. Cost Comparison

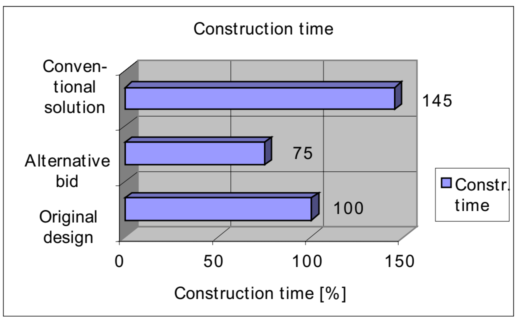


Figure 21. Construction Time Comparison

It can be clearly seen that the GRE solution is about 30% cheaper than the original design and about 50% cheaper than the reinforced-concrete conventional solution. The reasons for this are to found in the simple construction processes, the ability to do without drainage systems, formwork, and the fact that the old bridge could be broken up to use as fill material for the new GRE structure. Other cost savings are the result of shortened construction time, allowing the constructor to employ the equipment and personnel on other projects. The construction times tell a similar story, being about 25% shorter in the case of the GRE method (in this case about six weeks). A reinforced-concrete construction would require about 45% longer than the original design, since the stripping and final setting time must be taken into account.

8 CONCLUSIONS

The construction dealt with here shows that the GRE method can now be considered as a real alternative. Particularly in the field of bridge construction, where reservations still exist against this method, this construction proved its applicability. Even the results of the deformation measurements and the recalculations and rolling tests proved without a shadow of doubt that GRE abutments are just as capable as the conventional reinforced-concrete approach, both statically and during construction. Through the application of new types of geotextiles, it is possible to develop solutions with greatly reduced costs and construction times. The measurements show reserves in safety in accordance with current design methods. In relation to stability and longevity, GRE solutions are quite as capable as conventional methods. A lack of experience in relation to the long-term deformation characteristics of structures of this sort can be balanced out by using a deformation measurement and monitoring program. Since this construction method is clearly less expensive than conventional solutions, the extra costs related to a monitoring program do not represent a critical financial factor. For these reasons, it would seem to be of financial interest to consider alternative solutions through the application of GRE (geosynthetic-reinforced earth) technology.

9 ACKNOWLEDGEMENTS

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