Foundations under the 60 t wine fermentation cisterns, Gevgelija – Macedonia

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ABSTRACT: This paper presents a new design of foundations as a result of analyses of previous errors. The errors occurred due to a lack of geotechnical investigations, poor design and improper construction. As a consequence huge deformations and cracks on the fermentation cisterns platform occurred. The reasons for these deformations were bad compaction of fill material, as well as the bad design and construction of the nearby cellar wall, which sustained large horizontal movements too. The main concept of the proposed solution is considerable reduction of the horizontal forces, which endanger the stability of the cellar wall, and beading the cistern foundation on stiff rock. With the new design solution the shallow platform foundations are changed with new deep ones. The new foundation consists of RC console beams under the all four feet of each cistern, fixed on longer beams and circular pile columns anchored on bedrock.

1 INTRODUCTION

Wine cellars need to be specifically constructed and deep under the ground because of the requirement for low temperatures. The cellar walls are almost 9 meter under the ground surface. The site for the construction was on the hill with agriculturally non productive soil. Actually, the foundations were cut into local rock hill, which is considered to be a very good base for foundations. The high bearing capacity of the ground was so obvious that there was no need for geotechnical investigations to be performed.

In the excavation phase the contractor enabled the construction of the cellar by blasting the rock and over blasting happened. In haste to exploit before the annual gathering, other errors occurred. The filling behind the wall was made before the strength of the concrete was achieved and the proper compaction was not made. The construction of the wall was not tied with horizontal, perpendicular beams before the wall loading.

The horizontal displacement of the wall was obvious to the contractor, even so no measures for improvement were made. The construction continued, and the cellar and the hall above were built. A platform for the fermentation cisterns was made in continuation of the cellar wall too. The errors were covered and could not be discerned. The wine cellar with its surrounding equipment began functioning and the first hectoliter of wine was produced and exported (Fig. 1).

2 OBSERVATIONS, MEASUREMENTS AND INVESTIGATIONS BEFORE APPLYING THE SOLUTION

2.1 Observations

After the construction, the whole platform inclined to the side of the cellar and cracks in critical parts were noticed (Fig. 2). Large settlements over 150 mm
become obvious in the contact edge of the cellar and the platform (Fig. 3).

The horizontal deformations in the cellar wall were so extensive that in some parts the columns in the wall were touching the walls of 120 t wine cisterns.

Wrong measures were taken regarding the patching up of the cracks and additional watering. When the wine production season was over, the investor decided that a scientific approach should be taken.

2.2 Geotechnical investigations

Investigations were made to support the failure diagnostics. Two drilling holes were made and samples analyzed. The investigation revealed that the concrete was up to the designed quality standard and the top slab reinforcement was jammed in down part of the slab. The space under the slab was empty and the voids were more than 150 mm.

The soil material beneath was poorly compacted with the compression modulus less than 6000 kPa (Balusev 1971, Obradovic & Najdanovic 1999). The results of the investigations confirmed the previous suspicions.

3 ON THE WAY TO FINDING THE RIGHT SOLUTION

3.1 Structures observation and measurements

An expert team was invited to suggest a solution. On site, the irregularities were noted. The available technical documentation, investigations and measurements were analyzed. Additional geodetic measurements were made. From the measurements of the platform the rotation of the plate leading to differential settlements of more than 170 mm were measured.

The differential deformations were lower above the beam and larger in the field of the slabs.

The horizontal displacements on cellar wall were also measured. The maximum displacement measured in the middle part at a height of 9 m, was 230 mm. A diagram of the displacement of the wall with the columns is shown in Figure 4. Measurements of the horizontal displacements of the inner columns were also made.

These columns had deviated only 40 to 50 mm. These measurements show that the 80% of the deformations occurred before loading of the 60 t fermentation cisterns. The deformations occurred in the early stages of construction, from earth pressure.

3.2 Previous errors in the design

The review of the design documentation showed that the structure was poorly analyzed and designed, without 3D structural analysis, and not taking into consideration earth pressure, as well as the nearby 60 t fermentation cistern influences. The cellar wall was analyzed as a plate with fixtures on four sides loaded with plain earth pressure without the influence of the heavy cisterns.
The horizontal reactions from the earth pressure were not taken into account in the column and frame analysis. The columns were not stiff enough to endure those horizontal reactions.

4 ANALYSIS OF THE SOLUTION

The new 3D analysis was performed for the cellar and hall above. The results showed that the structure was burdened to a greater extent than was initially planned in the design. The safety of the structure was significantly reduced. Therefore, the solution of strengthening the cellar wall would be the most expensive one because it would require the dislocation of the fixed 120 t wine cisterns at the bottom of the cellar. To that effect, effort was made to reduce the loads. An analysis in Plaxis was performed (Brinkgreve & Vermeer 1998). Also, a model of the platform with the cellar walls and the fermentation cisterns was drawn up. In fact, two models are made: One without repairs, and the other with the suggested repairs. Both models are shown in Figure 5 and Figure 6. Geotechnical soil characteristics are shown on Table 1.

The bending moment in the first model was 448 kNm/m, and 111 kNm/m in the second model. This means that the influence on to the cellar wall coming from the fermentation cisterns was reduced four times using this model based on load reduction. Stress was reduced in the same ratio. The goal for load reduction has been achieved, thus the safety of the structure was raised significantly.

5 THE TECHNICAL DETAILS OF THE SOLUTION

The technical solution consisted of transferring forces from the cistern directly to firm rock hill. This could be achieved using the foundation structure shown in Figure 7.

The structure consists of reinforced concrete (RC) pile columns under every cistern. Each 60 t cistern has four feet. The feet are on the RC console beams 500/600 mm, finishing with transversal main beams 700/1000 mm which are set on the RC pile columns. The columns are anchored in the bedrock. The longer columns are Ø800 mm and shorter Ø1000 mm. This solution was chosen among other solutions because of its economical justification. This solution does not require the cisterns to be moved from their place, which means there are no costs for moving the cisterns and...
disassembling the joint equipment. In order not to move the cisterns the piles are dug up manually. A cross section of the new foundation structure with the cellar wall is shown on Figure 8.

The structural 3D analysis of the foundation structure was made by RadImpex Tower software. Calculation for the cases of worst loading and other combinations were taken into account, and the necessary reinforcement was obtained (Tomicic 1988). The construction drawings were made based on the required reinforcement.

6 CONSTRUCTING THE STRUCTURE

First the crushing of the old RC slab was made in the places were the new structure will be constructed.

Table 1. Geotechnical soil characteristics.

<table>
<thead>
<tr>
<th>Soil</th>
<th>Volume weight (kN/m$^3$)</th>
<th>Friction angle (°)</th>
<th>Cohesion (kN/m$^2$)</th>
<th>Compaction module (kN/m$^2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-Rock</td>
<td>22.00</td>
<td>40.00</td>
<td>40.00</td>
<td>100000.00</td>
</tr>
<tr>
<td>2-GFs</td>
<td>19.00</td>
<td>27.00</td>
<td>10.00</td>
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<tr>
<td>3-GW</td>
<td>19.00</td>
<td>32.00</td>
<td>1.00</td>
<td>7200.00</td>
</tr>
</tbody>
</table>

After that the hand dug well for pile columns was excavated (Fig. 9).

The design suggested protection during digging with 3 mm thick steel tubes, but because of the good soil conditions the digging proceeded without protection. Following this, the piles were heavily reinforced.
Figure 8. Cross-section through the foundation structure.

Figure 9. Hand dug well.

Figure 10. Reinforced beams under the cisterns feet.

With Ø20 mm ribbed steel reinforcement. The piles were filled with concrete with cube compression strength of 30 MPa after that. The beams were dug, reinforced and set in concrete (Fig. 10).

7 FURTHER ACTIVITIES

After the construction the feet of the cisterns were dropped on the beams. The geodesic measurements were made. The settlements were measured before and after the exploitation of the fermentation cisterns. Only minor settlements were measured. Even the elastic part of horizontal deflections was reduced. A second exploitation season passed without structural problems.

This year, on the same location the second part of the platform not occupied with fermentation cisterns had been repaired. The same approach was implemented. The extenuating circumstances were that the cisterns were not on that platform. This platform
started exploitation for the first time this year and no settlements occurred.

8 CONCLUSIONS

This paper was inspired from the errors that occurred in design and construction mainly due to the lack of geotechnical investigations and a geotechnical approach to the design. Perhaps, the reasons were the lack of time or coordination between the designer and contractor, or even insufficient experience.

The earth pressure forces must be taken into the consideration in all construction phases. Compaction of the filling gaps between foundation wall and the excavated profile must be properly made every time when any foundations should be designed above.

The best solution for recovery of such complex problems can be found after complete inspection on site and in the design has been carried out.

The proposed solution was adapted to suit local conditions and was designed having in mind the available construction technology. The main goal has been achieved – no additional vertical or horizontal displacement occurred. The security of the structures has been improved by reducing the internal forces and stresses in the old structure. During the carrying out of the above solution, the exploitation of the facilities was not detainted.

Solutions with deep excavations must be implemented when the structures are already constructed at the site and the functionality of these structures must be preserved. In the places where machinery has no access hand digging is the best solution.

REFERENCES