Reclamation and Soil Improvement of Elbe Bay as a Solution for EADS Plant in Hamburg.

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ABSTRACT: The paper presents the foundation of the new Airbus A380 assembly Plant built in front of Hamburg Port, along the Elbe River as an extension of the already existing Airbus Industries Plant. The project required reclamation of the Elbe bay by filling a part of its area. The solution of this complex task was achieved by applying combination of advanced soil improvement methods.

1. INTRODUCTION

1.1 Project overview

Since the end of last century the dynamic growth of airplane industry implies a need of very large areas under structures for construction-production of aircrafts. These needs often meet many difficulties such as lack of suitable location or very difficult ground conditions combined with high loadings (static and dynamic), typical for such structures. Both of these problems occur in case of EADS factory extension, located in Hamburg (North Germany), where parts of one of the largest carriers in the world - Airbus A380 will be produced. Due to the lack of available space for its localisation
corresponding to already existing part, an oxbow lake of the Elbe River was chosen. Building an extension in totally different location than existing part, which is by the Elbe side, was not interesting for the client. Solution for this case was to reclaim land and create a genuine polder and built on it. The problem was very complex, because of water and difficult soil conditions, described below, on which up to 10 m high fill was to be built in order to reach existing factory’s level. Apart from difficulties with “building on water” safety factor for the stability of such construction was to be reached. Solution was prepared by a joint venture Moebius-Menard.

Fig.1. General overview of Airbus site

1.2 Geotechnical conditions.

The area contiguous to the existing Airbus plant is an old sand quarry along the Elbe River. Alluvium has filled up the pit over the last 50 years and covered the old sand alluvium with a thickness of locally over 12 meters. The soil very heterogeneous and highly compressible, consisted of mud layers on the top, different clay layers (soft clay and gyttja) and peat below, deposited by the Elbe River. It’s also remaining under tidal influence. The area is nearly dry at low tide. In the higher tidal mud flat areas the water reaches a depth of almost one meter, which is a serious execution problem during reclamation works execution.

1.3 Soil parameters.

The very soft soil layer thickness varies between 8 to 14 m, and its consolidation could result in settlement in the range of 2 to 4 m. Its characteristics were so low that reclamation would have required a very long time. The mud is 3 to 12 m thick and the peat up to 5 m. Fig.2. Soil profile.

![Soil profile](image)

<table>
<thead>
<tr>
<th>Soil type</th>
<th>Water content</th>
<th>Organic content</th>
<th>Shear strength</th>
<th>Young Modulus</th>
<th>Coefficient of consolidation</th>
<th>Coefficient of secondary consolidation</th>
</tr>
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<td>peat</td>
<td>240</td>
<td>39</td>
<td>20 / 0</td>
<td>5 - 15</td>
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<tr>
<td>mud</td>
<td>142</td>
<td>13,5</td>
<td>20 / 0</td>
<td>0,5 - 5</td>
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<td>0,35</td>
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<tr>
<td>Soft clay</td>
<td>90</td>
<td>12,5</td>
<td>17,5 / 10</td>
<td>5 - 20</td>
<td>1,5</td>
<td>0,5</td>
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<tr>
<td>Sand</td>
<td>10</td>
<td>-</td>
<td>32,5 / 0</td>
<td>-</td>
<td>50</td>
<td>-</td>
</tr>
</tbody>
</table>

Table 1 Subsoil characteristics.

The mud consists on 50 – 90 % fine particles less than 0.063 mm and starts with a overage water content of 142%, measured between 58% and 233%. Its undrained shear strength was calculated by the theory of Bjerrum with 0.50 kN/m². Soil investigations did not indentify identify horizontal layers in the mud. Isotropic consolidation values were assumed and the consolidation coefficient of 0.35 m²/year characterized the mud in horizontal and vertical direction.

1.4 Technical solution.

The solution had to meet difficult soil conditions, high loadings, settlements and time limitations. Apart from service load for a plant also load caused by filling (up to 10 m) had to be taken into account. The filled area almost 1,320,000 m², which is equivalent of about 150 football fields. Such a big project was
divided into two main stages. First of all the area had to be closed from the influence of the tide – first phase. After that interior of the polder was filled with sand and optimized consolidation process was carried out – second phase. For the tide problem the solution of the client was a temporary sheet pile wall, which was changed into the joint venture’s alternate solution – a dyke founded on geotextile enclosed sand columns. The change was done to reduce: consolidation period (of 3 years!), amount of sand used to fill in area, number of vertical drains. It also avoids noise caused by sheet piles driving and eliminate creep polluted clay in the Elbe river.

Fig.3. Basic design and alternate solution.

2 GEOTECHNICAL SOLUTION’S EFFECT

The geotechnical conditions of the mud made filling difficult due to environmental reasons it couldn’t be removed. Because of too low shear strength of the soil it was impossible to build the fill to the full height, for stability reasons. It was necessary to bring the load stepwise and reduce it as much as possible. Traditional surcharge without any support was impossible. For this project combination of vertical drains (VD), Ménard Vacuum Consolidation (MVC) and Geotextile-Confined Columns system(GCC) were applied. It is known that the undrained shear strength increases with the degree of consolidation during the required consolidation time. For some parts of this project there was not enough time to wait for the consolidation process. In this case high fills were built in short time thanks to the Ménard Vacuum Consolidation, which was working as a “shear wall” in front of berms. The settlement calculations were done both for the first degree of consolidation in the different load steps and for the remaining settlements during the exploitation phase of EADS plant. The secondary settlements of the mud and peat can cause maintenance requirements to the structural areas for the next decades. The primary settlements of finally fill and life load had to be reduced according to 95 % degree of consolidation. This was achieved by vertical drains and vacuum technology, so that remaining primary and secondary settlements could be reduced to 0.15 m or 0.30 m within 5 years, depending of the specification of the area. Thanks to the Ménard Vacuum Consolidation (MVC) surcharge height could be considerably reduced as well as the risk of failure. Also time of consolidation and the soil pollution (because of water and air application) were limited. The diagram below presents following advantages in comparison with vertical drains.

Fig.4. Comparison consolidation process due to applied method.

2.1 Targets of Ménard Vacuum Consolidation.

In critical stability conditions the surface load can be replaced or increased by the vacuum method. The drainage blanket is covered by an
airtight cover membrane and sealed hermetically along its outer borders. The drainage blanket is connected to a vacuum pump, which produces depression in the drains in relation to the pore water pressure in the soil to increase the consolidation process. The depression achieved by the vacuum method in this case is maximum 70 to 80 kPa all over the vacuum package.

Fig.5. Scheme of Ménard Vacuum Consolidation.

2.1.1 Stability reasons.

For stability reasons MVC worked as a shear wall in front of berms. They protected a small polder inside the big polder because the fill had to be completed in short time.

Fig.6. MVC working as a shear wall.

2.1.2 Settlement control.

In the worst geotechnical case of the project, where maximum mud thickness reached 12 m, MVC was used to manage the settlement criteria of 0,15 m in 5 years for the crossing of the runway. The vacuum was applied on 66,000 m² in one block. The total settlements in the vacuum block were between 1.9 to 2.8 m, with an average of 2.46 m.

Fig.7. average settlements in the MVC block of 66 000 m².

2.2 Geotextile Confined Columns (GCC) application.

The GCC foundation system transfers structural loads onto the natural foundation. Geotextile utilization limits spread of sand into surrounding soft soil. The interaction of the supported columns with the soft soil gives the system a flexible, self regulatory effect, so that most consolidation settlements are limited to the actual construction period. The design of the bearing system (column pattern and diameter, strength of geotextile), deformations prognoses and proof of stability were determined through demanding numerical and analytical calculations. The diameter of columns designed was 80 cm. It was installed by vibrating steel pipes of diameter 80 cm and double base flaps down through the soft soil into the natural foundation. The pipes were driven by variable hydraulic vibrators with a frequency between 30 and 40 Hz. Also the weight and additional pre-stress influence on it’s driving. Used geotextile had radial tension strength of 200 kN/m and 400 kN/m at the core of the dike.
3 CALCULATIONS.

For the project both analytical and numerical calculations were proceeded.

3.1 Stability calculations.

The stability was calculated according to the different steps of loading. The first layers of sand were not more than 0.3 m thick under water, because of the undrained sheer strength of 0.5 kN/m². Since the installation of vertical drains the shear strength increased in relation to the following degree of consolidation.

\[ \tau = U \cdot (\tan \varphi \cdot \sigma + c) + (1 - U) \cdot c_u \]  \( (1) \)

This calculation was necessary and approved in all fill steps in combination with drains. In vacuum areas were no critical stages of stability.

3.2 Settlements calculations.

The Consolidation processes were predicted after Carillo / Barron settlement theory. The Ménard program TARAO was adapted to make calculations for eight different layers and load steps. The spacing of the drains and height of the fill was calculated immediately before the execution. Careful investigations and laboratory tests had been basis for a good prediction of results. By the field monitoring it was possibly to calibrate the soil parameters for the calculation process. All the experience was present for the calculation of the last 66,000 m² vacuum block. Two targets were followed: 0.15 m settlement criteria and saving sand of surcharge (see fig. 4).

4 SETTLEMENTS MONITORING.

Different monitoring systems like pore pressure measurement, ground water levels, horizontal and vertical inclinometers, vacuum pressiometers and settlement plates were installed.

Several settlement plates were installed at the equivalent investigation point of settlement prediction in the vacuum area. In figure 10 is the comparison of settlement prediction and measured settlements in one typical example of the vacuum block. The first settlements appear already through the first fill placed on the mud. The measurement and prediction start in the elevation of the working platform for vertical drains. The first settlements of 0.6 to 0.8 m were measured by analyzing cone penetration from the working platform. With that information the theoretical and practical values start at the same elevation with the vacuum. The monitored vacuum process fit to the predicted vacuum and dewatering effect of 80 kPa. The average total settlements were with 2.8 to 3.0 m around 10 % lower than predicted. The residual primary and secondary settlement are now 4 years later with a maximum 0.08 m on the largely less than the required 0.15 m settlement criteria.

Fig.8. GEC design concept.

Fig.9. Calculated settlements.

Fig.10. Comparison between predicted and measured settlements.
5 EXECUTION.

The first phase was the treatment of a 120 000 m² platform, covering 10% of the total area, on which the first factory buildings were to be built as early as possible. A 15 m wide intermediate dike was constructed forming a basin in which the water level varied between 0 and 2 m depending on the tide, to contain the area to be treated. Möbius Company placed a 2.5 m thick layer of hydraulic fill to act as a working platform. Menard then drove vertical drains down to a depth of 15 m, to reach bedrock. A total of 6 million meters of drains were installed, in 500 000 points set out on a 0.5 x 0.5 m grid. This very close grid was chosen to enable fast soil consolidation and to respect the defined absolute residual settlement criterion of less than 30 cm. Menard also used the MVC atmospheric consolidation method for the area adjacent to the dike and the rest of the basin that will be treated in a second phase, mainly a 26 m long strip (20 000 m²). This technical choice was made to prevent a soil failure close to the dike while placing the 6 m thick fill on the drained platform. However, the use of the MVC necessitated a modification to the terrain adjacent to the intermediate dike. The presence of a 1 m thick permeable sand lens under the area to be consolidated, the intermediate dike and the rest of the basin, made it impossible to create a vacuum and would have made the MVC process inoperative. Therefore, this layer had to be isolated. Menard had three alternative solutions to achieve this, firstly to create a vertical plastic membrane over the entire depth of the site down to bedrock, to inject grout, or to make a sealed wall. The first two techniques were too expensive or too difficult to apply on this site and were abandoned. The selected technique was a flexible and sealed wall and had the advantage that it was easy to implement and inexpensive since materials on site could be used. This wall was made by mixing in situ, mud, clay and sand, plus bentonite over the 8 m soil depth. This solution produced a 30 cm thick sealing layer, so that the MVC membrane could be installed to result in perfect water tightness. This efficient treatment was successful, since more than 1 m of settlement was observed only three weeks after construction of the vertical drains! The second phase of the work covered a larger area (1 200 000 m²), and included 30 million of meter drains to be installed at a larger grid than the first phase, since the settlement time can be longer (the last buildings will be constructed in 2007). The MVC was also used in the second phase in the crossing of the runway. The MVC was the only way of guaranteeing an absolute residual settlement of less than 15 cm in 5 years as specified by the client.

6 SITE ORGANIZATION.

This site was exceptional by its size, and also by the organization and the human resources mobilized. A genuine challenge in itself, that required about a hundred workers working six days a week from 7:00 in the morning to 8:00 in the evening. Menard teams worked on the design and defined an optimized organization, before the work started. It was decided to set up an “industrial production site” to achieve the rates necessary to meet the extremely short completion time and due to the size of the site. The machines and masts were selected and adapted at Menard’s head office in Nozay, France. The machines were chosen to satisfy two criterions: a low specific bearing pressure (ratio between the machine weight and power) and to respect the maximum allowable pressure of 0.07 MPa on the soil, this was achieved by widening the tracks and by modifying hydraulic flow rates. A total of 18 machines were prepared with masts specially
designed and fabricated. A team of 3 people (one operator and two drain cutters workers on each machine) were insuring the production. Operations are closely computer controlled to ensure the masts remain perfectly vertical and all parameters are recorded in a database to provide the client with a genuine quality commitment. These major human and technical resources enable the production of a 180 000 meters of vertical drains per day, which corresponds to an average of 12 000 to 15 000 points per day.

7 SUMMARY.
The reclamation works consisted of reclaiming and improving an area as large as 1,320,000 m² involving the reclamation of more than 12,000,000 m³ of fill. Thanks to combined application of Vertical Drains, Ménard Vacuum Consolidation and Geotextile-Confined Columns (60000 columns of 80 cm diameter and length 6-15m) soft soil’s conditions could be improved enough for stability of the fill which had to be placed. This contributed to reduce surcharge height needed to speed the consolidation process. Maximum measured settlements were 2.8m smaller then calculated. Conditions of the site were difficult, not only by the nature of soil but also client’s criterions, and time limitations. The final level to be reached after reclamation was 6 m above the existing level. Effort of design and site teams made and optimized soil improvement techniques this possible.

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