Proceedings of the 21st ICSMGE, Vienna, Austria, 14 – 19 June 2026. Pistrol, Adam & Schweiger (eds.)
Published by: ÖGG, Austrian Society for Geomechanics, Salzburg, Austria, ISBN 978-3-9503898-4-5
https://doi.org/10.53243/ICSMGE2026-109

Influence of subsoil geometry interpolation on embankment settlement

Johannes Beck, Sascha Henke
Professorship for geotechnics, Helmut-Schmidt-University Hamburg, Germany, beckjo@hsu-hh.de

ABSTRACT: The three-dimensional (3D) modeling of subsoil conditions is becoming increasingly important with the growing adoption of Building Information Modeling (BIM) in geotechnics. This trend is expected to be further reinforced by the upcoming requirement for geomodels in the next generation of Eurocode 7. A widely used approach for 3D subsoil modeling involves using interpolation algorithms to generate surfaces from scattered data points. These surfaces, when intersected with the project volume, result in a volumetric representation of subsoil layers. The choice of an interpolation method directly impacts the calculation model, as it is assumed to align with the 3D subsoil model. However, there is a notable research gap regarding the quantitative effects of different interpolation methods. This study investigates how various interpolation methods used in subsoil modeling influence the calculated settlement behavior of embankments. To consider the distribution of borehole data and stratigraphic variance, subsoil investigations from five projects are used in the 3D subsoil modeling using five different 2D-interpolation methods. For each scenario, soft soil volumes under an embankment with constant profile and settlements along its alignment are evaluated; in total at over 2500 sections. A simplistic, analytical approach is utilized for settlement prediction. The analysis shows that the interpolation method significantly impacts the calculation results and hence the geotechnical design. Therefore, engineers should pay attention to the selection and calibration of interpolation methods.

KEYWORDS: Interpolation, embankment, settlement, automation.

1 INTRODUCTION

Information-rich, three-dimensional (3D) models are the foundation of Building Information Modeling (BIM) which is increasingly adapted in the field of geotechnics. A three-dimensional representation of the subsoil conditions is also a form of geomodels required by the upcoming generation of Eurocode 7.

A 3D subsoil model is an interpretative model considering knowledge from desk study, experience and site investigation. There are several approaches to convert previously described data points into a geotechnical 3D model. The approaches can be differed by geometry types used to represent the subsoil or the method used to generate the model, see (Hubert, 2011; Stumpf *et al.*, 2021). The choice depends on geological conditions, experience of the modeler, limitations of the chosen software package and other project specific conditions. A very common approach is to define points on a geological surface with following application of an interpolation algorithm to obtain surfaces. The surfaces are then used to generate geological volumes. Geological history is usually considered by means of the intersection sequence.

Different modelling methods and interpolation models lead to varying subsoil models. (Batista & Concalces, 2020) generate subsoil models for the same project area using manual modelling based on interpreted cross-sections, a geostatistical approach using indicator kriging and an implicit approach. The authors found significant differences in rock volume quantity. (Hubert, 2011) compares different modeling approaches and investigates their influence on ground water simulations. Based on a major case study considering 114 boreholes and an area of appr. 16 km², significant influence on flow fields is found.

Hence, the interpolation method has an influence on the subsoil model geometry, which then is used to generate analysis models, an inherent influence on the analysis results can be deducted. Yet, there is a lack of quantification in literature. Therefore, the present research aims to get some indication of the influence of interpolation algorithms on geotechnical analysis results considering the problem of settlements of an embankment on soft soil. There are numerous factors that impact settlements besides geometry, such as soil and groundwater conditions, loading conditions as well as the calculation method and model. These factors influence each other; an edge case arises if all soil layers have the same properties, which leads to no influence of the interpolation of soil layer boundaries on the calculation results. Therefore, the influence of subsoil geometry interpolation significantly varies between projects and soft soil thickness alone is not sufficient to evaluate the implications of different interpolation methods on settlements and their differences, which are relevant for design. This study provides a methodology that can be applied to ambiguous embankment projects. Besides, an estimate on the influence of the interpolation method is given based on five adapted real-world sites considering ground conditions typical for northern Germany. This supports the decision, if and at which stage the uncertainty introduced by the interpolation algorithm should be considered. The study addresses the way calculation models are set up, but it does not compare the performance of different calculation models based on measurement data. Such comparisons are out of scope as the predicted settlements are not measured in the projects used as ground improvement measures are taken and significant model simplifications with higher influence on the calculation results than the interpolation method are made, e.g. on loads, stiffness parameters and their distribution as well as embankment geometries. The accuracy of interpolation methods is best evaluated using additional data of the predicted values, e.g. using cross-validation techniques and/or obtaining data during construction.

2 SUBSOIL MODELS

2.1 *Project description*

The five investigated sites are located in northern Germany. The subsoil conditions across the selected projects are comparable. The present geology is dominantly formed by glacial processes resulting in depositional and erosional patterns. The topography is almost flat while groundwater levels are close to ground level. The dominant soils are stiff, (semi-) load bearing boulder clays and organic peat layers on top of them. Minor soil types, e.g., sand lenses, are neglected in this study.

The three-dimensional ground investigation models represent the investigations as well as interpretations in the Ground Investigation Reports (GIR). Figure 1 illustrates the ground investigation model of one project with a vertical exaggeration factor of 3. Pink color indicates peat, while purple is used for boulder clays (color coding according to DIN 4023, pink instead of brown for better visualization). Table 1 shows the number of boreholes, the drilling meters and the number of interpreted layers. Information on location, groundwater measurements, primary and secondary soil types, consistency, drilling process and further soil properties and meta-data are assigned to the objects, such that typical requirements on information models are met.

For each project, the main alignment curve for the planned embankment / transportation infrastructure is extracted. The planar projection on the horizontal plane is the guide curve for the extrusion representing the embankment. A fixed embankment profile is used throughout all five projects. It is 4.3 m high with a base width of 26.4 m. The main slope is 1:1.8, accordingly the top slope is 1:20. The ends of the embankment are angled as well, though this is not of further relevance for this study. The cross-section represents an estimated average of what was built on these sites.

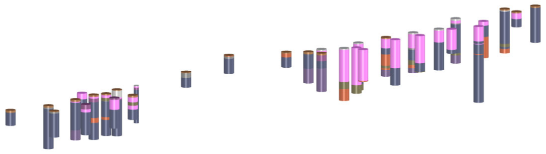

Figure 1. Ground investigation model of project 4.

Table 1. Overview of the ground investigation models.

Project	Boreholes	Dilling meters	Interpreted layers
1	17	141.0	103
2	23	206.9	125
3	17	148.2	96
4	34	403.7	232
5	42	538.5	336

2.2 *Interpolation*

Five 2D-interpolation methods are considered, meaning that horizontal coordinates are used to estimate the elevation, here of points on the horizon between the soft soil and the load bearing layer. Therefore, a 2.5D-surface, each location in the horizontal plane has one elevation assigned, is obtained. Complex geological geometries, such as thrust faults, cannot be represented accurately using a 2,5D-surface, see (Wellmann & Caumon, 2018) for more details. For the investigation projects, the soil horizons can be represented by such 2.5D-surfaces due to the erosional and continuous nature of the relevant subsoil.

The first method is Nearest-neighbor interpolation (NN). The algorithm does not consider the values of neighboring points at all, yielding a piecewise-constant interpolant. The modeling space is decomposed into cells using the Voronoi diagram, after which the elevation of its enclosed point is assigned to each cell.

The second approach is Delauny-Triangulation (DT). The convex hull of the interpolated points is subdivided into triangles whose circumcircles do not contain any of the points. Points close to a convex hull edge might cause sliver triangles and normal vectors, that do not fit geological surfaces well. If the modeling space exceeds the convex hull, its edges are extruded in the global directions accordingly.

The third interpolation method is Inverse distance weighting (IDW). It assumes explicitly that values that are close to one another are more alike than those farther apart, as the weighted average of the measurements is calculated, wherein the weights are inversely proportional to the power of the distance between calculation point and measurement locations. This method typically leads to smooth surfaces with a tendency of spikes at local extrema. Throughout the models, the inverse distance power is set to 1 (inverse relationship), all points are considered. This leads to rather smooth surfaces with overaccentuated peaks at extrema, that do not necessarily match erosional patterns considering the data point density. This setting is chosen to highlight the behavior of this interpolator; an appropriately increased distance power value rounds the peaks.

The fourth method is a radial basis function interpolator (RBF). RBF works by instantiating radially symmetric kernels centered at the measurement points. The weighted sum of these basis functions is evaluated, where the weights are determined by fitting the known data values. RBFs tend to produce smooth surfaces and can return values exceeding the extrema of the measurement data. A cubic base function is selected, and all points are considered.

The last method considered is Ordinary Kriging (OK). Within this geostatistical method values are estimated based on a weighted average of known data, where weights are derived from the spatial autocorrelation structure described by a variogram. A constant, but local mean is assumed. An exponential variogram is used. For simplicity, and as the data from some projects is very sparse, its parameters (sill, range, nugget) are fixed across all models. Kriging methods are very sensitive to variogram parameters, highlighting the importance of their validation in application. For a comparison of RBF and OK within geological modeling context refer to (Sanches & Deutsch, 2022).

The interpolation points, that are on the horizon between soft soil and load bearing layer, are manually selected based on the interpretation of the drillings. There is a maximum of one point per borehole. If no soft soil is found within a borehole, it is manually evaluated whether the theoretical horizon is above the borehole's top or below its end. If above, a theoretical value with the elevation of ground level + 2 m is assumed. Values below are omitted if the interpolated surface does not intersect the drilling path, which is given for all occurrences in the projects investigated. In horizontal direction, the models are 20 m wider in all directions than the maximum extent of the alignment curve.

A regular grid with uniform element size of 1 m is used for IDW, OK and RBF. The resulting point grids are used to construct smooth surfaces, with a tolerance distance of 1 mm. Areas above the assumed ground level are trimmed using the topography. This study does not compare different interpolation methods regarding their suitability to realistically depict the expected subsoil geometry, which would require calibration of the interpolators´ parameters and further validation data, but investigates the impact of interpolator choice in the setup calculation models, typically used in early design stages.

3 MODEL ANALYSIS

3.1 *Soft soil volumes*

The soft soil layer is decisive for the expected settlements and the ground improvement needed. To gain insight into its spatial distribution, volumes are evaluated. The overall soft soil volumes are influenced by the extrapolation behavior of lesser practical implications. Therefore, the soft soil volumes underneath the embankment are investigated. These volumes can be interpreted as base quantities if soil exchange is considered.

Each alignment is subdivided into 100 segments. Within each project the distance segment lengths are constant but vary between projects as the alignment extents differ. Each endpoint

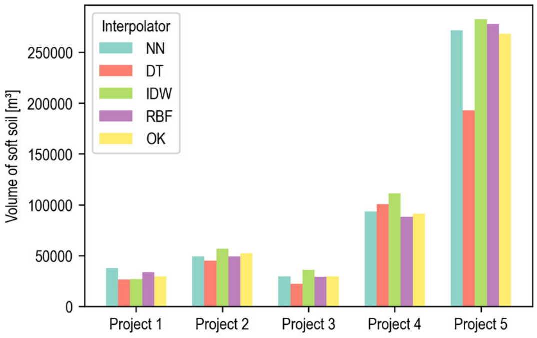

Figure 2. Total volume of soft soil underneath the embankment.

forms the origin of a cutting plane, whose normal vector is the tangent of the alignment at this point. The resulting solids are algorithmically as well as manually inspected, artifacts from the Boolean operations are fixed. Figure 2 shows the total volume of soft soil underneath the embankment for all five projects. The volumes within the projects significantly vary between different interpolation methods. The largest volumes are between 26 % (projects 2 and 4) and 60 % bigger (project 3) than the smallest ones.

A more detailed view on the volumes of soft soil under the embankment is shown in Figure 3. The abscissa shows the curve sections along the alignment. The colors in this heatmap indicate the ratio of soft soil to the total modelled soil volume. The values are normalized to 0 and the maximum ratio found in any interpolation method within a project.

Throughout the projects, major deviations at the ends of the investigated alignment are observed. This is due to the lower density of boreholes in these areas. In many cases, a singular borehole is placed well after the alignment begins. The strong averaging effect of the chosen parameters for IDW is particularly highlighted in project 2, 3 and 5, where other interpolators tend to estimate very low proportions or no soft soil, while IDW returns significant values. OK behaves similarly, but less accentuated. In project 5, the estimated volumes of the first section of the embankment by DT are far lower compared to the other algorithms. The reason for this is that the first borehole is 23 m off the embankment axis due to accessibility reasons and another borehole close to the other end is 78 m offset towards the other direction. These two form an edge of the convex hull. By applying the described extrapolation procedure, a basically unrelated data point at the other end of the project determines the estimated soil profile.

3.2 *Settlement analysis*

In the following section, the expected settlements generated by the construction of the embankment are investigated. Therefore, cross-sections are derived from the subsoil models using the planes described in section 3.1, which are then cleaned up for further processing with a maximum deviation of 1 cm. The settlement analysis is conducted for each cross section. The stress-strain calculation method is used to evaluate total settlement. The stress distribution in the ground due to loading from the embankment is computed based on elastic theory, assuming homogeneous isotropic soil using super-position of the solutions for triangular and rectangular loads found in (Poulos & Davis, 1974). The integration of vertical strains is approximated by discretizing the soil into sections, such that within a soil layer all sections are equally sized, the soil layers are on a section edge, and the maximum section size is 0.5 m. The vertical stress is evaluated at the center of each section. The chosen resolution in horizontal direction is 1 m, while considering additional points of interest. Young´s modulus is chosen to be $E_{S1} = 400$ kN/m² for the soft soil layer and $E_{S2} = 10'000$ kN/m² for the load bearing layer without depth dependency throughout all projects.

The calculated settlements at the center of the embankment are visualized in Figure 4. The abscissa shows the curve sections along the alignment from start (left) to end (right). The colors in the heat map indicate the calculated settlement in relation to the maximum settlement obtained within the project using any interpolator. The calculated settlements in Figure 4 and the volumes in Figure 3 are visually similar, as both primarily depend on the thickness of the soft soil layer. As all sections have a constant extent in vertical direction, the portion of soft soil underneath the embankment correlates with the settlements, e.g. the settlement in project 5 is the highest due to the large volume of soft soil under the structure. Yet, for the settlement calculation shown at the center of the embankment only the soil layer depth under this point is considered while for the volume calculation the spatial distribution of depths within

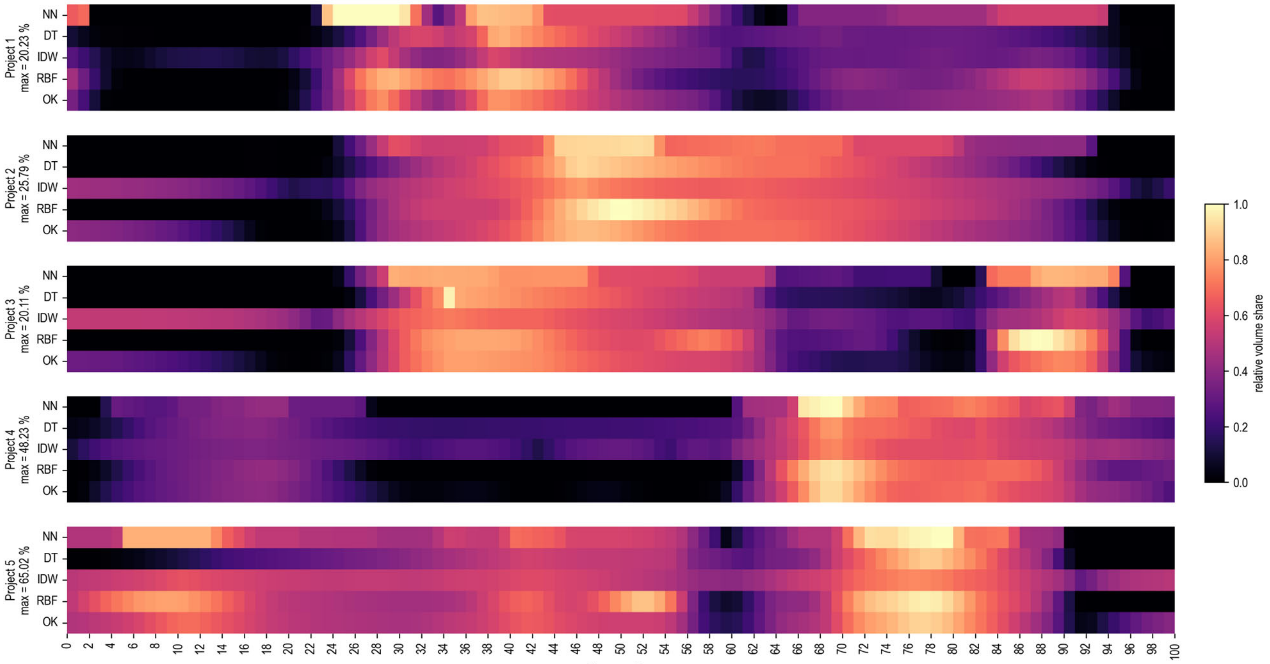

Figure 3. Proportion of soft soil underneath the embankment.

the section is captured. The implications show best in the NN interpolation, that returns hard stepped settlements.

The difference in settlements within the projects introduced by the interpolation algorithm is significant. Table 2 shows the maximum settlement at the embankment center line for the investigated interpolation algorithms. The difference between minimum and maximum ranges from 10 % in project 4 up to 50 % in project 3. With increasing soft soil thickness, the influence of the interpolator decreases, as the stress reduces with depth and therefore the soil closer to the surface has more impact on the calculated settlements. In project 3, the maximum settlements of the RBF-interpolated models exceed the settlements of the NN-model by 28 %. In the affected area, the interpolated values exceed the bounds of the input data points. Therefore, it is insufficient to consider the most unfavorable borehole solely, when deriving decisive cross sections or calculation models from a subsoil model that utilizes an interpolator with that property.

Table 2. Maximum settlement [m] at the embankment center along the alignment for different interpolation algorithms

Project	NN	DT	IDW	RBF	OK
1	1.32	1.11	0.99	1.33	1.14
2	1.52	1.47	1.26	1.60	1.44
3	1.05	1.02	0.89	1.34	1.03
4	2.78	2.65	2.53	2.71	2.65
5	3.36	3.21	2.88	3.28	3.20

4 CONCLUSIONS

Within this study, five projects of embankments on soft soil with comparable subsoil conditions were considered. Five 2D-interpolation algorithms (NN, DT, IDW, RBF, OK) were used to generate subsoil models. Each of the 25 models was evaluated regarding the volume of soft soil underneath the embankment as well as the settlement at the embankment center. It is found that the interpolator choice has significant influence on the results, hence on the possible improvement measures to be taken. For this, settlement calculations need to be conducted as in this study, the different layer geometries only provide a qualitative indicator.

Geotechnical engineers and others working with comparable models should be aware that the choice of the interpolation method is a source of uncertainty and that it can have decisive influence on the calculation model and hence the design. Therefore, the interpolation methods shall be carefully chosen and calibrated considering project data and model objective. Special attention must be paid to the areas of inhomogeneous data density and extrapolation.

This study is limited by the choice of projects, choice and calibration of the interpolation methods as well as the simplistic approach to estimate settlements. Further studies should consider numerical methods and more systems, e.g. considering geosynthetic encased columns and more complex subsoil geometries, for calculation. If the soil is exchanged, the bottom of the soft soil should be mapped to evaluate the prediction of interpolators for the present conditions.

5 ACKNOWLEDGEMENTS

We thank BBI Geo- und Umwelttechnik Ingenieurgesellschaft mbH for providing drilling data and reports of real-world projects.

6 REFERENCES

Batista, J.D. & Concalces, I.G. (2020) Comperative analysis between geological modelling methods. *Iberoamerican Journal of Applied Computing*, 10(1), 22–41.

Hubert, T. (2011) *Methodische Ansätze zur geologischen 3D-Modellierung oberflächennaher Schichtenfolgen und ihre Auswirkung auf die numerische Grundwassermodellierung*. Dissertation. Martin-Luther-Universität Halle-Wittenberg.

Poulos, H.G. & Davis, E.H. (1974) *Elastic solutions for soil and rock mechanics*. Wiley: New York.

Sanches, S. & Deutsch, C.V. (2022) Domain Delimitation with Radial Basis Functions. In: Deutsch, J. (Ed.) *Geostatistics Lessons*.

Stumpf, A.J., Keefer, D.A. & Turner, A.K. (2021) Overview and History of 3- D Modeling Approaches. In: Turner, A.K., Kessler, H. & van der J Meulen, M. (Eds.) *Applied Multidimensional Geological Modeling.* Wiley, pp. 93–112.

Wellmann, F. & Caumon, G. (2018) 3-D Structural geological models: Concepts, methods, and uncertainties. In: Schmelzbach, C. (Ed.). Elsevier, pp. 1–121.

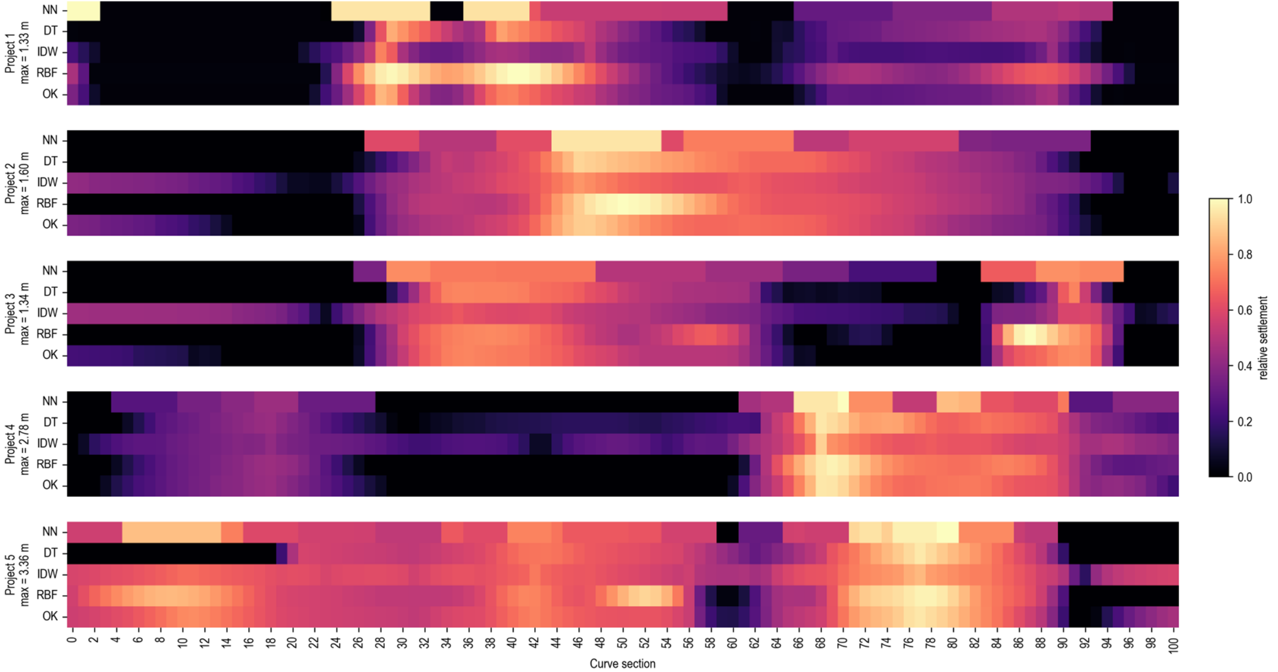

Figure 4. Relative settlement at the center of the embankment.