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# The Saudi Landbridge Project: the geotechnical model and the design solutions

## Le projet Saudi Landbridge: le modèle géotechnique et les solutions de conception

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**ABSTRACT:** The Saudi Landbridge is a railway project developed by Italferr S.p.A. The railway line will connect the city of Jeddah to Al Jubail, and it'll be aroung 1.300 km long.
After the description of the multimetodology investigation to define the geotechnical model and the geotechnical risks, the present paper describe the construction of the 3D geotechnical model by the Rockworks software and the design advantages that could be obtained in similar works, using 3D geotechnical model

**RÉSUMÉ:** Saudi Landbridge est un projet ferroviaire développé par Italferr S.p.A. La ligne de chemin de fer reliera la ville de Jeddah à Al Jubail et aura une longueur de 1300 km. Après la description du levé multiméthodologique pour la définition du modèle géotechnique et des risques géotechniques, le présent document décrit la construction du modèle géotechnique 3D à partir du logiciel Rockworks et les avantages de conception pouvant être obtenus dans des travaux similaires, en utilisant un modèle géotechnique 3D

**Keywords: geotechnical model, railway line, geotechnical investigation, geotechnical risks**

## 1 INTRODUCTION

In order to correctly plan the geotechnical investigations and to develop the geotechnical model, a preliminary analysis of the geological and geotechnical risks along the railway line fundamental.

Already during the analysis of the feasibility, the identification of the risks allows to immediately exclude critically area or to optimize the necessary investigations.

In fact, the design technical choices, the total cost of the work as well as the construction time are all elements that depend on the reliability of the geotechnical model. In summary it can be stated that:

- an excessively precautionary geotechnical model leads to oversized work and higher costs;
- a geotechnical model with too many gaps and / or hypotheses can have a strong impact on

the unexpected and therefore on the time of realization and on the total cost of the work.

These were the starting points for the Saudi Landbridge Project, the geotechnical model was developed on the basis of multimethodological survey campaigns according to the project needs. Finally, considering that in nature all geological, geomorphological, hydrogeological and geotechnical structures are three-dimensional, the geotechnical model was developed in 3D.

## 2 RAILWAY LINE DESCRIPTION

The Saudi Landbridge Project consists of about 1300 km of double-track railway line, freight and passengers, which, as mentioned, will across Saudi Arabia, connecting Jeddah - Red Sea - with Al Jubail - Arabian Gulf, crossing the capital Riyadh, *Figure 1*. The maximum design speed is 350 km / h for passenger trains, and 160 km / h for freight trains.


*Figure 1 Section 2 General Map*

The project has been divided into two sections:

- Section 1 from Jedda (on the Red Sea) at about 271 km;
- Section 2 from km 271 to end of section 1288 km . This section is analyzed in this paper

Along the line, flat areas, outcrops of magmatic rocks, sedimentary rocks (granular and limestone) more or less fractured and altered, desert areas and dunes areas, alternate.

The main works along the railway line are summarized:

- 138 viaducts for a total length of 138 km;
- 11 overpasses;
- 6 cut & covers to overcome areas of mobile dunes;
- about 104 million m3 of excavations for the construction of trenches;
- about 132 million m3 of material required for the construction of embankments, maximum height 15m;
- about 260 km of desert areas with over 35 km of mobile dune areas.

## 3 PRELIMINARY ANALYSIS OF THE GEOLOGICAL AND GEOTECHNICAL RISKS

Preliminary analysis of the geological, geomorphological and geotechnical bibliography, as well as those of aerial and satellite photographs and, lastly, the on-site inspections allowed to identify geological and geotechnical risks in the corridor where the new line project was developed. Risks can be grouped into the following main categories:

- Wind transport of sand and mobile dunes, *Figure 2*, *Figure 3*, *Figure 4*: in these areas there are loose sandy soils, not very thickened and, in some sections, medium-high mobile dunes. Sand carried by the wind has a significant impact on the railway infrastructure. Therefore, in the development of the project it was necessary to analyze the geomorphology of the places, characterize the direction and strength of the wind, the amount of sand transported, the length of the mobile dunes and the degree of cementation of the soil in order to design interventions to mitigate the the effect of sand on the railway infrastructure and works to overcome the mobile dunes.

*Figure 2 Blowing sand on NSR Project Segment 7 close to Al Jubail area*

*Figure 3 Sand dunes at ch. 831+000*

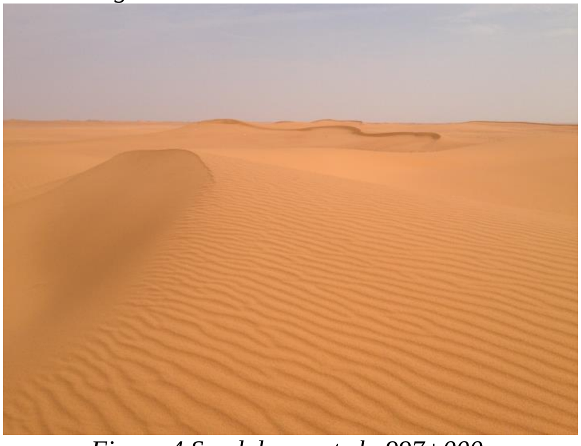

*Figure 4 Sand dunes at ch. 997+000*

- Soils with poor geotechnical characteristics, *Figure 5*, *Figure 6*: the presence of Sabkha was detected along the east coast near Al Jubail, and in the internal areas of the Arab Shield, where they are formed by rain, with high concentrations of dissolved salts. The Sabkha is a salt's crust discontinuous while the underlying soil can have variable density. In the presence of sabka there could be subsidence phenomena due to both the dissolution of the salts that compose it and the thickening of the underlying soils.In these situations the investigations must allow to define exactly the thickness of the crust, the type, the geotechnical characteristics, with particular regard to the depth and the excursions of the water table, as well as the extensionof the affected areatension and the stretch. of the affected route.

*Figure 5 Example of sabkha soil in Al Jubail area*

*Figure 6 Example of sabkha soil in depressed areas in the Arabian Shield*

- Floods, *Figure 7*: these events occur in wadi areas. In this environment, in the absence of vegetation, intense events lead to a high erosion of wadi and the slopes.

*Figure 7 Example floods*

- Slope instability (rock falls), *Figure 8*: this phenomenon occurs in stratified sedimentary rocks due to their different degree of alterability and erodibility. All the studies and surveys necessary to design stabilization and protection interventions were carried out for the development of the project.

*Figure 8 Example rock falls*

## 4 THE MULTIMETODOLOGICAL SURVEY CAMPAIGN IN ORDER TO BUILD A RELIABLE GEOTECHNICAL MODEL

The survey campaign (surveys, geological and geomechanical surveys, trial pits, geophysical surveys) was set up to allow the reconstruction of a 3D geotechnical model.

The activities were carried out according to the following procedures:

- collection and analysis of geological, geomorphological, hydrogeological and geotechnical data available on the arabian peninsula, with particular reference to the corridor on which the new railway line was to be designed;
- inspections along the line to identifyd geological risks, the geomorphology, the trend and characteristics of the geological structures, drainage surfaces and outcrops;
- planning, planning and execution of surveys and surveys for the various design phases

Overall, in the 2 phases, Preliminary and Detail Design, 983 continuous drilling surveys were carried out for a total of about 22,000 meters of drilling, 2,448 trial pits, about 70,000 meters of geophysical surveying, 1,688 geological, geomorphological and geomechanical surveys: 1783 grain size, 1361 UCS, 1145 chemical analysis 892 point load, etc., have been performed.

The geological and geognostic surveys have been divided into 3 lots that coincide with the 3 different geological situations. *Figure 9* shows the details of the investigations carried out in the individual lots for the individual design phases of Preliminary (PD) and Detail (DD) Design, which began in October 2015 and ended in August 2016. In the first 3 months the surveys and the first geological, geomorphological and geomechanical surveys were carried out for the Preliminary Design. The surveys have been carried out inside the corridor approved by the Saudi government.

The first 3D reconstruction have allowed to define spatially the geological stratigraphic contacts, important to define the risks analysis, as well as to provide an important contribution for the definition of the railway line.

In the Detail Design after additional investigations the 3D model have been completed and checked whit geophysical surveys.

The geotechnical profiles have been obtained from 3D geotechnical model, importing the railway track within the model itself and "cutting" the solid of the soil along the project axis. In *Figure 10* and *Figure 11* two examples of obtained solid are shown and the respective profiles extracted.

| | | Lot 1: km 271 - 686 | | | Lot 2: km 686 - 962,5 | | | Lot 3 km 962,5 - 1290 | | | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | PD | DD | Tot. | PD | DD | Tot. | PD | DD | Tot. | |
| Boreholes | Compl | 125 | 212 | 337 | 124 | 222 | 346 | 121 | 179 | 300 | 983 |
| | Lin. Met | 2357,07 | 4292,77 | 6649,84 | 2954,10 | 5081,49 | 8035,59 | 2547,06 | 4565,99 | 7113,05 | 21798,48 |
| Trial Pits | Compl | 0 | 1409 | 1409 | 0 | 473 | 473 | 0 | 566 | 566 | 2448 |
| CPT | Compl | - | | | - | | | 0 | 22 | 22 | 22 |
| Seismic refraction (m) | Compl | 5274 | | | 6575 | | | 765 | | | 12614 |
| Geoelectrical surveys (m) | Compl | 5398 | | | 0 | | | 0 | | | 5398 |
| MASW survey (m) | Compl | 0 | | | 28460 | | | 22670 | | | 51130 |
| DownHole (n°) | Compl | 5 | | | 4 | | | 5 | | | 14 |
| Geological, Geomorphological and Geomechanical surveys (n°): | | 575 | | | 555 | | | 538 | | | 1668 |
| Site descriptions | | 544 | | | 534 | | | 528 | | | 1606 |
| Geomechanical stops | | 22 | | | 15 | | | | | | 37 |
| Area descriptions | | 9 | | | 6 | | | 10 | | | 25 |

*Figure 9 Number of the geotechnical investigation*

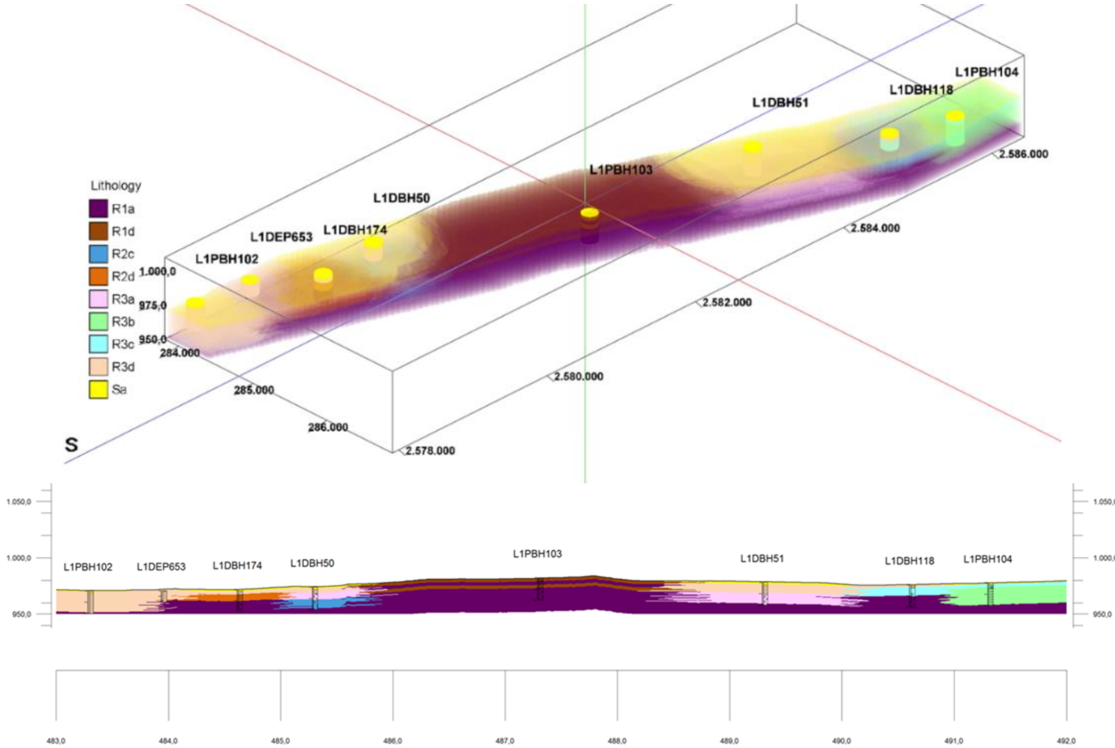


*Figure 10 Geotechnical 3D model pk 483_492 Saudi Landbridge Project*

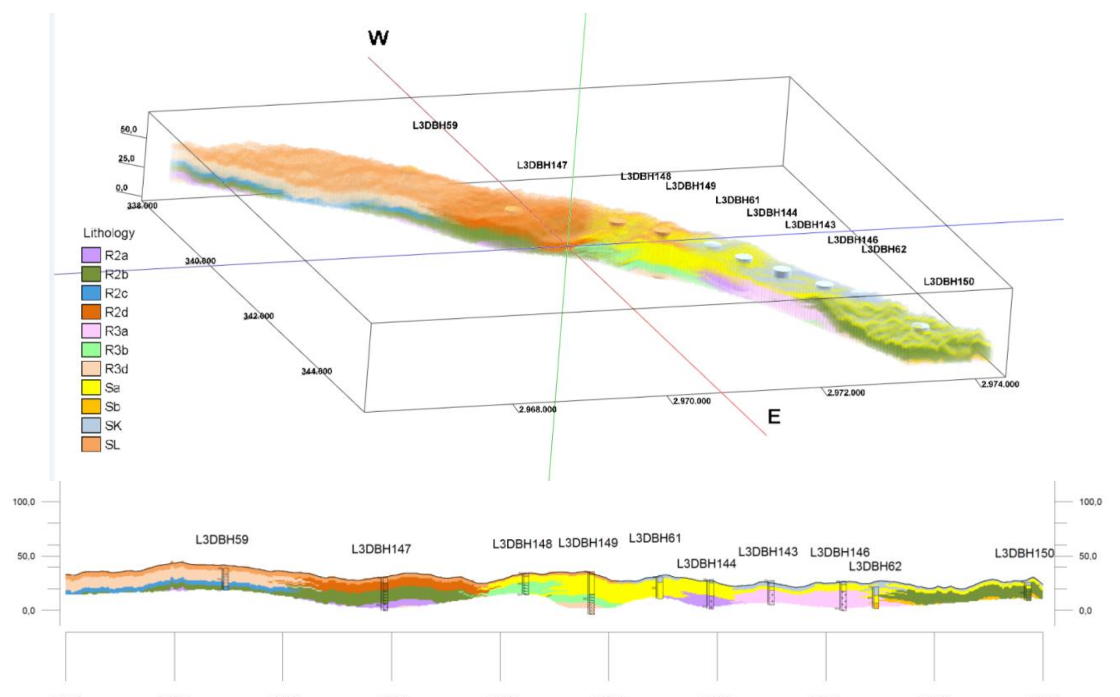


*Figure 11 Geotechnical 3D model pk 1264_1273 Saudi Landbridge Project*

## 5 THE ADVANTAGES OF THE 3D GEOTECHNICAL MODEL IN THE LANDBRIDGE PROJECT

The construction of a 3D geotechnical model has enabled:

- to use all the data acquired through surveys, trial pits, geological and geomechanical geomorphological surveys, penetrometric tests and geophysical surveys, even if not positioned along the railway line;
- to highlight the lithostratigraphic situation also for areas not easily investigated with classical techniques;
- to use the investigations realized off-axis to define the geologic strucutres. Long the railway line, crests of outcropping rocks meet in NE-SW direction with interclassed depressed areas filled with loose soils.

## 6 CONCLUSIONS

In order to achieve a correct geotechnical model, a quality investigation process must be set up. This quality process must be set starting from the surveys: the clarity of the client, the collaboration between various professional figures, the correct communication between the parties, the correct design of the survey campaign on the basis of the specific problems,
sufficient documentation of tender /initial, correct execution and monitoring of investigations, adequate resources, correct and timely data transmission, clarity and correctness in the return of data. In the Landbridge project, we tried to follow this directions with the purpose to create a reliabe geotechnical model, looking for a careful initial analysis to identify the risks integrating data where necessary.

In general, 3D representation methods could be useful in landslide areas, areas affected by complex geological contexts, areas where the development of the infrastructure is mainly areal rather than linear.

In addition, the 3D model allows the use of existing surveys even if "distant" from the preliminary railway track, providing important information even during the feasibility analysis phase, when the surveys dedicated to the project have not yet been carried out.

Where the execution of surveys in axis with the project should be complex for particular situations, such as the mobile dune areas in the Landbridge project, the 3D model allows to use and interpolate all the surveys and surveys carried out, returning a more realistic design stratigraphy.

In the case of uncertainties on the railway plan, in the most complex sections, a 3D geotechnical model, can be used to optimize the railwa track.

The experience of the landbridge makes it possible to affirm that a project developed in this way reduces the uncertainties of the model and probably allows an optimization of costs and time.