Towards performance-based design of Steel Sheet Piles retaining walls in seismic areas

In current practice, steel sheet piling (SSP) retaining wall structures are usually designed using user-friendly calculation tools, based on SubGrade Reaction Models (SGRM) or Limit Earth Pressure Approach (LEM). If seismic actions are to be considered in accordance with Eurocodes, then the same models may be used together with the ground pressure coefficients, according to Mononobe-Okabe (MO) pseudo-static method.

However, the MO coefficients were developed for rigid walls and thus, cannot take into account the flexibility of SSP solutions. This very conservative approach can lead to an unfavourable sheet pile wall design or, in the worst case, lead to the fact that SSP solutions might not be applicable in highly seismic areas.

Therefore a research project, led by ArcelorMittal Global R&D, has been initiated, aiming at promoting an economical and safe seismic design approach for steel sheet piling structures to engineers and port authorities. It is worth noting that marine waterfront structures are the traditional field of application for steel piling products.

In this frame accurate dynamic finite element (FE) analyses were performed and compared to conventional design methods with MO.

A typical case study, using a combined steel sheet pile wall HZ®-M / AZ® (Figure 1), was designed with the help of the two approaches: SGRM with MO coefficients and an accurate dynamic FE analysis.

Figure 1: Cross-section of the sheetpile wall HZ®-M / AZ® utilised for the FE analysis

The results for the dynamic load case (considering a Peak Ground Acceleration PGA= 0.4g at the ground surface) clearly demonstrate that the maximum bending moments are up to 40% smaller when using a dynamic FE model than when using the SGRM model with MO coefficients.

Based on this typical case study it has become clear, that seismic effects are overestimated by current design methods.

HZ-M / AZ combined wall | Maydon Wharf, Rehabilitation of Berth 12, Port of Durban - South Africa (© Stefanutti Stocks Marine)

In a second phase, in collaboration with Professor Gazetas, Athens University, an assessment of seismic loads on a combined steel sheet pile wall (Figure 2) has been carried out with various soils and earthquake intensities to confirm the results of the pre-study.

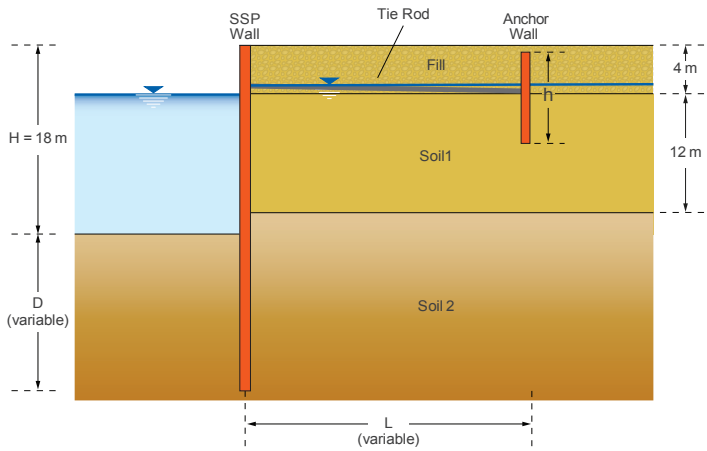


Figure 2: Example of a configuration calculated by SGRM model for different soil cases and acceleration intensities which has been tested by FE analysis

Combined steel sheet pile wall | Tidal Flood Defences River Arun Littlehampton - UK (© High Camera Ltd | UK)

The results have been compared between current design methods with MO and FE analysis, as well as finite differences models, to validate the tools to be used for the (pre-) design of structures.

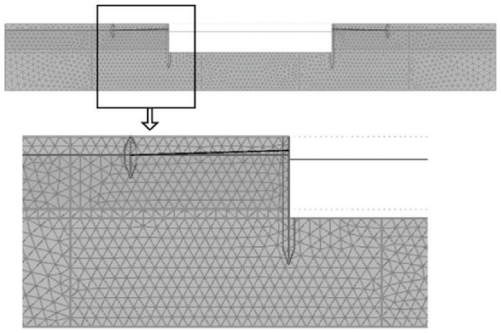
As use of FE models might be time consuming, optimization of the modelisation helped to decrease calculation time.

As a conclusion, bending moments obtained were again significantly smaller with advanced models than with SGRM. Bending moments were not sensitive to FE or finite difference software that was used. With increasing earthquake intensity, displacements however showed more scatter. An outcome of this study is a set of ground motions, fitted to Eurocode 8, to be used for pre-design. These ground motions cover different situations, depending on the intensity and fault mechanism of seismic event.

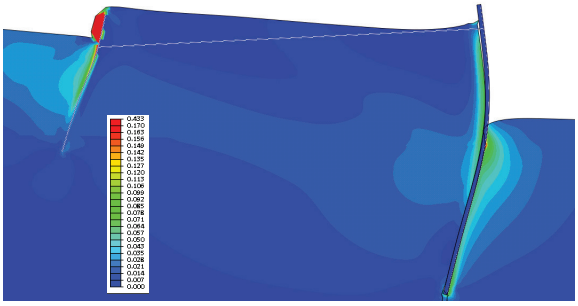
Results of this study have been presented at the 6th International Conference on Earthquake Geotechnical Engineering (New Zealand) and ICONHIC 1st International Conference on Natural Hazards & Infrastructure (Greece). A publication in the Journal of Soil Dynamics contains further details.

Further information and specific design recommendations for a SSP project, in order to account for all needed design verifications for the standard load cases as well as the seismic event together with the corresponding safety approach, are available from our Technical Assistance (sheetpiling@arcelormittal.com).

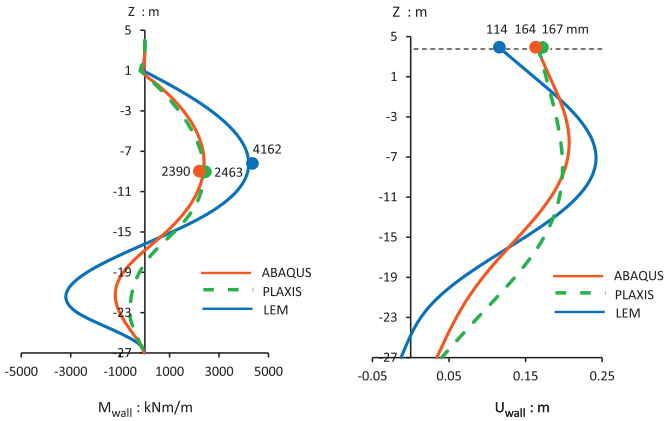
It is to be outlined, that a significant cost reduction in the quay wall can additionally be obtained by moving from the traditional Ultimate Limit State (ULS) approach to a performance-based approach using FE analysis, to benefit from the flexibility of the wall.



Finite element mesh of the examined sheet pile wall (PLAXIS)



Detail of the FE model showing the deformed shape with superimposed contours of plastic deformations (PEMAG)



Comparison of bending moments M_{wall} and displacements U_{wall} for one case analysed with 3 different methods

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