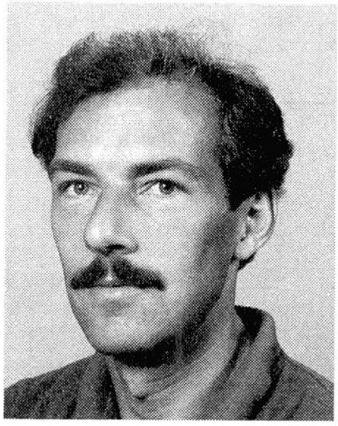
Zeitschrift: IABSE reports = Rapports AIPC = IVBH Berichte
Band: 67 (1993)

Artikel: Is there still life after the lifetime of sheetpiling?
Autor: Toorn, Ad van der
DOI: https://doi.org/10.5169/seals-51368

Is there still Life after the Lifetime of Sheetpiling?
Est-il possible de prolonger la durée de vie des rideaux de palplanches?
Gibt es lebensverlängernde Massnahmen für Spundwände?

Ad van der TOORN
Civil Engineer
State Public Works
Utrecht, The Netherlands



Ad van der Toorn, born in 1951, got his degree at the Technical University Delft. For two years he was working on the Royal Military Academy as a teacher, followed by a five year as project leader on large infrastructural works. Now he is working as researcher partly on the State Public Works and the University of Twente.

SUMMARY

This paper deals with the way in which an existing and so deteriorated structure of sheetpiling can be evaluated. Applying more advanced structural methods than the ones used in the design stage will uncover hidden structural reserves and together with the once more adjusted safety margin it may give a new residual lifetime. To stretch this 'life after death' a range of possible maintenance actions, inclusive 'doing nothing', should be weighted against cost and ectended lifetime.

RÉSUMÉ

Cet article traite de la vérification de structures existantes comportant des réseaux de palplanches dégradés. Il est possible de mobiliser des réserves latentes de résistance, donnant ainsi à ces constructions une longévité supplémentaire, par l'utilisation de méthodes de calcul plus affinées, contrairement aux hypothèses de calcul et aux coefficients de sécurité admis à l'origine. Cette prolongation de durée de vie devrait résulter de la comparaison de mesures d'entretien possibles, y compris de ne rien faire, avec les coûts correspondants et le supplément le longévité ainsi acquis.

ZUSAMMENFASSUNG

Der Beitrag behandelt die Überprüfung bestehender, verfallener Spundwandskonstruktionen. Werden gegenüber den ursprünglichen Berechnungsannahmen und Sicherheitsbeiwerten verfeinerte Nachweisverfahren angewendet, können versteckte Tragreserven für eine neue Restlebensdauer mobilisiert werden. Um sie zu verlängern, sollten mögliche Unterhaltsmassnahmen (entschliesslich der Option der Untätigkeit) gegen die Kosten und die verlängerte Lebensdauer abgewogen werden.

1. INTRODUCTION

All civil engineering structures deteriorate, so don't trust the one who tries to sell you a 'maintenance-free' structure.
Only the scale of time in which the ageing-processes takes place can vary and so can save or foolish us.
The ancient pyramides, though still in function if we have not robbed them, suffer from a substantial surface-damage when given a nearby view.
For the more ordinairy structures of our times we don't have to wait so long.

Civil engineering structures like roads have the shortest lifecycle (15 - 25 year), primairy caused by the wear and tear of the traffic, but speeded up by the ever growing intensity and a bad quality of subsoil.

Sheetpiling-structures, allthough designed for a fifty years or more, often appeares to have a much shorter lifetime (10 - 25 year), because of the much more aggressive environment.
Corrosion-velocities of 0.25 mm per year with maxima in the order of 0.5 mm are measured, not only along the seashore but also for inland polluted canals.
When design or building-failures makes airsupply to the backside of the sheetpiling possible, these velocities will nearly double.
So even heavy walls with a steel thickness of 10 mm or more are in that case of 'a short breath'.

Most of our civil engineering structures have a protection layer on the actual bearing construction. For example a paint-coating on a steel bridge, a concrete cover on buildings or the armour-blocks on the slope of a dike.
So degradation is from a so called 'two-stage-mechanism', in which the damage of the first stage is a warning-bell for the starting attack of the second underlaying structural more essential part.

In contrary a sheet-piling structure most of the time is from the type 'one-stage-mechanism', that is degradation (corrosion) allmost starts from the very early beginning.

It's a lucky circumstance that in contrast with others, this degradation (corrosion) is rather easy to measure by way of ultrasonic waves or more destructive by drilling or oxygen burning followed by a normal thickness measurement.
So on the side of 'the assessment of the condition-parameters' there are less problems than on the side of 'the assessment of structural (reserve) capacity' but above all 'the adjustment of acceptable risk'!

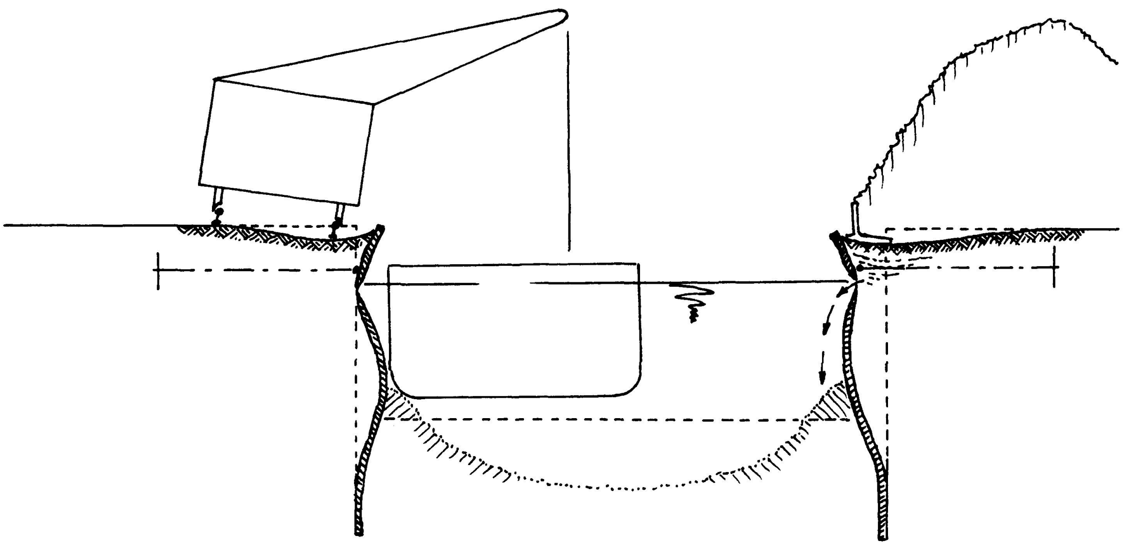


Fig.1 Structural reserve and acceptable risk

2. THE STANDARD DESIGN METHODS

In normal practice a sheetpiling wall is at best designed as a two-dimensional structure, which has an infinite extent in the third dimension.
The variation in this third dimension, with respect to loads, geometry, soil and construction properties is considered to be small or to be brought into account in the variation of the other two dimensions.
Even local loads or anchors are translated in a kind of equivalent line-loads, so the third dimension can be neglected.

For the two-dimensional computation of sheetpiling walls there are a few analytical or grafical methods available, like Rowe, Brinch Hansen, Blum.
Because the mechanical problem is in fact staticaly indetermined, these methods give approximate solutions under certain assumptions like infinite rigid piling and only hydrostatic active or passive earth pressure.

More recently developed computer programs (like the dutch programs MSHEET or DAMWAND/3) do take into account the stiffness of the sheetpiling and the stiffness of the soil by bi-linear springs (dependent on the horizontal displacement they come at last in the active or passive plastic stage).

The input for these computations is in general as follows:

Given or assumed by experience: - GEOMETRY (H,h,α,β)
- SOIL PROPERTIES (ϕ,c,γ,δ)
- LOADINGS (q,F)

Estimated by rules of thumb : - SHEETPILING (l,I)

Than computation results in : - BENDING MOMENTS $M(z)$
- SHEERFORCES $D(z)$

With the admissible stresses : - MODULUS OF RESISTANCE (W min.)
- THICKNESS OF BODY (t min.)

If the estimated profile doesn't fit, design is repeated with a better one.

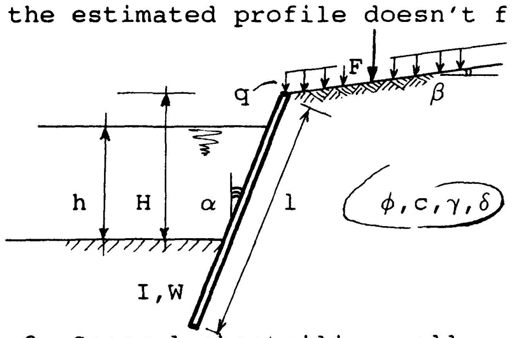


Fig.2 General sheetpiling wall

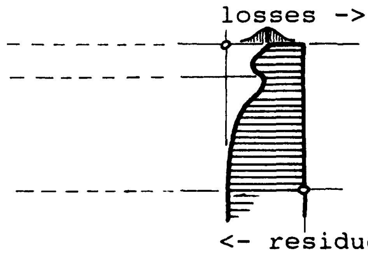


Fig.3 General corrosion profile

The actual sheetpiling profiles are mostly heavier than strictly needed with respect to the computation.
If extensive corrosion is expected the designer will take a few millimeters more (if he is aware of the phenomenon and in the possition to do so!).
But in fact at that moment he has first to answer the difficult question:

> What could and should be the minimum thickness of flange and body at the end of the designlife in relation to the function of the sheetpiling, so the consequencies of failure, the influence of inspection on this, the ability of a new (more plastic) equilibrium, etc.

If ram-ability of the sheetpiling in that specific soil is expected to be a problem, this can result in a heavier profile too.

The sheetpiling that finally will be found at location still can differ from the one selected above, because of delivery problems, sheetpiles in stock of the contractor, problems with achieving the right depth etc.
This 'as build' data should be saved well in a kind of birth-register because it is of great importance for the reassesment of the structure!

3. THE DEGENERATION PROCES

In the case of sheetpiling composed of steel profiles like Larssen, Hoesch etc. the degeneration process is mainly ordinairy corrosion. Besides steel there are two elements needed for the initiation and the continuation of this corrosion process, namely oxygin and water.

So in general a vertical corrosion profile is found with two maxima, one just beneath the low water level and one in the splash zone (Fig.3).
The first is limited by the amount of oxygin, and the other by the amount of water.

Also in horizontal direction there will be found a wide spread in loss of material.
The first fluctuation is measured within one single plane of a sheetpile and may be in the order of 100 mm due to local steel properties.
The next fluctuation is found between flanges, bodies and edges. Especially for cold-rolled profiles at the deformed outward corners, the grid is 'open for corrosion', so warm-rolled profiles are prefered in cases of extensive attack.
Over the sheetpiling wall there may be spots working like anodes and others like cathodes, caused by the metal composition, deformations and soil properties. The addition of copper and other more precious metals ment to prevent or to decrease corrosion, after some times proves to intensify this anodic and cathodic spots perhaps due to unequal alloys.
The largest fluctuation in horizontal direction may have its origin in the location or use of the sheetpiling wall. Tidal streams in combination with fresh water tonques, manoeuvring ships, etc. may cause a tendensy to vary over distances in the order of a 100 meters.

It will be clear that there is a discision problem. On the one hand in the case of too little information (thickness measurements) it is impossible to make distiction between the sources of above mentioned fluctuations.
So this 'all on one heap' approach will lead to an overestimated loss of thickness and so to an underestimation of the remaining strength.
At the other side more information will ask for money, but may lead to a better understanding and probable to a longer residual service life.
The smallest fluctuations over one plane are just of interest for the moment that minimum thickness will become zero and so loss of soil material may start, because strength will depend on the mean value.
The largest fluctuation in the order of the construction length, sometimes will lead to a seperate consideration and perhaps measurements for parts of the wall.
So in that case only the spread in the midrange-variations remains of direct interest for the reassesment of sufficient strength.

Besides the decreasing thickness (that influences strength), the geometry and the loads may change in time too.

Geometry may differ from design because of dredging, scouring, additions, so in case of doubt measurements like sounding the bottum can give insight. Keep in mind taht the computation and so the behaviour of sheetpiling is more sensitive to the retaining height H than to the thickness t!

Loads may differ from design because the destination of the adjacent site may be different (gravel storage is not covered by the often arbitrairy chosen one ton per square meter!).

Allthough soil properties will hardly change, original design assumptions may be of an arbitrary or global level. Supplementary measurements may give a better insight in the present situation.

After the state of the sheetpiling wall is well mapped, the evaluation will finally start.

4. THE REASSESMENT OF SHEETPILING WALLS

4.1 The general concept

In principal during the design stage of a structure there ought to be made a weighing between the initial investment plus expected maintenance cost of this new structure on the one hand versus the risc involved with the loss of functions on the other hand and so looking for the total cost optimum in the life-cycle.
Allthough this is a sound economic concept it is hardly been done.

As in most of the cases there are design codes or at least practical rules that relieves the designer of this difficult economic approach.
These codes of practice prescribes certain safety-margins that covers the above mentioned balance 'on the safe side', that is a rather low risc gained by a little bit more investment (Fig.4).
The consequencies of this practical concept is that during lifetime the risc won't dominate so fast and we may say 'nature is mild'!
These safety-margins are historically grown and reflects the level of prosperity and the aversion of society against structural failure, because this risc is extremely low in comparison with others [1].

For existing structures things have changed even without deterioration!

Design values for geometry, loads, soil and material properties may be known better by measurements, deteriorated construction properties are more scattered than before, consequencies of failure can be better estimated but in comparison with design, cost of adjustment are now of higher order.

Yet for existing structures the engineer still tries to hide behind design codes, because that is the easiest and common way but unfortunately in many cases no more practicable.
As special codes or rules for existing structures are hardly available at this moment, every engineer has to do this unknown exercition himself.

First he tries to uncover all hidden structural reserves. Material reserves like differences between 'as build' and 'as needed' profiles or mechanical reserves applying more advanced models. But if deterioration is extensive this won't be enough.
Then trying to exploit reliability-reserves, he will be confrontated with the basic questions about safety-margins and acceptable reliability-levels for existing structures in relation with design-values.
The considerations may be:

- Well known loads and resistance by way of measurements may lead to less variation so to a smaller safety-margin with equal probability of failure (Fig.6)
- A shorter residual lifetime may lead to lower extreme loads (if time dependend) and less loss of material so to smaller safety-margins, ending up with a margin for temporary sheetpilings (if known!).
- More costly maintenance measures together with better known failure consequencies may lead to a higher probability of failure (Fig.5) so to a smaller safety-margin but should not exceed other social riscs.

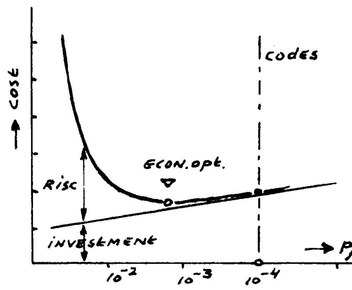


Fig.4 Economic balance in design stage

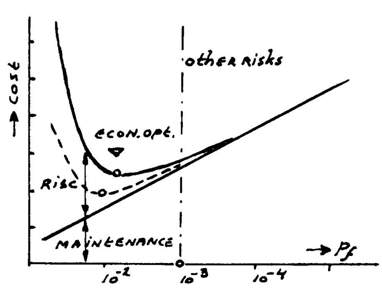


Fig.5 Economic balance for maintenance

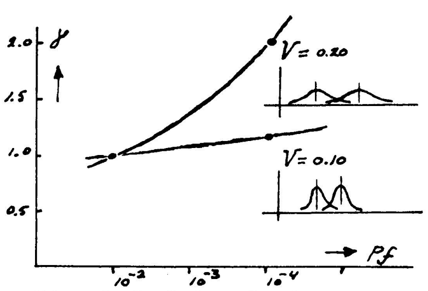


Fig.6 Safety-factor vs. failure probability

4.2 The evaluation of a sheetpiling wall

The reassesment of a sheetpiling wall follows the above given concept.

First the engineer tries to interprete all the thickness measurements in terms of a 'representative value' at the different levels. For instance using the 5%-value of the normal probability function. So overthickness given in design or construction stage will be included. With this new adjusted values and all others like in design he tries to passes through the 'design-loop' with the ordinairy two-dimensional computation.

If this still doesn't satisfy the present-day design rules, the more hidden and so less computable structural reserves will be taken into account.

In vertical direction there may be a certain redistribution of moments, if a more plastic behaviour of the sheetpiling in the computation is possible. There are computer programs written for the design of concrete retaining walls, that can handle yielding moments (for example the dutch program DIEPWAND/1). Yet reduction of the fieldmoment leads to increasing (acceptable?) moments and forces about tie level and the fixed end (Fig.7).

Also in horizontal direction there is a possibility of a certain redistribution between the individual sheetpiles.
Less corroded piles will take over a part of the load on heavy attacked sheetpiles. In fact in the third dimension the wall can be seen as a structure with a certain amount of parallel elements. What exactly will be the zone to be mobilized by a weak pile depends on the given local situation.
The stiffness of the wale, the geometry and the soilproperties play an important role in this.
A three dimensional computation (with the dutch program DIANA) has proved that in particular for the case of an anchored sheetpiling this horizontal redistribution may be considarable (Fig.8) [2].
Though this mobilized zone is in the order of the retaining height of the sheetpiling it has not been possible yet to derive a general rule of thumb.

The expectation is that within this zone short and midrange fluctuations may be ignored and only the mean value of the thickness have to be taken into account.

So in opposite if combined measurements are always done for such a to be mobilized zone, the mean value of that thickness may be of direct use in the normal two-dimensional computation.

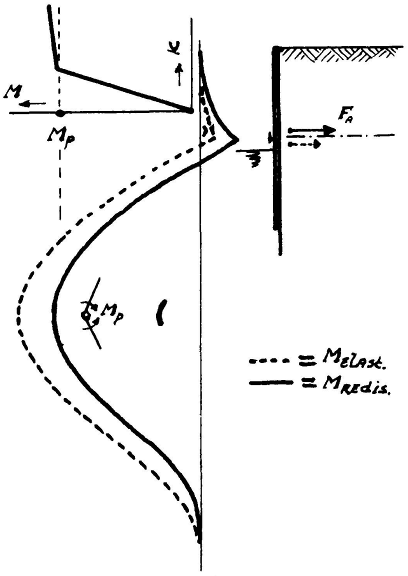


Fig.7 Redistribution of bending moments

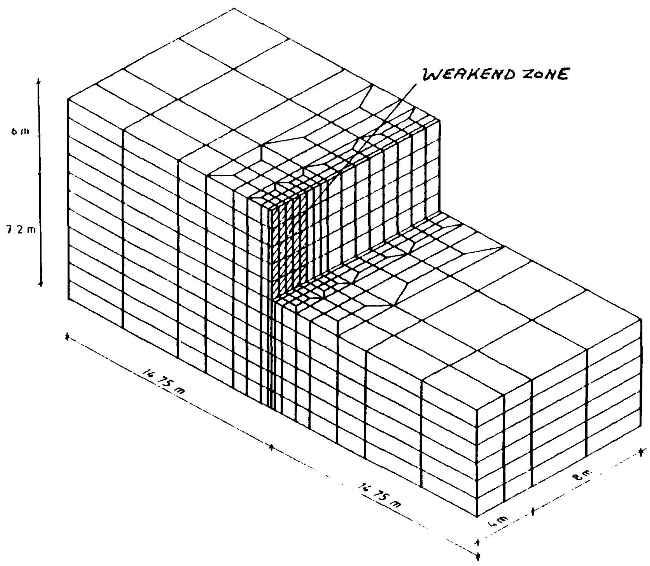


Fig.8 A 3-dimensional FEM-model of a sheetpiling wall.

Now a lot more hidden structural capacity is brought into sight it is possible that the sheetpiling wall satisfies the present-day (!) design rules.

If not it has been argued that for existing structures and time passes by safety-margins may decrease with relation to the original design-values. The arguments already given above are shortly:

1. A better knowledge about strength and loads so less uncertainty.
2. A shorter residual lifetime so less extreme loads and losses.
3. More costly (maintenance) measures i.r.t. design changes.
4. Better known failure consequencies i.r.t. design starting-points.

Quantifying these arguments leads to:

ad.1 Main contributions to the failure of a sheetpiling are given by the soil properties (ϕ,c), the retaining height (H), the thickness of the sheetpiles (t) and if applied the anchors.
Measurements may give the actual coëfficient of variation (0.1-0.2), so with reliability theory it may be possible to check if an other safety-margin may be applied (Fig.6). But since design was based on traditional building codes, first a calibration is needed to know the hidden starting-points in terms of coëfficients of variation.

ad.2 As sheetpilings usually are not designed for time varying loads, the only benefit could be the time dependend loss of material. But again in the traditional design it is not clear which part of the total safety margin was reserved for this.

ad.3 In general maintenance measures are from a higher order (factor 10) in relation with design measures having the same effect on risc.
So the new cost optimum will result in an higher probability of failure (factor 5) and so in a reduced safety-margin (factor 1.1).

ad.4 If failure consequencies are from a lower order (factor 10), the probability of failure may rise with the same magnitude for constant risk. This may lead to a reduced safety-margin (factor 1.2). But again the original starting-points are not known.

Although tendencies are clear, the traditional safety-margin used like a 'dust-bin' makes it hard to pay the individual aspects.
Only calibration of traditional designs based on probabilistic methods taking into account al relevant parameters and used mechanical model may give better insight! In Holland this study is now underway [3,4].

So in the meantime a more arbitrairy reduction factor up till 1.3 is used now in practice, mainly affected by the consequencies of failure [5].

5. STRETCHING THE REMAINING LIFETIME

Now it has been proven by measurements and calculations that there is still any 'life after death', the responsible authority should be informed about the best way to manage that structure in the future. So the next step is the weighing of alternative scenarios.

There are a few technical possibilities to stretch the residual lifetime of sheetpiling by applying a (combination of) preventive maintenance action(s) like the wellding of plates or beams to seal and strengthen the sheetpiles, painting and cathodic protection to slow down the corrosion proces, ground-injection to stop losses of soil etc.

Each alternative has his own cost and expected stretch of lifetime.

Cost may be the direct cost of the maintenance action plus cost ahead to sustain or maintain this action.
Cost also contains the risk involved with this solution, by which risk is the probability times the consequences of function loss (inserviceability or failure). On its turn this probability is dependent on the frequency of inspection, which again represents cost.
On the other hand the expected lifetime is inflenced by these inspection and maintenance actions too.

It is up to the engineer to bring all this in the right weighing within one scenario and next to balance these scenarios against the zero option 'doing nothing', so replacement after certain time [6].
Now this complex desicion may be sustained by some analytical or Markovian models which brings into account cost, lifetime and interactions [7,8].

Nevertheless this rational approach there are often practical restrictions like budget-shortage and traditional philosophies that dictates the real life, especially when no one is responsible for the total life-cycle cost!

REFERENCES

1. CIRIA Report 63. Rationalisation of safety and serviceability factors in structural codes. July 1977.

2. BIJNAGTE J. e.a., The consequencies of corrosion for the computation of a sheetpiling wall (in dutch). Grondmechanica Delft. May 1992.

3. CALLE E., Safety of cantilever sheetpiling structures (in dutch). A probabilistic method for the determination of partial safety factors. Grondmechanica Delft. May 1987.

4. SPIERENBURG S., Safety of anchord sheetpiling structures (in dutch). A probabilistic method for the determination of partial safety factors. Grondmechanica Delft. June 1988.

5. TOORN van der A., The evaluation of existing sheetpiling walls (in dutch). Rijkswaterstaat-Bouwspeurwerk. June 1989.

6. TOORN van der A., Management and maintenance of sheetpiling walls (in dutch). CUR-Rijkswaterstaat. Jan.1992.

7. WIJNMALEN D. e.a., Minimisation of maintenance cost by flexible strategies (in dutch). TNO-FEL. Dec.1990.

8. WALTMANS M. e.a., Computation of an optimal maintenance strategy for a sheetpiling wall (in dutch). ICIM. July 1991.