PROTECTION OF COASTS

Jan van de Graaff
Department of Hydraulic Engineering, Delft University of Technology, The Netherlands
j.vandegraaff@tudelft.nl

The narrow strip of the beach and say the first 150 m of the mainland adjacent to the beach is considered in this paper as the *coastal zone*. Coastal zones are present bordering seas (salt water) and bordering large inland waters (fresh water). In some parts of the coastal zone many different functions are present (e.g. housing, recreation and transportation). The coastal zone is bordered by an often hostile sea or inland water (e.g. a reservoir upstream of a dam in a river). Already existing properties in the coastal zone call often for a proper protection. However, because of global sea level rise, climate change and also an expected increased joint use of the coastal zone, much more protection schemes must be designed and executed along our coasts in future. There will be a large 'market' for adequate, sustainable and cheap coastal protection tools and coastal protection concepts.

In this paper (basic) existing coastal protection concepts are discussed. Some attention is paid to the possibilities of innovative protection concepts and protection tools.

1. Introduction

The *coastal zone* is considered here as the (rather) narrow strip of land consisting out of the beach and the first 150 m of the mainland adjacent to the beach. In Integrated Coastal Zone Management (ICZM) plans the coastal zone is often defined much wider. Here the zone is meant which is directly under the influence of the sea or large inland waters.

Large parts of the coastal zones along oceans and seas of the world are still mainly natural; nature and environment are the main functions there. The coastal zones in e.g. coastal cities, coastal villages and in coastal holiday resorts have to serve much more functions. For example recreation, housing, economy, transportation, fishery and shipping are then important functions as well. In some cases (like in The Netherlands) the coastal zone also protects the low-lying hinterland; hinterland even below mean sea level. For these coastal zones proper ICZM plans should take all such functions into account in a balanced way.

Because coastal zones border a sometimes hostile sea, the caprices of the sea must be fully taken into account in the planning process of a coastal zone. Two caprices of the sea are most relevant:

- The everyday morphological processes caused by the sea, sometimes resulting in structural erosion of the coast.
- The occurrence of a severe storm resulting in a (temporal) retreat of the coast.

Both effects might harm established functions in a coastal zone. Adequate and effective coastal protection schemes are sometimes required to restrict the damage to these functions.

Although because of tides (and storm surge events) the water level at sea is continuously varying, the mean sea level is rather constant at a time scale of e.g. a year.

The water level of inland waters might vary considerably over a year; e.g. seasonal fluctuations of the water level in a reservoir. In ICZM plans one has to take such water level fluctuations fully into account; the design of adequate required protection schemes is then highly complicated.

In the present situation Coastal Zone Managers are already confronted with many difficult issues related to coastal protection schemes. E.g. protection schemes showing malfunctioning, or schemes afflicted with unexpected side-line effects. (Of course also appropriate functioning protection schemes do occur.)

In the future the need for proper protection schemes will rapidly increase. The increasing use of coastal zones, but particularly the additional threats of global sea level rise and climate change for the stability of a coast, are reasons for this.

With a proper application of already existing coastal protection concepts and protection measures many coastal protection problems might be resolved. This holds also for the specific problems in the future because of global sea level rise and climate change. However, it is expected that the call for adequate coastal protection measures will become so loud and so frequent, that a lot of room will become available for new, innovative, robust and sustainable coastal protection tools and concepts. Many interesting ideas arise in this respect, however, often being still in its infancy, so actual applications in real life cases are still rare. Some examples will be discussed; a plea will be made to seriously foster some of the promising ideas.

It is a great challenge for the coastal engineering community to develop innovative coastal protection tools and concepts; society calls for that.

2. Starting points and two basic problems

2.1. Starting points

In the further discussion we are mainly dealing with rather small pieces of sandy coasts (up a few kilometres in alongshore direction) bordering open seas and oceans. Many different functions are present in the coastal zone of such a piece of coast. Taking the transition between the beach and the mainland/dunes as reference (edge of the mainland/dunes), houses and hotels have been built up to rather short distances to this edge in the past; also valuable infrastructure might be present in this zone.

We further assume that it refers to a booming area; tourism and economic developments are growing. Some kind of a Coastal Zone Authority is assumed to be present. A proper and fair ICZM plan has been developed taking all different interests into account. The Authority has legal backed opportunities to give permissions for activities in the coastal zone which match the Management plan (or to withhold permissions for activities which do not match). Some topics discussed in this paper might be taken into account while one is still in the phase of developing a proper ICZM plan.

At both alongshore sides of the (rather small) well-developed part of the coast as was assumed, stretches are present where the coast is still more or less natural and undeveloped; nature and environment are there the main functions.

We are mainly dealing with a sandy coast. A nice sandy beach is considered as a necessary condition for recreation. In all alternatives for (eventual necessary) protection schemes an important requirement is that the quality of the beach is maintained. [If the presence of a high quality sandy beach is not a strict requirement, much more protection tools and protection schemes are possible.]

Other types of coast (e.g. muddy, rocky or coasts along wide estuaries) have quite different characteristics and call often for a different approach as discussed in this paper.

2.2. Two basic problems with sandy coasts

Type 1) Structural erosion

Generally sandy coasts are daily affected by tides, waves, currents and wind, resulting in a continuous change of characteristic features of the coast; e.g. the position of the mean waterline, or the position of a bar. The development with time of the volume of sand (m^3/m) in the so-called control area (control volume) is a useful measure to judge the 'behaviour' of a coast. The control area (see Fig. 1) is an area between fixed limits; a landward vertical limit well in the dune/mainland area; a seaward vertical limit outside the active part of a cross-shore profile and an arbitrary horizontal level in a cross-shore profile.

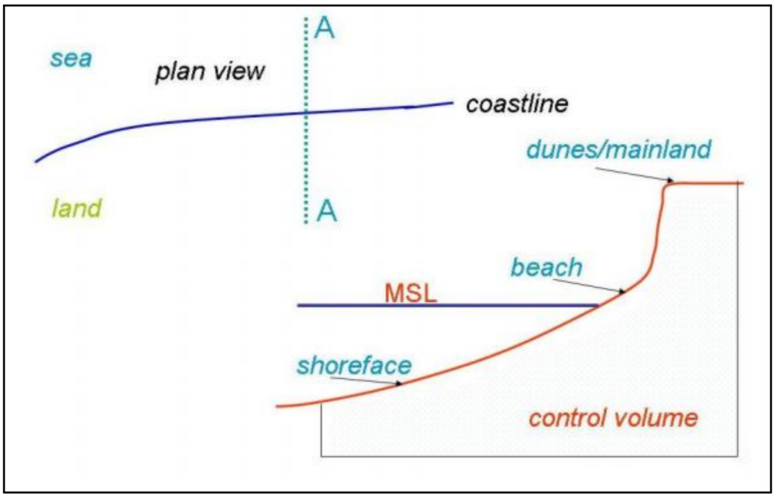

Fig. 1. Control volume in cross-shore profile

[Notice that in order to be able to carry out an analysis of the development of the volume of sediment in the control volume versus time, long time series are needed of entire cross-shore profile measurements. In many cases this type of measurements is not yet available. Adequate coastal protection schemes, however, must be based on a proper insight in the morphological processes involved. With an insufficient knowledge of some basic behaviour related aspects of the piece of coast under consideration, easily mistakes in a (protection) design are made. Field measurements should be extended in many cases.]

Although sometimes large year to year fluctuations are to be observed (≈ 100 m^3/m), seen over a number of years three different types of development can be noticed in a plot of control volume versus time:

- stable: apart from fluctuations no clear trend.
- erosion: negative trend; cross-section loses sediment with time (see Fig. 2 for a schematic example).
- accretion: positive trend; cross-section gains sediment with time.

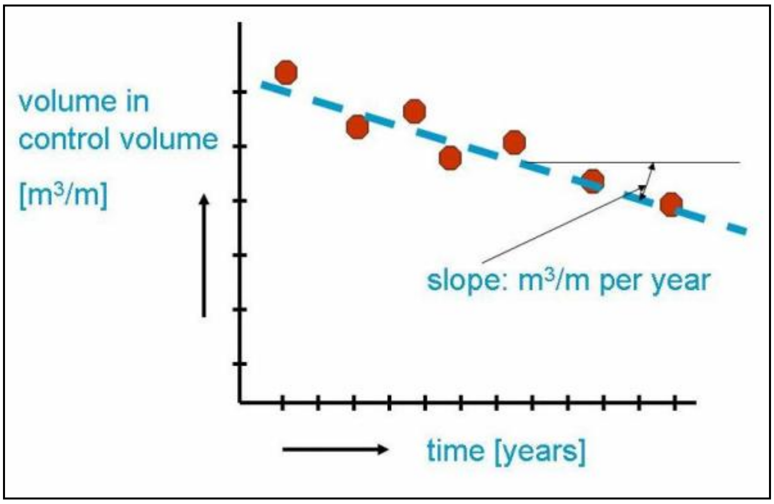

Fig. 2 Control volume and eroding coast

Stable and accreting coasts are not further especially dealt with in this paper.

Continuous, gradual, structural, year after year erosion results in a retreat of the position of the waterline in a cross-shore profile, but this retreat holds for all contour lines; a horizontal shift of the profile is observed at the end of the day.

Structural erosion of a piece of coast with a lot of infrastructure and buildings in the coastal zone is a serious problem for a Coastal Zone Manager. Even with a rather modest continuous erosion rate of 1 m/year, sooner or later buildings will be destroyed. Adequate coastal protection measures are then required.

Type 2) Dune/mainland erosion during a severe storm surge

During a severe storm surge higher water levels and higher waves do occur during a relatively short period of time. Provided that the level of the dunes/mainland is high enough to prevent overwash, the dunes/mainland will be eroded. During a short period of time large volumes of sand from the mainland are transported to deeper water and settles there (see Fig. 3). Contrary to the situation with structural erosion, during a severe storm surge to a first approximation no loss of sediments occur out of the control volume; only a redistribution of sediments within the cross-shore profile can be noticed.

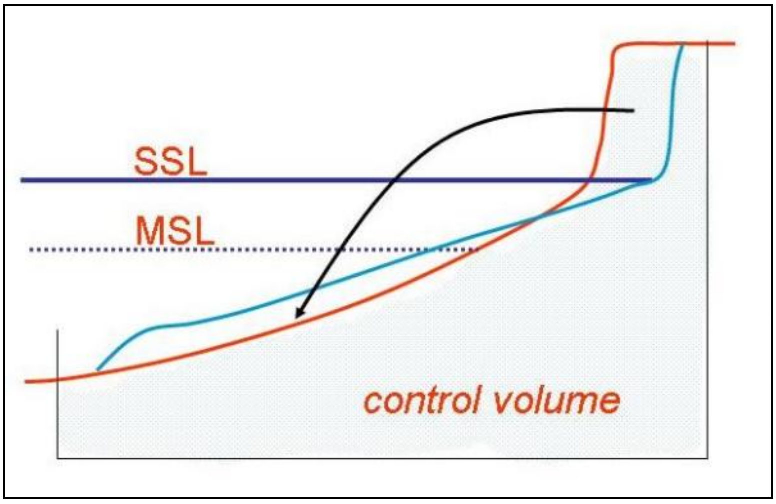

Fig. 3 Control volume and dune erosion

Of course the actual storm surge conditions determine the rate of erosion. Because of the stochastic nature of the boundary conditions (e.g. water level, wave conditions; shape of initial cross-shore profile) during a 'next' storm surge, one might conceive that a relationship exists between the rate of erosion and the frequency of exceedance. The farther the erosion proceeds landwards during a storm surge, the smaller the chance that this happens (see Fig. 4 for a schematic example from The Netherlands).

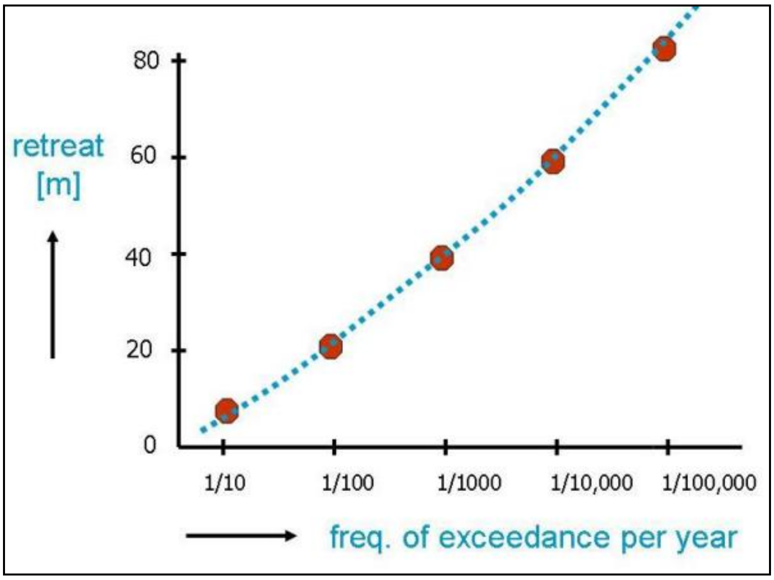

Fig. 4 Retreat of coast due to storm surge as a function of frequency of exceedance

If it is felt that the chance of failure of a structure built rather close to the edge of the mainland/dune is too large, or that the chance of a breakthrough of the dunes is too large (causing flooding of low-lying hinterland), coastal protection measures have to be considered.

Really severe storm surges which cause damage are often seldom. Inexperienced Coastal Zone Managers sometimes neglect this threat.

2.3. Distinction

In Par. 2.2 two different main processes/problems have been addressed where coastal protection might be required. (Viz.: day to day processes sometimes leading to structural erosion and episodic mainland/dune erosion.) Both problems call for quite different protection concepts and protection tools. An often complicated factor in practice is that a concept or tool which resolves the one type of problems, might have detrimental effects on the processes which cause the other problem. This means that in a proper analysis of coastal protection schemes both potential threats must be adequately addressed.

3. General strategy and draw-back

If erosion problems [either type 1) and/or type 2)] must be resolved, it is in most cases quite essential to get a clear insight of the real reason of the origin of the erosion problem as is felt.

Next a clear set of requirements must be formulated which an alternative has to fulfil. For instance: whether or not leeside erosion is allowed while protecting a particular stretch of coast, results in quite different options for protecting that piece of coast. This makes adequate coastal engineering practice often rather complicated. This holds especially when coastal protection matters are concerned. Often quite a number, and sometimes conflicting, requirements are formulated. It is then difficult to find a reasonable solution for the coastal protection task.

Nowadays still many malfunctioning coastal protection schemes can be found along our coasts. Two main reasons are relevant to understand this to some extent.

- Coastal engineering is a fast developing field of interest. 'Old', existing coastal protection schemes have been designed and constructed in a period that our knowledge of the occurring processes was less than at this moment.
- A second reason might be that the pressure of the society 'to do something' to protect their properties is so powerful, that it easily might happen that a (wrong) fast and easy solution for the protection is chosen to release the pressure.

4. Increased threats and further developments in future

Global sea level rise and climate change are possible future threats which directly will affect the 'behaviour' of a piece of sandy coast. Consider for instance a piece of coast which is stable (see Par. 2.2) at this moment. No structural erosion takes place; the shape of the cross-shore profile 'fits' with the occurring boundary conditions (tide; waves; particle size). Even if no climate change effects are present, but only a certain rise of the sea level occurs, it is easy to understand that the existing shape of the cross-shore profile does not 'fit' anymore with the new situation of an increased mean sea level. Cross-shore sediment transport processes will take place in order to reshape the cross-shore profile. In essence this happens with sediments of the upper part of a cross-shore profile (dune and beach) which is transported to deeper water. After a new equilibrium has been settled the coast has been eroded at the end of the day. [Equilibration process; Bruun-rule; Bruun (1962); see Fig. 5.]

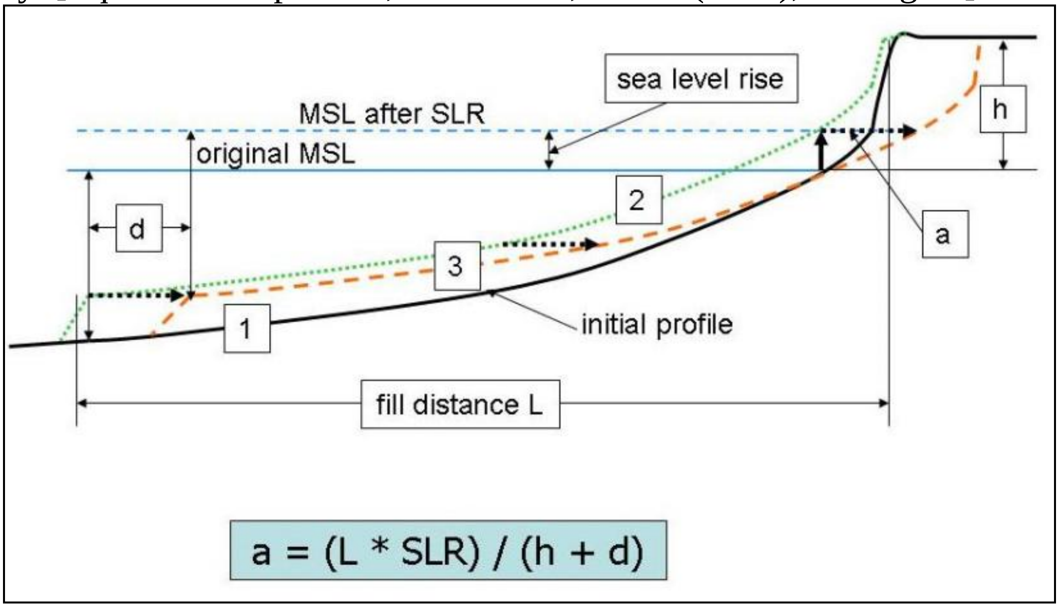

Fig. 5 Sea level rise and profile adaptations

In the present situation profile [1] is assumed to be in equilibrium with the wave and tide conditions. If after (during) sea level rise (SLR) profile [1] would be artificially (vertically) filled with a layer with thickness SLR over a sufficient long distance in seaward direction (fill distance L in Fig. 5) the position of the coastal profile (profile [2]) in horizontal sense is still the same as profile [1]. The waterline and beach are for instance at the same positions as before SLR, but at a higher level compared to the original MSL.

If one likes to keep the position of the coast at the same position indeed, irrespective of the rate of SLR, a volume of SLR times L is necessary.

With e.g. SLR = 1.0 m per century and L = 1000 m, a volume of 1000 m^3/m is required in 100 years. A volume of 10 m^3/m per year is a quite acceptable volume to artificially nourish in order to overcome the 'threats' of such a sea level rise.

If nature is allowed to do the adaptation job without human interference, a new equilibrium is achieved by a horizontal shift [a] of profile [2] towards profile [3] in Fig. 5. The magnitude of the horizontal shift [a] can be determined from:

$a = (SLR * L) / (d+h)$. With SLR = 1.0 m (e.g. per century), L = 1000 m, d = 10 m and h =10 m, the horizontal shift [a] becomes 50 m. In an undeveloped stretch of a sandy coast a retreat of say 50 m due to this effect might be considered as inevitable. Together with the rather long time span such an increase of the sea level covers, this type of erosion might be accepted and no action is foreseen for the time being.

In a well-developed part of a sandy coast a retreat of 50 m due to sea level rise is often considered as unacceptable. Existing buildings close to the sea, might be lost. If not yet lost directly, then the chance of destruction because of a severe storm surge might become too high. In conclusion: action to protect such a piece of coast is required.

The policy in The Netherlands is to avoid any coastal retreat so the option with profile [2] in Fig. 5 is strived after.

If, apart from global sea level rise, also climate changes (assume worsening conditions) are to be expected in future, a sandy coast will be confronted with additional parameters which ultimately determine the over-all ‘behaviour’ of the coast. Changes in the shape of the equilibrium cross-shore profile, increased structural erosion or increased chances of destruction of buildings in the coastal zone due to storm surges, are examples of what might happen. This type of possible consequences must be thoroughly investigated and quantified, before possible counter measures are designed.

The ‘behaviour’ of many pieces of sandy coast depends still partly on the continuous input of river sediments into the coastal system. Because of damming projects (e.g. for irrigation and hydro-power) and sometimes sand mining in the river, the input of the river sediments into the coastal system has been reduced with time in many cases. The coast has to adapt oneself to such a ‘new’ situation. This often yields to continuous coastal erosion at some places along the coast.

In a case where still entirely natural conditions are present (including a river which feeds the beaches), because of global sea level rise the water level rises in the lower reaches of the river. This results in an adaptation of the bottom level in the river. While because of the sea level rise the coast calls for more sediments, a part of the original input from the river to the sea is very firstly used for the adaptation of the bed of the river. A twofold shortage of sediments results for the coast.

It is expected that in future ever growing parts of the coasts are used for other functions than nature and environment only. The pressure from society to 'use' the coast for economic developments is in many countries very intense. This undoubtedly leads sooner or later to the need of more and better coastal protection schemes.

5. Innovative concepts and tools for coastal protection

5.1. Existing concepts and tools

With a consequent and skilful application of already existing coastal protection concepts and protection tools, many coastal protection problems are to be properly resolved. This holds also for additional (erosion) problems resulting from global sea level rise and climate change effects.

In practice (too) often coastal protection schemes have been designed and executed which (afterwards) turned out to malfunction. For a broad public this often leads to the idea that the existing tools are apparently insufficient and that better and innovative concepts and tools must be developed. As far as the disappointment in the performance of a protection scheme as applied, results from in fact a wrong application of existing tools, better designs might tackle this problem.

It is assumed that the reader is more or less familiar with notions like 'hard' and 'soft' protection methods and with the ins and outs of tools like groynes, detached shore parallel offshore breakwaters, seawalls and revetments and artificial under water and beach nourishments. In standard text books and in for instance the Coastal Wiki one can find relevant information with respect to these tools.

Of course also depending on the set of requirements a protection scheme has to fulfil, often artificial nourishments (to be repeated regularly) turn out to be a fair and at the end rather cost-effective alternative.

5.2. Innovative concepts and tools

Apart from a skilful application of existing concepts and tools in a coastal protection project, it is still worthwhile to investigate whether new ideas and innovative approaches can be used in the coastal protection task. We have to realise that some of these ideas are still in its infancy. Actual applications in real life coastal protection cases are still rare.

Next a few remarks are made of concepts and tools for coastal protection which are expected to become important in future. It refers to some concepts which already do exist and are applied in some cases, but also to so-called innovative concepts.

Risk analysis**:** More and more it is understood and accepted that a fair risk analysis might be helpful to judge whether a (often expensive) coastal protection project is really necessary. It might happen that the risk for the buildings in the coastal zone (risk = consequence $*$ chance) is in fact so small that the costs of an adequate coastal protection project are too high if a fair judgement is made. Something similar holds for the design of a protection scheme itself. The more robust the design, the smaller the chance that the protection scheme will fail, but the costly the protection scheme would be.

Very large nourishment project: Artificial nourishment projects are nowadays mainly meant to replenish occurring losses. In a single project a refill of 200 m^3/m over say 2 - 3 km alongshore is a reasonable order of magnitude. It is worth to consider a project with much larger volumes over a rather short distance alongshore. 'Nature' will next distribute the sediments.

Beach dewatering: With active beach dewatering steeper and wider beaches might be achieved in comparison with the existing situation.

BioGrouting (Bio-dune) developments: Specific bacteria with sufficient nutritious matter are able to stick loose sand together, forming some kind of sandstone. To save a specific building in the coastal zone close to the edge of the dunes, this method might be locally applied in future by creating a 'sandstone foundation'. (See e.g. http://www.smartsoils.nl/)

Floating breakwaters: Floating breakwaters, anchored at some distance from the shoreline, will reduce the wave conditions at the landward side of the structure. In some specific cases floating breakwaters might be a tool to protect a part of the coast.

Vertical drains: The Skagen Innovation Center claims that by just putting some vertical, partly perforated tubes into the beach, accretion of the beach is stimulated.

(See e.g. http://www.shore.dk/company.htm)

6. Discussion

It is expected that coastal protection projects will increasingly be needed in future. A successful project is only possible when it is quite clear what the requirements are a project has to fulfil. A protection project has many consequences introduced by the morphological coastal system. The consequences are often visible over large spatial and temporal scales. One should be aware of these consequences and take these fully into account in the design process.

So-called innovative concepts and tools need to be seriously fostered. It remains a good sequence first to formulate the 'problem' which must be resolved, and next to look for a possible 'solution'. It is a pity to some extent that especially with respect to some innovative ideas which are proposed, the sequence is sometimes reversed: the 'solution' is already available, and next we have to find and to match a 'problem'.

Much more information on the topics addressed in this paper can be found in the Coastal Wiki.

References

1. Bruun, P. (1962)**:** Sea-level rise as a cause of shore erosion: ASCE, Journal of Waterways and Harbors Division. Vol. 88, pp 117 – 130.
2. Coastal Wiki: http://www.encora.eu/
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