

# “De Stenen Man”: strong guardian or weak link?

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## ABSTRACT

De ‘Stenen Man’, standing on top of the Westerzeedijk near Harlingen, was built to commemorate the construction of the sea defenses. However, there is reason to believe this monument to flood safety endangers the stability of the dike. In our study, we quantify the effect of the statue on the failure probability of the dike. This is achieved through a combination of archive research, ground survey, and probabilistic assessment within the new legal framework. Results show that the monument increases the probability of failure by inward macro-instability tenfold. Therefore, further study into opportunities for reinforcement is recommended.

## Keywords

De Stenen Man, macro-instability, flood safety.

## 1. INTRODUCTION

The monumental artwork ‘De Stenen Man’ is located on the *Westerzeedijk* (lit.: Western sea dike) south of the Dutch harbor city Harlingen (see Figure 1). The statue on top of the dike serves as an immortalization of the former Spanish governor Caspar de Robles. Under his rule, the flood defenses around Harlingen were restored, after they had been destroyed during the All Saints’ Flood in 1570. An army of 3300 men realized a dike heightening from 2.66 m to 3.46 m above mean sea level (+NAP) in 1575 (Harlinger Courant, 1972). The dike trajectory was divided in a northern and a southern section. The statue is originally located on the foot of the dike where both sections came together (Hosper, Karstkarel, & van der Woude, 2008). The two heads of the statue look along the dike in northern and southern direction, standing guard over the dike.

The *Westerzeedijk* near Harlingen has been heightened several times: in 1812, 1912, 1928 and most recently in 1966. Throughout the years, the dike has been heightened from 3.46 m +NAP to 9.54 m +NAP. During the most recent dike heightening in 1966, ‘De Stenen Man’ was taken down and later put back (in 1969) on the crest, instead of the original location at the foot of the dike (see Figure 2).

Even though ‘De Stenen Man’ has a rich historical background, little is known about how the statue has been constructed. This kind of information is nonetheless important for the manager of the *Westerzeedijk*, water board *Wetterskip Fryslân*, who is responsible for its safety assessment and maintenance. The failure probability of the dike will be re-assessed within the new legal framework “Wettelijk beoordelingskader” (WBI), and the presence of De Stenen Man may potentially decrease the stability of the dike.

‘De Stenen Man’ is a special object which belongs to the category of so-called *Niet-Waterkerende Objecten* (NWO). This category covers all objects without flood defense functions that are located in a dike, on top of a dike or closely behind the dike (Regeling Veiligheid Primaire Waterkeringen 2017, 2017). In literature, NWOs are shown



Figure 1 ‘De Stenen Man’ at the Westerzeedijk near Harlingen



Figure 2 Renovation of ‘De Stenen Man’ in 1969 (Nieuwsblad van het Noorden, 1969)

to affect the stability of the dike. For example, Aguilar López et al. (2018) found that a road on top of a dike decreases dike safety. Likewise, sewer pipes inside dikes are expected to increase the risk of piping (Aguilar López, 2016). For the safety assessment of the primary flood defenses, it is therefore required that the impact of NWOs to these types of failure is considered. For this particular monument, it is considered most likely that the risk of failure of macrostability is affected. Macro-instability, or slope failure, is a failure of the outer or inner slope following a slip circle (Vrijling, 2001), see Figure 3.

The objective of this case study is to find out whether the statue is a strong reminder of flood safety, or a weak link in the flood defenses, by investigating to what extent ‘De Stenen Man’ increases the failure probability of the *Westerzeedijk* through macro-instability. This study was carried out at and on the request of *Wetterskip Fryslân*.

## 2. METHODOLOGY

Our analysis proceeds in three steps. (i) Archive research and (ii) a soil survey give us insight into the composition of the statue’s foundation. Finally, (iii) the probability failure is assessed within the framework of the Wettelijk Beoordelingskader (WBI; specifically, the guidelines given



Figure 3 Schematic depiction of inward (left panel) and outward (right panel) macro-instability. Figure adapted from Vrijling (2011)

in Ministerie van Infrastructuur en Milieu, 2016).

The first step is to gather insight in the statue ‘De Stenen Man’ through historical research. The primary goal is to find technical drawings that provide additional information about the foundation of ‘De Stenen Man’. Our main source of information is the archive of the Frisian historical institute *Tresoar*. Other sources used are the Municipality of Harlingen and *Rijksmonumentendienst* (i.e., the national service for monuments).

To investigate the depth of the foundation of the statue, a seismic probe as well a magnetometric probe is used. Both techniques are ground-penetrating and yield information on the composition of the materials in the subsoil. The seismic probe starts at 0.80 m beneath the dike crest and ends at a depth of around 15 m beneath the crest. The magnetometric probe ranges from 0.80 m to 4.50 m beneath the crest. Both seismic and magnetometric signals are generated at intervals of 0.25 m and include measurements of the local frictional resistance. The results are also used to determine the material of the soil layers underlying the statue. The survey is carried out by Fugro on commission from *Wetterskip Fryslân*. Results from the soil survey are used to validate the results from the archive research, while the results from the archive research are used for interpretation of the results of the soil survey. This gives a range for plausible values of the depth of the foundation of ‘De Stenen Man’.

The safety assessment of the *Westerzeedijk* is done conform WBI 2017. First, the safety assessment for inward and outward macrostability is performed, assuming that the statue is not present at the crest of the dike. D-Geostability software is used to calculate probabilities of failure for different WBI-scenarios. This leads to probabilities of failure for inward and outward macrostability at the dike section at which ‘De Stenen Man’ is located. Next, the similar assessment is performed again, however, this second assessment actually does consider the presence of the statue at the dike crest.

The geometry of the dike is schematized according to Bijlage III Sterkte & Veiligheid (Ministerie van Infrastructuur en Milieu, 2016b). In the schematization of the composition of the dike it is assumed that the old clay dike is still present on the seaward side, while the core is built up from sand. The dike is covered by a clay layer that varies between 0.8 m on the seaward side and 0.5 m on the landward side. A sand layer varying from 0.5 m to 2.0 m is present on the landward side of the dike.

Uncertainties of the composition of the subsoil are considered by retrieving four scenarios from software D-Soilmodel, according to the *Stochastische Ondergrond Schematisatie* (Hijma & Lam, 2015). The different soil types are each characterized by a specific cohesion, internal friction angle, unsaturated volumic weight and saturated volumic weight, based on NEN 9997-1 (Eurocode, 2011). Several load types are used in the safety assessment. The hydraulic loads are determined by using Hydra-NL software

(Ministerie van Infrastructuur en Milieu, 2016a). The hydrostatic pressure lines are based on TR Waterspanningen bij Dijken (Technische Adviescommissie voor de Waterkeringen, 2004). The weight of the statue is represented by a uniform load of 54.2 kN/m<sup>2</sup> over a width of 4.85 m, while the wind load is represented by a vector load of 128.3 kN acting on a distance of 1.0m from the horizontal centre of the statue. The calculations from D-Geostability lead to probabilities of failure for the representative WBI-scenarios.

The safety norm for dike trajectory *Waddenzee Friesland & Groningen* is a recurrence time of failure of 3000 years. This means that the maximum allowed probability of failure for the dike is 1/3000 yr<sup>-1</sup>. However, this failure probability is subdivided first over the length of the dike trajectory, and second over various failure mechanisms. Therefore, the allowed failure probability for the dike section of ‘De Stenen Man’ is much lower than the maximum allowed probability of failure of the whole trajectory. For the specific dike-section on which the Stenen Man is located, the so-called default failure budget is used to get the maximum allowed probability of failure for both failure mechanisms inward and outward macrostability. The calculated cumulative probability of failure is compared with the maximum allowed failure probability that yields for inward or outward macrostability at the specific dike section.

### 3. RESULTS

#### 3.1. Archive research

Documents from the archives of the Municipality of Harlingen and the *Rijksmonumentendienst* were found to describe the history of the statue in broad terms, but they do not provide sufficient information about the construction of ‘De Stenen Man’. The archives of *Tresoar* do provide the information of interest. The inventory of the former water board *Waterschap Vijf Deelen Zeedijken Binnendijks* contains information regarding the restoration and replacement of the monument ‘De Stenen Man’. The information exists of technical drawings from the most recent renovation in 1969.

Figure 4 shows the side view of the dike. ‘De Stenen Man’ is placed on the crest of the *Westerzeedijk*. It shows that the statue is placed on a pedestal that is supported by a shallow foundation. Further, it shows on which side the old clay dike is located, and how the dike has been heightened. Figure 5 shows a side view of the pedestal and a shallow foundation. The pedestal is filled with rubble as well as with mud and sand. Figure 5 shows that the bottom of the foundation is

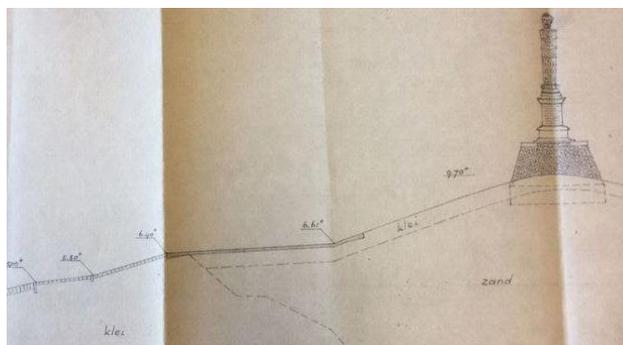


Figure 4 Side view of the Stenen Man on the dike. The old clay dike is visible to the left. Source: photo the original sketch (1968-1971, *Tresoar* inventory number 485)

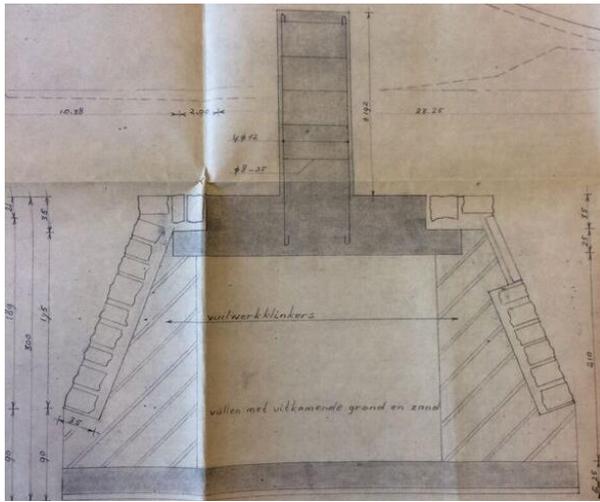


Figure 5 Side view of pedestal and shallow foundation. Source: photo the original sketch (1968-1971, Tresoor inventory number 485)

located at 1.50 m below the ground level at the crest. The ground level is 9.54 m +NAP, so the foundation is located at 8.04 m +NAP.

### 3.2. Soil survey

Both the magnetometric and seismic probes give the most plausible depth of the bottom of the foundation. Both probes have got an accuracy of 0.25m. The results in depth below ground level (m +MV) and above mean sea level (m +NAP) are given in Table 1.

The accuracy of the magnetometric probe and the seismic probe are both 0.25 m, so the range of the measured depth is 0.50 m for both methods. Table 1 shows that the difference between the measured depth between both methods is exactly 0.25 m, which means that, taking the accuracy into account, the actual depth of the bottom of the foundation must be within -1.65 m +MV and -1.40 m +MV. The technical drawing from the archive research shows a depth of -1.50 m +MV and is therefore in accordance with the soil survey. For the safety assessment, it is therefore confirmed that the bottom of the foundation is located at a depth of 8.04 m +NAP. Based on this information, 'De Stenen Man' and its foundation have been schematized (see Figure 6).

Table 1 Results magnetometric and seismic probing. NAP: mean sea level, MV: ground level (here, top of crest)

Probe	Depth [m +MV]	Depth [m +NAP]
Magnetometric	-1.65	7.89
Seismic	-1.40	8.14

### 3.3. Safety assessment

The cumulative failure probability is derived from the individual failure probabilities for the different representative WBI-scenarios. This is compared with the maximum allowed failure probability. These results are given in Table 2 and Table 3 for both inward respectively outward macrostability. The results compare the failure probabilities for the scenario without considering the statue with the scenario with inclusion of 'De Stenen Man'.

Table 2 shows that the calculated failure probability does exceed the maximum allowed failure probability for the scenario excluding as well as the scenario including 'De

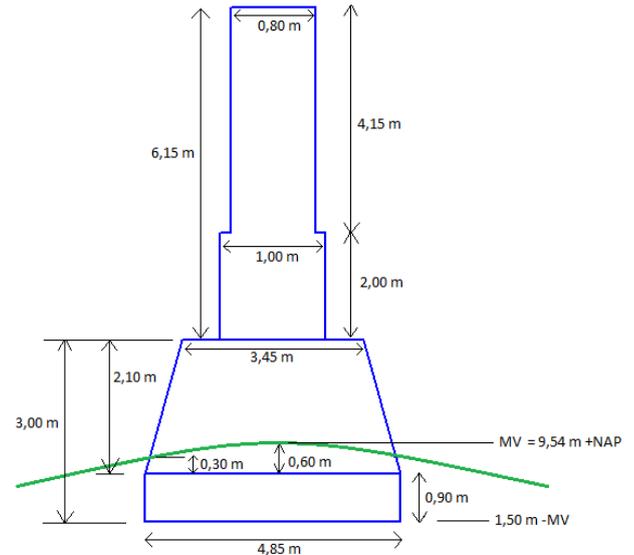


Figure 6 Schematization of 'De Stenen Man'. NAP: mean sea level, MV: ground level at the crest of the dike

Stenen Man'. Therefore, the dike section is assessed as unsafe for inward macrostability. Further, it shows a tenfold increase of the probability of failure due to the inclusion of NWO 'De Stenen Man'.

Table 3 shows that the calculated failure probability is negligible with respect to the maximum allowed failure probability for outward macrostability. This yields for both the scenario excluding and including 'De Stenen Man' and therefore the dike section is safe for outward macrostability. Results show an increase of five orders of magnitude of the failure probability of outward macrostability due to the extra loads by the statue.

Table 2 Results safety assessment inward macrostability

Inward macrostability	Cumulative prob. of failure [year <sup>-1</sup> ]	Max. allowed prob. of failure [year <sup>-1</sup> ]
Excluding 'De Stenen Man'	$1.21 \cdot 10^{-5}$	$1.40 \cdot 10^{-6}$
Including 'De Stenen Man'	$1.25 \cdot 10^{-4}$	$1.40 \cdot 10^{-6}$

Table 3 Results safety assessment outward macrostability

Outward macrostability	Cumulative prob. of failure [year <sup>-1</sup> ]	Max. allowed prob. of failure [year <sup>-1</sup> ]
Excluding 'De Stenen Man'	$2.50 \cdot 10^{-16}$	$4.67 \cdot 10^{-6}$
Including 'De Stenen Man'	$2.36 \cdot 10^{-11}$	$4.67 \cdot 10^{-6}$

## 4. DISCUSSION

During this study several assumptions were made to be able to estimate the failure probabilities of the dike. Here, we reflect on these assumptions.

Based on the results of the archive research and the soil survey, it was determined that -1.50 m +MV is the most reasonable depth of the shallow foundation. However, the soil survey defines a range in between which the depth of the bottom of the foundation must be located. A full probabilistic safety assessment may include a range of all possible depths instead.

Likewise, we used conservative estimates for soil characteristics to ensure that the chance of failure is not

underestimated. In general, taking conservative values when real values are uncertain is a common approach. This likely overestimates the actual probability of failure. Nonetheless, we assume that the effect of 'De Stenen Man' on the failure probability can be estimated regardless of how conservative our values are assumed, since the assumptions are the same in the situation with and without the statue.

This study is limited to macrostability. We found that the failure probability for inward macrostability even without the statue exceeded the maximum. This could be a reason for concern for *Wetterskip Fryslân*. However, exceedance does not necessarily mean that the entire dike section is unsafe, as this may be compensated by low probabilities of failure for other failure mechanisms. The assessment of the safety of the dike section requires therefore also results from the evaluation of the remaining failure mechanisms.

Another failure mechanism that is potentially affected by the presence of the statue is indirect failure. An example of indirect failure is loss of stability due to erosion. In particular, we noticed that transition from the grass cover to the NWO is a potential weak spot. During design water levels, the waves could cause erosion of the grass cover, which could eventually lead to instability of the whole dike body.

## 5. CONCLUSION & RECOMMENDATIONS

The results show that the probability of failure increases due to the extra loads by 'De Stenen Man' for inward as well for outward macrostability. The impact of the statue to the probability of failure is significant for both failure mechanisms, so it is recommended to consider this impact in future safety assessment.

Results show that the maximum allowed failure probability is exceeded for both scenarios of inward macrostability, which indicates that the dike section is not safe. However, as discussed, the final safety judgment of the dike can only be given when each failure mechanism has been assessed.

As the calculated failure probability is negligible with respect to the maximum allowed failure probability, the dike is safe for outward macrostability. This yields for both excluding and including the statue in the safety assessment. Furthermore, this study has demonstrated how archive research and soil survey reinforce each-other in the safety assessment. This paper does therefore show that combining both kinds of research will contribute to the safety assessment of historic objects like 'De Stenen Man'.

In conclusion, while 'De Stenen Man' is unmistakably a monument to flood safety, it significantly increases the probability of dike failure. In this light, the two heads of the statue might gain a second meaning; one for flood safety, the other for enduring vigilance.

## 6. ROLE OF THE STUDENT

The study documented in this article is entirely conducted by Marc Frankena during an internship of ten weeks at water board *Wetterskip Fryslân* in Leeuwarden, to obtain the degree of Bachelor of Science from the University of Twente. The main outline of the research was framed by

*Wetterskip Fryslân* and has further been specified in consultation with student Marc Frankena and Koen Berends, who was functioning as supervisor representing the faculty of Engineering Technology, department of Marine and Fluvial Systems, of the University of Twente.

This article is written by the first author. The second author has contributed in terms of style, outline and general review. We gratefully acknowledge Anne Steegstra, who was the daily supervisor of Marc during his internship, as well as *Wetterskip Fryslân*, for providing a friendly and engaging working environment.

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