K_D AND SAFETY FACTORS OF CONCRETE ARMOR UNITS

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Recommended design K_D are associated to implicit global safety factors to Initiation of Damage (IDa) and Initiation of Destruction (IDe). Zero-damage criterion is valid for double-layer armors of massive CAUs, but single-layer armors require a lower-than-zero damage criterion. A simple methodology is proposed to calculate design K_D for Cubipod armors and to obtain reasonable explicit global safety factors to IDe and IDa when compared to benchmark CAUs. The stringent SF(IDe5%) is the lowest for double-layer trunk armors, higher for double-layer roundhead armors and the highest for single-layer trunk armors. Single-layer roundhead armors were not analyzed.

Keywords: mound breakwater; concrete armor unit; Cubipod; stability coefficient; global safety factor

INTRODUCTION

Since the Tetrapod was invented in 1950, many concrete armor units (CAUs) have been designed to optimize the armor layer of large breakwaters, enhancing safety and reducing construction and maintenance costs during lifetime. The hydraulic stability and performance of the armor layer depend on the specific weight and CAU geometry (cube, Tetrapod, etc.), the placement arrangement (random, patterned, etc.), the number of layers (single or double) and position (trunk or roundhead). The higher the hydraulic stability, the lower the consumption of concrete, the smaller the filter stones and the less powerful the placement equipment. However, structural integrity must be guaranteed, and slender CAUs with high hydraulic stability may break if unit size is too large.

Probabilistic approaches have been proposed by CIRIA/CUR (1991) and PIANC (1992) to design large mound breakwaters; using existing design formulae, partial coefficients (Level I) were obtained through probabilistic Level II calculations. Furthermore, ROM 0.0-01 recommended the probabilistic Level III design for large breakwaters. Given the difficult traceability of these methods, to compare the hydraulic stability of different CAUs, most practitioners continue using the stability coefficient (K_D) and Hudson's formula (see Equation 1).

$$W = \frac{1}{K_D} \frac{H^3}{\left(\frac{\gamma_r}{\gamma_w} - 1\right)^3} \frac{\gamma_r}{\cot \alpha} \qquad (1)$$

K_D was proposed by Hudson (1959), and popularized by SPM (1975 and 1984), to characterize the hydraulic performance of different armor units placed on conventional double-layer armors. Even today, it is still widely used to characterize a variety of CAUs placed on single-layer armors despite their completely different hydraulic performance. The zero-damage design criterion originally used by both Hudson (1959) and Iribarren (1965) co-exists today with lower-than-zero damage criteria used for single-layer armors.

This paper focuses on the explicit and implicit assumptions associated with the K_D reported in literature for different CAUs. If ignored, these assumptions and implicit global safety factors can lead to misunderstandings and errors when designing the armor layers of mound breakwaters. Any design K_D for a given CAU, placement arrangement, number of layers and position (trunk and head) is always explicitly or implicitly associated to certain safety factors which should be reported explicitly. This paper describes a simple methodology to estimate the global safety factors associated to a design K_D.

SINGLE- AND DOUBLE-LAYER ARMORS

The popularization of the use of Hudson's formula and K_D to design armor layers of mound breakwaters favored the invention of new CAUs with high K_D. However, the numerous Dolosse breakages in large breakwaters such as Sines (PT-1978) with W[t]=42 and San Ciprián (ES-1980) with W[t]=50, focused the engineering community's attention not only on hydraulic stability but structural strength as well. Large unreinforced CAUs required a suitable geometry to balance hydraulic stability

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and structural strength. According to Dupray and Roberts (2009), bulky CAUs are the results of attempts to balance hydraulic stability and structural strength, and examples of these include Accropode (1980) and the second generation CAUs as shown in Fig. 1.

Figure 1. Evolution of bulky and second generation CAUs over time.

The first bulky CAU was developed along with the concept of single-layer armor to reduce the concrete consumption and construction costs of conventional double-layer armors. Improved manufacture, handling and placement techniques and better monitoring systems have allowed the construction of hundreds of single-layer armors with bulky CAUs worldwide. Better construction techniques and environmental concerns have also given rise to the use of single-layer armors instead of intense cement-consuming double-layer armors. However, the stability coefficient K_D for single- and double-layer armors is being used by practitioners without any clear distinction between technical fundamentals and explicit safety factors to Initiation of Damage (IDa) and Initiation of Destruction (IDe). The design K_D for conventional double-layer armors may be associated to IDa (zero-damage), but K_D for single-layer armors are much lower.

Massive CAUs (cubes, parallelepiped blocks, Antifer cubes, Cubipods, etc.) in conventional double-layer armors show a tenacious failure function; a design K_D corresponding to IDa provides a wide margin of safety to failure. On the contrary, single-layer armors have brittle failure functions; a design K_D corresponding to IDa would provide a very narrow margin of safety to failure. Therefore, to maintain a reasonable margin of safety to failure, the criterion to define the appropriate design K_D for both single- and double-layer armors must be related to IDe rather than IDa.

Additionally, Burcharth and Brejnegaard-Nielsen (1986) pointed out that the stress level in CAUs increases linearly with CAU size for static and hydrodynamic loads and is proportional to the squared root of the CAU size for impact loads. Therefore, CAUs never break in small-scale tests; however, if a certain CAU size is exceeded, slender and bulky unreinforced CAUs can break at prototype scale. The maximum CAU size depends on the number of rows on the armor, concrete tensile strength and CAU geometry. For non-massive CAUs (see Medina et al., 2011), small-scale armor failure functions should be taken with caution given the potential breakage of CAUs at prototype scale.

Vincent et al. (1989) analyzed the prototype and small-scale performance of single- and double-layer armors and found that in double-layer armors built with slender and bulky CAUs, the upper layer is less stable and more difficult to construct than the bottom layer. These authors reported that unstable units from the upper layer of double-layer armors could become missiles, increasing the risk of breakage and other damage. They concluded that single-layer armors were safer and more cost-efficient than double-layer armors. Although this vision has spread worldwide during the last decades, mound breakwaters in severe wave climates are beyond the range applied to bulky CAUs in single-layer armors (e.g. 20 m^3 Accropode™ II CAUs were used in Busan Geoje Tunnel to resist H_s[m]=8.7 and T_p[s]=16.2).

On the coast of Japan, slender reinforced CAUs have been used to resist rough seas; for instance, Hanzawa et al. (2006) reported the use of high density fully reinforced Dolosse up to 80 tonnes to resist H_s[m]=12.1 and $T_{1/3}$[s]=14.5. On the coast of Spain, conventional double-layer armors of massive CAUs are common in deep waters and rough seas; for instance, 150-tonne unreinforced cube blocks were placed in the Punta Langosteira breakwater (A Coruña) to resist a design storm of H_s[m]=15.0 and T_p[s]=18.0 (see Maciñeira-Alonso et al., 2009). More recently, the Cubipod (see Fig. 1), a massive CAU, designed for use in double- or single-layer armors, has provided higher hydraulic stability than conventional double-layer cube armors (see Medina et al., 2010b). At present, then, there are several bulky and one massive CAU which can be used to construct single-layer armors in any environmental condition, including those placed in deep waters under very strong wave storms.

GLOBAL SAFETY FACTORS TO IDe

Hudson's formula (Eq. 1) was first published in 1959 as a simplification of the hydraulic performance of conventional armor layers, based on the results of small-scale tests using regular waves. Only the stability coefficient (K_D), the wave height (H), the relative submerged specific weight ($\Delta=[(\gamma_r/\gamma_w)-1]$) and the slope angle (cot α) were related to the nominal diameter of the CAU ($D_n=[W/\gamma_r]^{1/3}$). The uncertainties generated by the neglected variables (wave periods, storm duration, tolerances, model effects, etc.) had to be considered in the methodology to determine the recommended design K_D. Hudson's formula was generalized later using the equivalence $H=H_s$ for random waves, which can be re-written using dimensionless stability numbers:

$$N_s = \frac{H_s}{\Delta D_n} \text{ and } N_{sd} = \frac{H_{sd}}{\Delta D_n} = \left(K_D \cot\alpha\right)^{1/3} \qquad (2)$$

Most reports refer to Eq. 2 as the generalized Hudson formula when analyzing CAUs in small-scale hydraulic stability tests. However, it is necessary to clarify the methodology to determine K_D for each specific CAU, placement pattern and armor thickness (single- or double-layer). Without a clear methodology to determine K_D from small-scale tests, any comparison among different K_D reported by different authors may lead to misunderstandings in practical applications.

Hudson (1959) as well as Iribarren (1965) proposed an armor design method based on the zero-damage criterion to IDa, but implicitly assumed a global safety factor to IDe, SF (IDe)≈1.6. Conventional double-layer armors of quarrystones, cubic blocks and Tetrapods, tested extensively in the 1950s and 1960s, required nearly a 60% increase in the stability number to IDa, N_s(IDa), to reach IDe. In short, Hudson (1959) and Iribarren (1965) promoted an armor design with the following global safety factors: $SF(IDa)=N_s(IDa)/N_{sd}\approx1.0$ or zero-damage criterion and an implicit $SF(IDe)=N_s(IDe)/N_{sd}\approx1.6$ for IDe. Nevertheless, modern CAUs in single-layer armors have a $SF(IDa)=N_s(IDa)/N_{sd}>>1.0$. The design of modern single-layer armors means that the traditional zero-damage criterion must be changed to a more restrictive less-than-zero damage criterion.

Small-scale hydraulic stability tests usually fix the number of waves per run (i.e. N=1000) and the spectral density attacking the model. Significant wave height (H_s) is increased in the test, and damage is measured from IDa (significant CAU movement) to IDe or failure. In each specific series of tests i on a small-scale model, $[H_s(IDa)]_i$ and $[H_s(IDe)]_i$ are recorded. After a number of series of tests in different conditions using the same CAU and armor slope, Gaussian probability density functions (pdfs) of N_s(IDa) and N_s(IDe) can be estimated as illustrated in Fig. 2. Thus, explicit global safety factors {SF(IDe5%), SF(IDe50%), SF(IDa5%) and SF(IDa50%)} can be calculated for each CAU as the 5% and 50% percentiles of the corresponding pdfs, using Eq. 3 and Eq. 4.

$$SF(IDeN\%) = \frac{N_s(IDeN\%)}{N_{sd}} \qquad (3)$$

$$SF(IDaN\%) = \frac{N_s(IDaN\%)}{N_{sd}} \qquad (4)$$

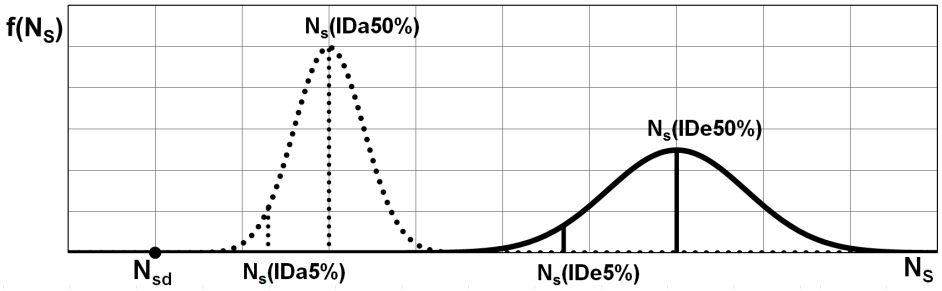

Figure 2. N_{sd} and scheme of N_s(IDa) and N_s(IDe) probability density functions.

Double-layer armors of massive CAUs (cubes, Antifer cubes, Cubipods, etc.) with high structural strength have $N_s(IDa)<<N_s(IDe)$; therefore, it is reasonable to design them to IDa as proposed by Hudson (1959) and Iribarren (1965) half a century ago, $N_{sd}\approx N_s(IDa)<<N_s(IDe)$. On the contrary, modern single-layer armors (Accropode, Core-Loc, Xbloc, Cubipod, etc.) show $N_s(IDe)$ not much higher than $N_s(IDa)$; therefore, single-layer armors must be designed far below IDa so as to obtain a reasonable global safety factor to IDe, $N_{sd}<N_s(IDa)<N_s(IDe)$. Prototype failure of slender CAUs (Dolos, Tetrapod, etc.) is conditioned by structural strength, which can differ significantly from the failure observed in small-scale models; consequently, the design of armors with slender CAUs must pay attention not only to hydraulic performance but also to structural strength.

When using the generalized Hudson formula (Eq. 2) to design a given armor, global safety factors to IDe must be taken into consideration. There are several sources of risk and uncertainty: (1) structural and environmental uncertainties, (2) scale effects, (3) model effects and (4) unknown factors. The mass density of concrete and the significant wave height attacking the structure are the two primary sources of uncertainty directly affecting Hudson's formula; the concrete mass density may be controlled during the manufacturing process, but H_s is an environmental variable beyond human control. Using Froude similarity, the scale effects for hydraulic stability of armors are assumed to be negligible if the scale is appropriate, that is having a Reynolds' number $Re=(Ud)/\nu=D_n(gH_{sd})^{1/2}/\nu>3.5.10^4$; however, scale effects may be significant for core permeability, overtopping rates and other structural characteristics (see Burcharth and Lykke-Andersen, 2007). Model effects are always relevant because of the numerous environmental and structural variables fixed in small-scale testing (wave peak period, spectral shape, number of waves, wave direction, armor porosity, CAU placement, etc.), none of which are explicitly included in Hudson's formula. Finally, the unknown variables related to the prototype site conditions and breakwater performance are additional sources of uncertainty. As a result, the global uncertainty associated with the generalized Hudson formula (Eq. 2) must be assessed so that the appropriate global safety factors can be guaranteed.

Some of the uncertainties mentioned above can be estimated quantitatively; however, other sources of uncertainty have to be assessed subjectively. The difficulty in assessing global uncertainty and fixing global safety factors can be observed when analyzing the drastic changes of criteria in popular engineering manuals. For instance, both SPM (1975) and SPM (1984) proposed using Hudson's formula along with a very similar table of design K_D values for a variety of CAUs. Nevertheless, SPM (1975) and SPM (1984) recommended the use of the equivalence $H=H_{1/3}$ and $H=H_{1/10}\approx1.27H_{1/3}$, respectively; in just 9 years, the most popular coastal engineering manual in the world increased the implicit global safety factor by 27%. Three decades later, it is again common to use the equivalence $H=H_{1/3}$; new knowledge and more precise construction techniques seem to have increased the confidence of the engineering community and reduced the global uncertainty when using Hudson's formula. Engineering judgment seems to have played a key role in the drastic increase in the implicit global safety factors of the late 1970s, probably arising from the catastrophic failure of the 42-tonne Dolos breakwater in Sines (Portugal), and reducing the implicit global safety factors decades later, when relatively few breakwaters failed.

Single-layer armors with brittle failure functions must have higher global safety factors than double-layer armors with tenacious failure functions. The safety factors to IDe are much higher but, since the 1980s, new knowledge and more precise construction techniques have also reduced the assessed global uncertainty when using Hudson's formula. For instance, Vincent et al. (1989) suggested a design $K_D=10$ for single-layer Accropode® armors, while CLI (2012) recommended $K_D=15$ for their design significantly reducing the implicit global safety factors. Once again, engineering judgment is reducing safety factors while increasing confidence in modern design and construction techniques.

METHODOLOGY TO CALCULATE DESIGN K_D

In order to define appropriate design K_D for Cubipod armors (single- and double-layer trunk and roundhead), global safety factors to IDa and IDe were estimated first for double-layer cube armors (trunk and roundhead) and single-layer Xbloc and Accropode armors (trunk). Table 1 specifies the design K_D recommended by Negro and Varela (2008) for cubes and by the owners of the patents and trademarks of Xbloc® and Accropode®, respectively (www.xbloc.com and www.concretelayer.com).

For each armor type, small-scale hydraulic stability test results were then used to estimate the corresponding Gaussian pdfs of $N_s(IDa)$ and $N_s(IDe)$, characterized by the mean value and standard deviation. Cube armor results were obtained from Van der Meer (1988) and Medina et al. (2010b);

Xbloc® armor results were those reported by Bakker et al. (2005) and Accropode® data were obtained from Van der Meer (1988) and Holtzhausen and Zwamborn (1991). Stability number observations of tests carried out in different laboratories were considered belonging to the same Gaussian pdf if differences between mean values and standard deviations were not significant; however, when results from different laboratories were significantly different, two pdfs were considered for Ns(IDa) and Ns(IDe) for each laboratory.

Safety factors were calculated first for cube double-layer trunk and roundhead armors as the benchmark cases for double-layer armors. Design stability coefficients for Cubipod double-layer trunk and roundhead armors were fixed (K_D[trunk]=28 and K_D[roundhead]=7) to maintain similar safety factors to IDe, SF(IDe5%)=1.09 ≈ 1.05 for trunk and SF(IDe5%)=1.19 ≈ 1.17 for roundhead.

Analogously, safety factors were calculated for Xbloc and Accropode, the single-layer trunk benchmark cases for single-layer armors. The design stability coefficient for Cubipod single-layer trunk was fixed (K_D[trunk]=12) to maintain similar safety factors to IDe, SF(IDe5%)=1.31 ≈ 1.17 and 1.05<1.31<1.40.

Table 1 shows the K_D and the global safety factors for Cubipod (single- and double-layer armors) obtained from the results of the small-scale model tests described by Gómez-Martín and Medina (2007, 2008), Lomónaco et al. (2009) and Burcharth et al. (2010). Cubipod safety factors are similar to those obtained for cube (double-layer armors) and Accropode and Xbloc (single-layer armors). Fig. 2 illustrates that safety factors to IDa and IDe, {SF(IDa5%), SF(IDa50%), SF(IDe5%) and SF(IDe50%)}, are dependent on design stability number, N_{sd}, related to the design K_D (see Eq. 2). Given a specific armor type (CAU, #layers, etc.), a decrease in the design K_D means an increase in the global safety factors. SPM (1984) changed the wave height recommendation $H=H_s$ for random waves given by SPM (1975), to $H=H_{1/10}\approx 1.27H_s$ which was equivalent to a 50% reduction in design K_D maintaining $H=H_s$. The severe damage to several large breakwaters constructed between 1975 and 1984 may again explain the drastic increase in implicit safety factors recommended by SPM (1984). The relatively few breakwaters damaged since there may be the reason why numerous designers and practitioners are using the generalized Hudson formula (Eq. 2), closely related to the design K_D recommended by SPM (1975).

Table 1. Design K_D and global safety factors.

					Initiation of Destruction (IDe)		Initiation of Damage (IDa)	
Section	CAU	K_D	# layers	slope	SF (IDe5%)	SF (IDe50%)	SF (IDa5%)	SF (IDa50%)
Trunk	Cube	6	2	3/2	1.05	1.35	0.67	0.86
	Cubipod 2	28	2	3/2	1.09	1.40	0.82	0.99
	Cubipod 1	12	1	3/2	1.31	1.64	1.06	1.27
	Accropode	15	1	4/3	1.05 to 1.40	1.26 to 1.51	0.93 to 1.24	1.15 to 1.38
	Xbloc	16	1	4/3	1.17	1.68	1.17	1.32
Roundhead	Cube	5	2	3/2	1.17	1.40	0.88	1.13
	Cubipod 2	7	2	3/2	1.19	1.36	0.99	1.18

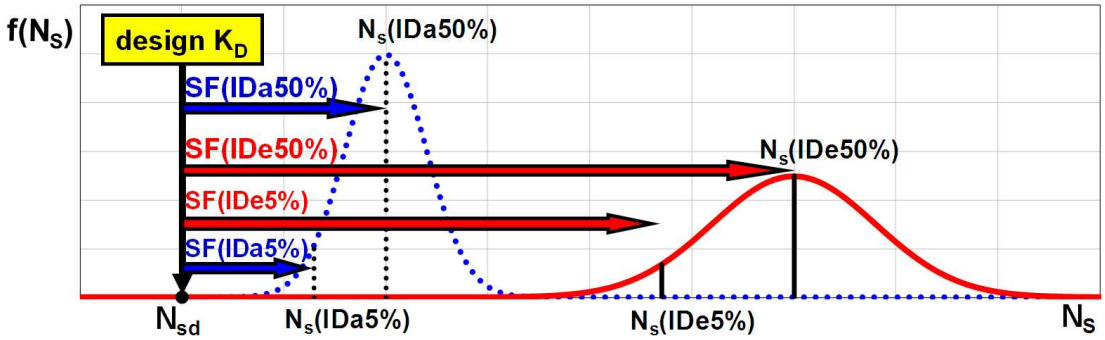

Figure 3. Schematic representation of design stability number (N_{sd}) and Safety Factors to IDa and IDe.

ANALYSIS OF RESULTS

Practitioners frequently believe that recommended design K_D values refer to the start of damage, zero-damage or initiation of damage. Nevertheless, Table 1 shows that K_D=6, commonly used to design double-layer cube armor trunks (see Negro and Varela, 2008), corresponds to armor damage larger than IDa, SF(IDa50%)=0.86<1, while recommended K_D values for single-layer armors are related to armor damage much lower than IDa. Fig. 4 illustrates the lower-than-zero damage criterion to IDa for single-layer armors compared to the zero-damage criterion to IDa for double-layer armors.

SF(IDa50%)= 1.32[single-layer Xbloc in trunk]>>1> 0.86 [double-layer cube in trunk]
SF(IDa50%)= 1.27[single-layer Cubipod in trunk]>>1≈ 0.99 [double-layer Cubipod in trunk]

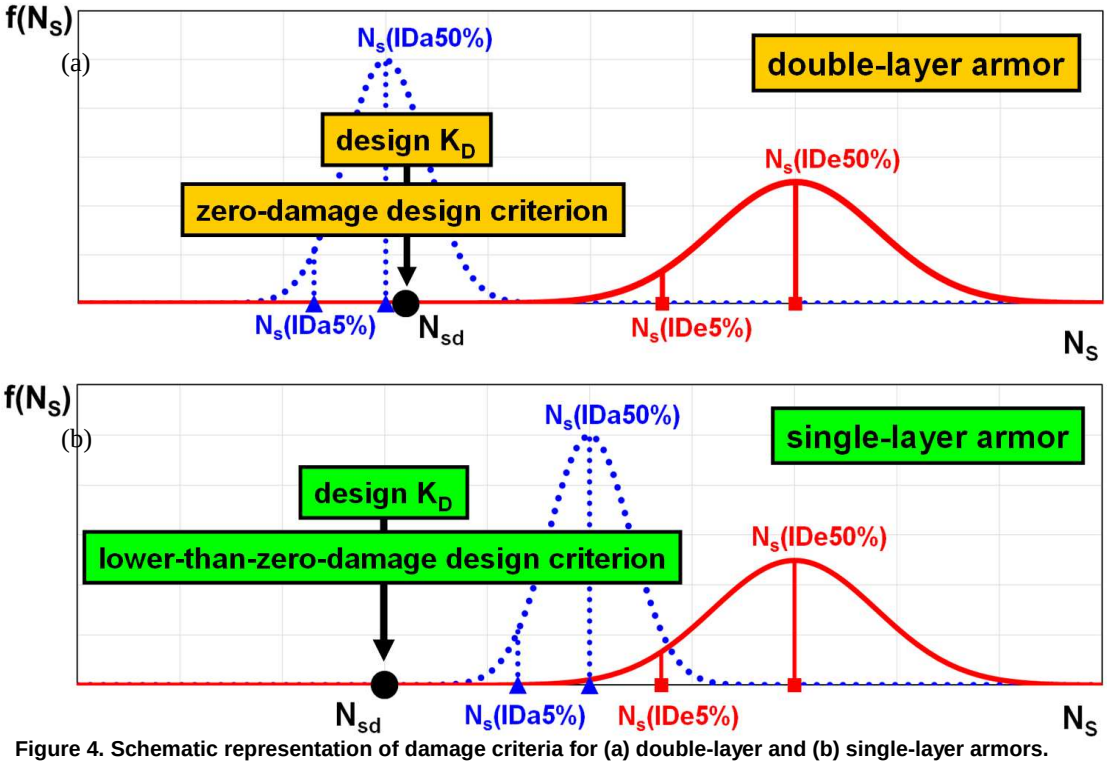

Figure 4. Schematic representation of damage criteria for (a) double-layer and (b) single-layer armors.

The recommended K_D value for double-layer cube armors in roundheads (K_D=5) is associated to the higher safety factors of cube armors in trunks. Fig. 5 illustrates the higher global safety factors of double-layer armors in roundheads compared to trunks.

SF(IDa50%)= 1.13[double-layer cube in roundhead]>1> 0.86 [double-layer cube in trunk]
SF(IDa50%)= 1.18[double-layer Cubipod in roundhead]>1≈ 0.99 [double-layer Cubipod in trunk]

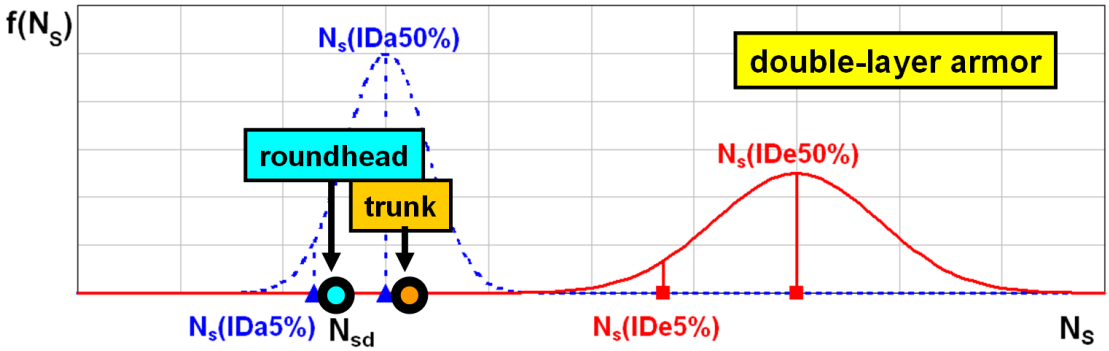

Figure 5. Schematic representation of design stability number (N_{sd}) for roundheads compared to trunks.

In contrast to the considerable differences between safety factors to IDa for different armors, recommended K_D values for different CAUs and number of layers are associated to similar safety factors to IDe. Thus, double-layer armors in trunks and roundheads have global safety factors corresponding to 50% and 5% percentile values:

SF(IDe50%)= 1.40[double-layer cube in roundhead]≈1.35 [double-layer cube in trunk]>>1
SF(IDe50%)= 1.36[double-layer Cubipod in roundhead] ≈1.40 [double-layer Cubipod in trunk]>>1
SF(IDe5%)= 1.17[double-layer cube in roundhead]>1.05 [double-layer cube in trunk]>1
SF(IDe5%)= 1.19[double-layer Cubipod in roundhead] >1.09 [double-layer Cubipod in trunk]>1

The higher global safety factors, SF(IDa50%) and SF(IDe5%), associated to the recommended design K_D for roundheads, may be related to model effects and special restrictions for the construction of breakwater roundheads in laboratories and at prototype scale. Analogously, recommended K_D values for single-layer armors (trunk) are associated to higher safety factors to IDe. The higher global safety factors SF(IDe50%) and SF(IDe5%) associated to the recommended design K_D for single-layer armors (trunk), compared to double-layer armors, may also be related to model effects and special placement prescriptions associated to the construction of single-layer armors in laboratories at prototype scale.

SF(IDe50%)= 1.68[single-layer Xbloc in trunk]>1.35 [double-layer cube in trunk]>>1
SF(IDe50%)= 1.64[single-layer Cubipod in trunk]>1.40 [double-layer Cubipod in trunk]>>1
SF(IDe5%)= 1.17[single-layer Xbloc in trunk]>1.05 [double-layer cube in trunk]>1
SF(IDe5%)= 1.31[single-layer Cubipod in trunk]>1.09 [double-layer Cubipod in trunk]>1

It must be stressed that physical models are built by hand under ideal conditions, without water, and with perfect viewing (see Medina et al., 2010a). In contrast, real mound breakwaters are usually built in long stretches under poor conditions (blind underwater placement with waves and crawler cranes). The greater the expected model effect or difference between the prototype and the scaled model, the higher the global safety factor must be; thus, single-layer armors require higher safety factors to IDe than double-layer armors, and roundheads need higher safety factors than trunks. Thus, SF(IDe5%) seems to be the most relevant global safety factor when comparing different CAUs. After analyzing Table 1, it seems obvious that safety factors to IDa were not relevant to fix the recommended design K_D; design K_D values for different CAUs and different numbers of layers are associated to safety factors to IDe. In Table 1, SF(IDe5%) is the most stringent safety factor, being SF(IDe5%)= 1.05 for the benchmark double-layer cube armor in trunks and SF(IDe5%)= 1.17 for the benchmark roundheads (double-layer cube armor) and single-layer armor (Xbloc in trunk).

The design K_D depends on the required global safety factors and other site-specific characteristics of a given project, such as breaking or non-breaking conditions, overtopping rates, trunk or roundhead, etc. The design K_D values given in Table 1 for the Cubipod are related to the prescribed safety factors to IDa and IDe of the benchmark armor in each category (single- or double-layer, trunk or roundhead) in standard non-breaking and non-overtopping conditions.

Considering the results given in Table 1, single-layer Cubipod armors significantly reduce the economic cost as well as the energy and materials footprints corresponding to the double-layer Cubipod armor. Nonetheless, it is necessary to consider that K_D values are calculated from results of small-scale 2D tests with ideal construction and complete control, conditions which are far better than those typically found in real breakwater constructions. Therefore, double-layer Cubipod armors may be recommended for the trunk when the breakwater is subjected to considerable uncertainties in the construction process and design conditions; e.g. poor construction control, uncertain wave climate or geotechnical problems. On the contrary, Cubipod single-layer armors are recommended for the trunk when the breakwater is subjected to few uncertainties related to the construction process and the site specific design requirements.

SUMMARY AND CONCLUSIONS

The stability coefficient (K_D) concept for single- and double-layer armors is currently used by designers and practitioners to compare the hydraulic stability of different CAUs. Implicit global safety factors to IDa and IDe are used without explicitly distinguishing technical fundamentals of different

armor types. This paper analyzed the implicit and explicit global safety factors associated with the recommended design K_Ds of the generalized Hudson formula.

Design K_D is a parameter in Hudson's formula, originally associated with IDa and having an implicit safety factor SF(IDe)≈1.6. In the case of massive CAUs in double-layer armors (cube, Cubipod, Antifer, etc.) with flexible response, the design K_D values used in practice correspond approximately to an armor damage close to IDa. However, in the case of single-layer armors, the design K_D values used in practice are far below IDa, so as to maintain an adequate safety margin to IDe. Table 1 shows the K_D values and the explicit safety factors for IDa5%, IDa50%, IDe5% and IDe50%; The data in Table 1 refer to conventional cube, Cubipod, Accropode and Xbloc for specific slopes and the indicated number of layers in non-breaking and non-overtopping conditions.

Safety factors to IDa were not relevant to fix the design K_D of different CAUs; design K_D values for different CAUs and number of layers are associated to safety factors to IDe. SF(IDe5%) is the most demanding safety factor, being SF(IDe5%)= 1.05 for benchmark double-layer cube armors in trunks, and SF(IDe5%)= 1.17 for the roundheads (double-layer cube armor) and single-layer armors (Xbloc in trunk). The greater the expected model effect or difference between the prototype and the scaled model, the higher the global safety factor to apply; thus, single-layer armors require higher safety factors to IDe than double-layer armors, and roundheads, higher safety factors than trunks.

The K_D used for massive CAUs such as cubes and Cubipods, in double-layer trunk armors, are related to global safety factors $1.05<SF[IDe5\%]<1.09$ and $1.35<SF[IDe50\%]<1.40$. K_D used for Accropode, Xbloc and Cubipod CAUs in single-layer trunk armors are associated with global safety factors $1.17<SF[IDe5\%]<1.31$ and $1.4<SF[IDe50\%]<1.7$. Finally, K_D used for cubes and Cubipods in double-layer roundhead armors are associated with safety factors $1.17<SF[IDe5\%]<1.19$ and $1.36<SF[IDe50\%]<1.40$. Safety factors are the lowest for massive CAUs in double-layer trunk armors; they were higher for double-layer roundhead armors and the highest for CAUs in single-layer trunk armors. Single-layer roundhead armors were not analyzed in this paper.

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