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REVIEW ARTICLES

Canons of Coastal Engineering in the United Kingdom: Seawalls/Groynes, a Century of Change?

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ABSTRACT

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A Royal Commission on Coast Erosion and Afforestation, 1911, investigated the state of coastal erosion and the resulting protection measures carried out in the U.K. This paper looks at progress undertaken with respect to seawall and groyne protection in the more than 100 years since publication of the report. Seawall design has been greatly modified, although curved and stepped designs were built in the Victorian era, as well as the more common vertical ones. Groynes have also been modified from invariably using wood and rock to other materials, *e.g*., metal, concrete precast elements, geotextiles, as well as shape, *e.g*., Y, gamma, or T shaped groynes rather than orthogonal to the beach. Numerical/physical modelling has now made both structures much more robust and rigorous, although arguments are still ongoing regarding how they are used. A strong environmental concern and the need to maintain the beach for recreation characterize most present day projects and are factors that were considered but spasmodically a century ago. These factors favoured new solutions from submerged structures to beach nourishment, which limit the leading role of the seawall/groyne structures used 100 years ago.

ADDITIONAL INDEX WORDS: *Coastal defence history, seawalls/groynes, numerical/physical models, nourishments*.

INTRODUCTION

Coastal engineering has a long history, as land/sea barriers have been a global phenomenon. In the Mediterranean, harbour jetties/breakwaters were constructed by Egyptians, Phoenicians, Greeks, Etruscans, and Romans (Vitruvio, 30 BC). Little changed until Napoleonic times, when "modern coastal engineering" can be said to have begun (Franco and Verdesi, 1999). Just after this era, Sir John Rennie (1845, p. 24) wrote, "I may confidently ask, where can we find nobler or more elevated pursuits than our own; whether it be to interpose a barrier against the raging ocean." The barrier referred to was a seawall/breakwater, as "soft engineering", *e.g*., nourishment was not considered. Emphasising the seawall point, Bascom (1964, p. 243) in his classic book wrote, "If wave motion is arrested by any imposing barrier, a part at least of the energy of the wave will be exerted against the barrier itself, and unless the latter is strong enough to resist the successive attacks of the waves, its destruction will ensure."

For centuries, coastal protection as a barrier (usually seawalls/groynes) against the sea has been necessary to counter erosional trends. A rising sea level is expected in the future, possibly up to 0.98 m by the end of the 21st century (IPCC, 2014), which could result in more frequent/severe weather events in some regions furthering a consequent increase in erosion/flooding (Church *et al*., 2013). Protection structures come at a high cost, but generally the price paid for hard/soft engineering usually balances out through time, although great variability can occur due to factors, *e.g*., location, labour costs, current erosion rate. For example, construction + maintenance (€/m coastline/year) costs over 50 years: for straight rock groynes is €50–100; seawalls €50–300; shoreface nourishments (every 5 years) of €100–200 (with readily available sand); rock revetments €100–200; (Marchment, 2010).

Udovyk (2003, p. 377) made an apt comment to the concepts expressed in this paper:

> Assessments of adaptation strategies for coastal zones have shifted emphasis away from hard protection structures of shorelines (*e.g*., seawalls, groynes) towards soft protection measures (*e.g*., beach nourishment),

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managed retreat, and enhanced resilience of biophysical and socio-economic systems in coastal regions.

Currently, three alternatives exist for stabilizing an eroding shoreline with sand/gravel beaches. Interventions stabilizing mud, rock cliffs, and rock platform coasts are not considered here.

- Hard: fixed location emplacement of a permanent/hard structure, *e.g*., a seawall, groyne, which tends to preserve upland property and infrastructures.
- Soft: beach replenishment and/or dune reinforcement, used more and more in coastal management.
- Managed retreat: moving structures backwards along with sea-level rise.

However, many organisations, *e.g*., National Trust, U.K., have a philosophy of, "letting nature take its course," unless strategic structures/settlements are threatened. A combination of hard plus soft engineering is also becoming increasingly popular, the former used to lessen engineering maintenance costs; the latter—visual impact reduction. As sand is a possible finite entity, "in the future, in order to have sustainable beaches and coasts, we may need to optimize our coastal beach fills with appropriate structures to reduce annual losses of sand and maintenance costs" (Magoon, Edge, and Ewing, 2001, p. 34). However, dredgers can now reach sand reserves previously unavailable, and it could be expected that even more sand will become available, but this can have negative impacts on the marine ecology (Erftemeijer and Lewis, 2006; Newel, Seiderer, and Hitchcock, 1998).

In this paper, advances and new developments in the design of coastal protection structures such as seawalls and groynes have shown what has been learned since Rennie's (1845) comment together with tenets given in the early years of the last century, when a report by the Royal Commission on Coast Erosion and Afforestation (RCCEA, 1911) was published on the state of U.K. coastal erosion/protection. In Table 1, quotes 1 through 4 are key remarks from the report; quotes 5 through 16 are supplementary ones. The RCCEA (1911) report was written when U.K. was a world power. Since then and especially after World War II, coastal protection has become a global entity, and ideas no longer are the prerogative of any one nation. Hence, this paper gives examples outside the realm of the U.K., as the authors of the 1911 report would today be well aware of the global nature of current research in this field.

BACKGROUND TO THE RCCEA (1911) REPORT

The attention of many early U.K. coastal practitioners was geared to what Bascom (1964, p. 1) once asked, "is there anyone who can watch without fascination the struggle for supremacy between land and sea?" Prior to 1911, published Ordnance Survey (OS) coastal surveys, *e.g*., 1870 and 1899, were simply estimates at best, and there should be no reliance placed on coastal erosion figures given. Erosion figures recorded were patchy apart from areas where large swathes of land had been removed by storms (RCCEA, 1911, point 7).

Table 2 shows some estimates given by the RCCEA (1911) report—compare these with Table 3, which emphasises this comment. No similar early measurements to that shown in Table 3 could be found even after an exhaustive literature search. However, it was emphasized that, "the amount and rate of erosion . . . must be governed to a large extent by the nature and arrangement of the geological formations on the coast line" (RCCEA, 1911, point 132, p. 40), which is certainly valid today. Furthermore, "erosion at many places is aggravated by the erection of defences of the wrong type. . . . And small isolated attempts at protection fail where larger schemes embracing a longer stretch of the coast would prove more effectual" (RCCEA, 1911, point 146, p. 141), again a valid current viewpoint.

Mathews (1918) showed that the 56 km (35 miles) long Holderness coastline had exhibited serious erosion problems, some 1,900,000 tons of cliff material being eroded annually, and since 55 BC the amount lost related to *ca*. 5.6 km (3.5 miles) of coastal retreat. As an example, the Bridlington–Spurn Head section had the most serious erosion issues in Britain—2.7 m (3 yards) per annum from 1848 to 1893. County examples of loss were

- Yorkshire from 1858 to 1906: 313,000 ha (774,000 acres)
- Lancashire from 1842 to 1893: 221,000 ha (545,000 acres)
- Kent from 1858 to 1906: 213,000 ha (526,000 acres)
- Suffolk from 1879 to 1904: 210,000 ha (518,000 acres)
- Lincolnshire from 1833 to1905: 162,000 ha (400,000 acres)
- Very serious erosion existed at Cromer, Southwold, Lowestoft, Flamborough Head, Herne Bay, Beachy Head, Selsey Bill and the Dee Estuary (England and Wales), Solway Firth, Irvine, Croman (Scotland) and Kilmichael Point, Wexford, Tralee, and Cork (Ireland).

The RCCEA (1911) report concluded that options for a sea defence appear to fall conveniently into two distinct parts—either a hard (inflexible) seawall, or a soft (flexible) defence, both either with or without groynes. Seawall failure was deemed to be caused by a loss of mass in the section, deficient foundation depth, and want of efficient surface protection against the force of the falling water. Comments on the remarkable diversity of views held on the subject of erosion and its remedies were catholic in scope (RCCEA, 1911, p. 117). One such was that of an almost vertical seawall with a prominent tooth, which, "at Hastings the form sent the bulk of rising water outwards, a design feature being the weight above the projection" (RCCEA, 1911, p. 133; Figure 1a).

Many examples were given of the fact that seawalls and groynes were interlinked*, i.e.* "In all works of sea defence, groyning is of the first importance, and is necessary in most cases where a sea-wall or any kind of breastwork is built so that seawalls have little value unless accompanied by groynes" (RCCEA, 1911, p. 43; Figure 1b). Grantham (RCCEA, 1911, p. 43) further commented on this theme stating that seawall scour was recognised, in that "to build seawalls first, and thus set up scour, and then to protect them by groynes, was putting the cart before the horse."

RESULTS

Many examples of coastal protection can be given, but the main thrust of the RCCEA (1911) report was on groynes and

Table 1. *Selected key quotes from the RCCEA Report (1911).*

Quote No.	Quote	Page No.	Notes
General			
1	Sea walls, unless properly constructed . . . are agents of their own destruction inasmuch as, if a wall be not carefully designed and erected, the waves breaking against it, when recoiling from its face, tend to scoop out the beach material at its foot; removal of this material, if not held in place by groynes or other adequate means, causes an undermining of the structure, which not infrequently leads to destruction of the wall	83	Point 20
2	Considerable difference of opinion exists . . . with regard to the most suitable type of groynes to adopt, along any given portion of the coast, more particularly with respect to height, length, distance apart, the angle at which groynes should be placed on the shore, their life and their cost	84	Point 51
3	With regard to seawalls and similar works of defence, for the reasons we have given their construction should almost invariably be accompanied, by suitably designed groynes extending seawards continuously from the base of such works and carried out simultaneously therewith	89	Point 51
4	With respect to groynes, . . . our view is that, to be of maximum efficiency, they should be of a distance apart about equal to their length; that they should extend continuously from the shore or work to be protected, to the vicinity of the low water of spring tides	89	Point 51
Further seawall comments			
5	Protection of land by a low sea-wall formed a just cause of complaint by a proprietor of adjoining unprotected land, who might be victimized through his neighbour adopting this particular method of protection as an expedient for saving his own land. In this respect legislation might be extended to prevent such.	118	A comment applicable to the present day
6	A tar-paved surface exposed to the sea and formed over made ground was not sufficient. It would break up.	118	See later—the tarred pavement at Porthcawl, which has proved to be a distinct success
7	A stepped wall protected the upper vertical surface from the upward scour when the water rushed up and then fell upon the setoff	128	A common practice today, *e.g.*, the $11 million seawall plus groynes recently finished at Towyn, Wales, U.K.
8	It was a mistake to construct a sea-wall with concrete facework . . . the concrete needed protecting by face-stones. While such stones should be hard, he did not see any necessity for their being smooth.	138	
9	As an addendum, the report also alluded to “the suicidal policy of allowing the removal of shingle from the beach where it was used for the purpose of defence”	132	It is well known that removal of any beach sediment should only be considered after careful examination of the environment. Beaches form one of the best possible counters to coastal erosion.
Further groyne comments			
10	Engineers had tended to give rise to conflicting theories than to establish facts	111	In a “state of the art” paper, Brampton and Motyka (1983, p. 153) argued that “until the 1950’s progress was mainly the result of practical experience, but research carried out since then has given us more insight into groyne behaviour. However, it must be admitted that there is still a considerable divergence of opinion on how to design groynes effectively.”
11	The best angle, length, height, and distance apart of groynes could be ascertained only by experience and trial. As regarded height and distance apart . . . a much better pleasure-beach was obtained if the groynes were comparatively close together, thus avoiding too great a drop on the “lee” side, and this plan also demanded a less substantial form of construction.	130	Brampton and Motyka (1983, p. 153) pleaded for, “the engineer to make known both his successes and his failures in using groynes for coast protection.”
12	The best direction was at right angles to the prevailing winds	107	For angle
13	longer groynes should be carried out to low-water mark of ordinary spring-tides, but this had been objected to by the Town Council as being likely to cause inconvenience to persons riding or driving on the foreshore	139	For length, a salutary thought, as today with a few exceptions (*e.g.*, Brean, Somerset) driving is forbidden on most U.K. beaches; horse riding not so
14	that some 2–3 feet above the surface was sufficient	121	For height, one that is standard today
15	No general rule can be laid down as to the space that should intervene between groynes; so much depends on local circumstances that experience of these alone can determine this factor	117	For distance apart; see also quote 11
16	Timber groynes on a foreshore were, in the case of marine watering-places, unsightly and inconvenient obstructions on the beach-whether they were high groynes or of the Case type . . . but also that, as a means of coast-protection, they were, speaking generally, a **complete failure** [emphasis added]	104	A final note; so again a catholic spectrum of viewpoints.

Table 2. *Coastal gain/loss (ha) of the high/low water lines, mainly from 2.5 cm to the 1.6 km (6 inches to the mile) OS maps based on the RCCAE (1911) report.*

	High-Water Limit		Low-Water Limit	
	Foreshore and Land		Foreshore and Sea	
	Loss	Gain	Loss	Gain
England and Wales	1,899	14,344	18,061	5,422
	+12,445		−12,639	
Scotland	330	1,904	5,037	1,649
	+1,574		−3,388	
Ireland	458	3,177	5,273	2,250
	+2,719		−3,023	

seawalls. Consequently this review paper has concentrated upon these two types of structures.

Sea Walls (RCCEA quotes 1 through 9, particularly 1 and 3)

These are built not only to protect settlements, industrial plants, roads, railways, and promenades from wave attack and storm surge, but also to prevent low lying lands flooding. The classic Mathews (1918) book showed how well seawalls protected a coastline; however, the report (RCCEA, 1911, p. 136) commented that, "jetties were cheaper and preferable to seawalls." One century later, Kim (2015) wrote that seawalls and revetments create a hard engineered shoreline that can resist wave forces/storm surge action and provide hinterland development protection (Figure 2a). It should be noted that erosion processes developing downdrift are frequently countered (especially in Mediterranean areas) by adding further engineering structures—the so called "domino" effect (Anfuso, Martínez-del-Pozo, and Rangel-Buitrago, 2012).

It is generally accepted that beaches experiencing erosion, *e.g.*, because of relative sea-level rise (or reduced sediment budget) and fronting a seawall, will eventually disappear, since they cannot adapt to the new sea level. Coastline landward migration becomes impossible because of man-made structures, and erosion processes related to sea-level rise together with increasing storminess can deepen nearshore areas fronting the structures causing complete disappearance of the beach/salt marsh, *i.e.* the coastal squeeze (Doody, 2004). The effects on beaches tend to be most sensitive to its surf zone position, beach slope, and the reflection coefficient (Ruggero, 2009) which can be reduced with dissipative rubble-mound seawalls (Figure 2a) or with complex structured profiles. If seawalls are built they should have the lowest possible reflectivity and highest possible permeability to drain groundwater from the landward side (Toyoshima, 1985).

More controversy exists on the seawall effect on beaches experiencing active erosion during episodic events, and each seawall construction produces an ongoing debate over its long/short-term effects. Van Rijn (1998) has given an overview of the physical processes and the seawall effect on nearby hydrodynamics and morphology distinguishing between two scouring types caused by a sea wall: toe and dune/beach scour at seawall ends. Several empirical formulas were presented to quantify these types of erosion mechanisms.

Seawalls do modify onshore-offshore/longshore sediment movement. Allsop (2005) raised the following questions.

Table 3. *Current coastal erosion and protection in the U.K. islands with a surface area smaller than 1 km² and inland shores (estuaries, fjords, bays, lagoons), after Masselink and Russell (2008).*

Region	Coast Length (km)	Coast Length Eroding		Coast Length with Artificial Beaches and Defence Works	
		km	%	km	%
NE England	296	80	26.9	111	37.4
NW England	659	122	18.5	329	49.9
Yorkshire and Humber	361	203	56.2	156	43.2
East Midlands	234	21	9,0	234	99.8
East England	555	168	13.3	282	68.8
SE England	788	244	31,0	429	54.2
SW England	1379	437	31.7	306	22.2
England	4273	1275	29.8	1947	45.6
Wales	1498	346	23.1	415	27.6
Scotland	11154	1298	11.6	733	6.6
N Ireland	456	89	19.5	90	19.7
Total	17381	3008	17.3	3185	18.3

"How and how much" do they affect transport processes? Are "effects beneficial/detrimental"? Do they "best serve public interest"? Dean (1987a) evaluated common assumptions in the light of engineering concepts, whilst a state of the art paper by Kraus and McDougal (1996) summarised findings of many workers concluding that the seawall/beach interaction is very complex, and seawall effects on beaches have not been well documented, many statements being mere conjecture based on limited observations and quantitative data. Even up to the mid 1980s, viewpoints on seawalls were still unclear, *i.e.* "the effect of seawalls on beaches and on coastal processes has not been well documented" (Weggel, 1986, p. 29).

Basco (1999) and in particular Basco (2004), emphasised that there are many misconceptions behind the perception that seawalls increase erosion and destroy beaches. The latter argued that most negative effects attributed to seawalls have been proved wrong. Basco *et al*. (1997, p. 208) commented that:

> . . .volume erosion rates are not higher in front of seawalls but seasonal sand volume variability in front of walls is generally greater than at non-walled locations. Winter season waves drag more sand offshore but summer swell waves pile more sand up against walls in beach rebuilding.

Hill *et al*. (2004) also showed that beaches with seawalls recover after storms, but later than natural beaches. Similarly Gabriel and Terich (2005) found few differences between seawall backed and non–seawall backed beaches.

A completely different opinion was expressed by Bernatchez and Fraser (2012, p. 1559–1560) who, in two coastal sectors located in the Gulf of St. Lawrence, found that "hard reflective defence structures built parallel to the coast contribute to the sediment deficit of beaches formerly backed by sandy coast" and that, "the rates of shoreline retreat were found to be 3 to 5 times higher around the structures after they were implanted." Similarly, Romine and Fletcher (2012) found that armouring on eroding coasts can lead to beach destruction.

So how much progress has been made since the statement of Mathews (1918), that seawalls neither promote accretion nor

Figure 1. Old and new shore protection structures in U.K. (a) The Hastings seawall in the 1960s (East Sussex Library). (b) Seawall and groynes at Dimchurch, *circa* 1940s. (East Sussex Library). (c) Towyn, 1960s. (d) Towyn, 2015. (e) Groynes at Seaford, 1912 (East Sussex Library). (f) Seaford, current conditions (East Sussex Library).

reduce any regional erosional trend of generally stabilising a contained area but not protecting the fronting/adjoining beaches? Beach width reduction, and later disappearance, is due to the resilience reduction of the coastal system, which cannot adapt to the new sea level (or reduced sediment budget) with inland profile migration. In essence seawalls represent shore protection structures and not beach protection structures—a very important distinction on an eroding coast.

Allsop *et al*. (1999) showed that seawall associated processes all relate to wall base scour depth. However scour does not always take place (Kraus and McDougal, 1996), being a function of location and structure type. Carter, Monroe, and Guy (1986) also emphasised location, concluding that increased protection leads to narrower beaches. Runyon and Griggs (2003) showed that Californian armoured structures (18% of the total Californian

Figure 2. Shore protection structures in use in RCCEA times. (a) 3 km long rubble-mound rock armour revetment, Buddon Ness, Scotland. Built 1992/3 by Ministry of Defence to protect a military training area. Sand/beach interchange is now inhibited causing degraded dunes. Photo by Robert W. Duck. (b) Vertical masonry walls dating back to the 1800s at Pittenweem, Scotland. It has been repaired many times. Photo by Robert W. Duck. (c) Rock groynes (Rosslare, Ireland). (d) Wood permeable groyne (Kołobrzeg, Poland).

beach area) reduce the sediment annual supply by some 20%, but stressed the uncertainties, as natural processes vary spatially and temporally. In a later paper, Kinsman and Griggs (2010, p. 73) argued that, "shoreline orientation and blocking distance are the most important factors contributing to sand retention success based on the impermeable structures present along California's coastline today." Their findings suggested that seawall removal to increase sediment supply did not have significant impacts on the normal littoral budget.

Toe scouring is the major concern with vertical structures, so much so that in 1906 the Porthcawl seawall, U.K., had eroded to its toe; in 1982 a tar macadam ramp was superimposed on fronting cobbles (Figure 3a) and has been a resounding success, as waves now break some 30 m from the seawall (Blott *et al.,* 2013). Today, there exists a variety of design shapes for these walls, all designed to extract wave energy and protect the toe, which in turn protects landward infrastructures. Design is frequently focused on certain parameter values, *e.g.*, $p_{\max}$ for impact pressure and $V_{\max}$ as maximum overtopping wave volume. A structure can then be designed using the proper partial safety factors, or with a full probabilistic approach (van der Meer, 2015), *e.g.*, slope breaks in the concrete seawall profile, inserting prominent elements to increase roughness, and using perforated elements discharging water in an underlying permeable core.

In 2010, a series of papers appeared in *Shore and Beach*, giving examples of the structural response to erosion, and a salutary thought is that:

> …many of us have recognised for many decades that both natural and engineered structures play a crucial part in maintaining beach width where there would be less or no beach without them, . . . to say that all structures on the coast are "bad" is, well structurally deficient, and downright wrong (Flick, 2010, p. 2).

This echoes the codified elements of coastal hazards, seawalls, and coastline natural character adopted by New Zealand, where they are part of a "package" of responses focused on a long-term sustainable outcome, where policies permit seawalls only where they are the best (as compared with nourishment) future practicable option (Jacobson, 2004).

Figure 3. Shore protection projects in use today. (a) Seawall and tar macadam ramp (Porthcawl, Wales). (b) Groyne with a crest walkway (Cecina, Italy). (c) Low-crested breakwaters (Emilia-Romagna coast, Italy). (d) Beach nourishment with "rainbowing" (Tuscany coast, Italy).

Groynes (RCCEA quotes 1 through 4, particularly 2 and 4, and quotes 10 through 16)

Quotes 2–4 relate to techniques that are "an old and intuitive means of reducing beach erosion and are found along the coast worldwide as both engineered and nonengineered, ad hoc structures" (Kraus and Kelly, 2004, p. 1). The possibility of using any kind of material, wood, rock (Figure 2c), bricks, steel sheet pile, geocontainers, precast elements, *etc*. and apparent ease of design make them one of the most widespread and oldest shore protection structures (Traynum, Kana, and Simms, 2010). The RCCEA (1911) documents groynes at Spur Head (Yorkshire, U.K.) in 1850, but European groynes are very old, *i.e*. at Texel, the Netherlands, "beginning in the early 17th century, the first defensive works such as wooden groynes and underwater willow mattresses were placed on the southern embankment to retard the erosion and to protect the toe of the dikes" (Elias and van der Spek, 2006, p. 12). Mathews (1918) showed how many different groyne types were in existence, *e.g*., high/low timber, concrete block, Owens-Case reinforced concrete, adjustable/flexible, the RCCEA (1911, p. 136) adding "that low groynes gave better results than high groynes." Today, groynes extend laterally for kilometres in many countries, *e.g*., Italy, where more than 200 elements "should" defend 20 km of Puglian coast.

Groynes should generally not be considered the most appropriate shore protection method along low/moderate erosion rate beaches (Traynum, Kana, and Simms, 2010)—the dictum followed in 1911. The basic groyne introduction effect is nearshore longshore sediment transport (LST) reduction, triggering upcoast expansion with a consequent limited feeding effect on downdrift sectors. Walter and Douglass (2011, 3) argued that downdrift effects may be minimal or null where, "net littoral drift is small and littoral drift is not dominant in one direction or the shoreline is dominated by adjacent headlands or other structure." Groynes are seemingly most successful where net LST is substantial (Everts and Eldon, 2011). In mixed sediment beaches, groynes trap coarse material in updrift cells, allowing finer grains to overpass groyne tips so feeding downdrift segments (Cipriani and Pranzini, 1990).

A dictum is that upcoast filled beach size is a function of effective groyne length, spacing, tip alignment, sediment size, and relative angle between incoming waves and coastal orientation determining the net/gross transport rates, with fillet slope increasing with the sediment size contained within beach (Everts and Eldon, 2011). French (2001, p. 76) suggested extending groynes for, "40–60% of the width of the surf zone in order to interrupt enough sediment for beach accumulation, but allow sufficient to proceed downdrift to minimize the impact of sediment starvation." Design criteria generally differ between permeable/nonpermeable groynes. Suggested groyne spacing/groyne length values have varied from 1:1.5 to 1:5 (Silvester and Hsu, 1993). Permeable groynes (Figure 2d) should have a length slightly larger than surf zone width, and spacing should be equal to their length (Trampenau, Oumeraci, and Dette, 2004). Impermeable groynes generally have a groyne spacing (S) between 1.5 and 3 times the groyne length (Van Rijn, 2011), and the effectiveness of these dimensions has been confirmed by wave basin experimental research (Özölçer *et al.,* 2006). To promote sufficient sand bypassing, groyne length should be smaller than storm surf zone width. These studies were not exactly alien in 1911, but the prevailing viewpoint was width equal to length, and extent from shore to low water spring tide position.

Groyne lengths have been classified as long (overpassing the breaker line) and short (staying inside), and as the bulk of LST occurs between the shoreline and breaker line, long groynes trap almost all the sediment flux and are effective but trigger stronger erosion on the downcoast beach segment. This was known in 1911, but perhaps not on a theoretical level. In the U.K., many such examples of long groyne fields exist, *e.g.*, Lancing, where in 2006 an £18 million scheme for 4.3 km of coast constructed 44 rock groynes (160,000 tonnes) to replace 34 original timber ones with additional wooden ones in between. A more recent example is the $11 million coastal protection structures at Towyn, Wales, U.K., involving a seawall and extensive groyne series, carefully chosen with respect to length, spacing *etc*., as over the last 100 years, the beach width had decreased and its level dropped by up to 3 m (Figure 3d; Atkins, 2009).

At present, T, Γ (gamma), Y groynes, or fishtail groynes, frequently with a submerged appendix, are common, but they were essentially unknown in 1911. For example, as part of a £36 million coastal defence scheme funded by the U.K. Environment Agency and Essex County Council, 23 new fishtail rock armour groynes, 90 m in the length and with a 220 m distance between groynes, are currently being installed. These groyne types can be designed along very exposed, eroding coasts to reduce wave energy into the compartments preventing/diminishing rip current generation near groyne heads (Van Rijn, 2011). For T-groynes to further accrete, head length should be as long as possible, resulting in more expensive construction; therefore, cost–benefit analyses is required, but, "in order to reach more reliable conclusions, more field data are necessary!" (Özölçer *et al*., 2006, p. 402).

Other configurations have been developed to increase containment efficiency, with structures curving more or less sharply to the updrift direction, *e.g*., bayonet groynes whose construction started at Marina di Pisa in 1913. Groyne orientation research, mentioned in the 1911 report, is an area that has been studied intensively in the past century. In 1911 groynes were essentially normal to the beach, and it was far sighted of the 1911 report authors to challenge this viewpoint. Currently, oblique groynes have been used to reduce scouring at their heel (root), with an angle suggested to be equal to that of the strongest wave's crests, which, when combined with nourishment, reduces down coast erosion (Donohue, Bocamazo, and Dvorak, 2004). Reflection on oblique groins can be used to reshape a beach following specific needs, *e.g*., an oblique (20°) steel sheet pile constructed at Elba Island (Italy) pocket beach prevented longshore sediment transport silting a marina (Farrell, Pranzini, and Steinhardt, 2003).

Groynes have fallen out of favour, since they do not always achieve their objectives and may exacerbate erosion problems (Short, 1991), and in this context an interesting observation was that of Bruun (1953, p. 68), "in many cases it would probably have been better if groynes had never been constructed, because they have done more harm than good," and a sound example of this comment is the Seaford groyne system (Figure 1e). In 1987, groynes were eliminated and a major beach recharge project was formulated using seabed shingle. Apart from the terminal groyne at Splash Point (foreground of Figure 1f) no groynes stop longshore drift, and each year lorries take accumulated shingle from the groyne westwards to replenish the beach.

The long groyne northern Tuscany coast sequence, built to counteract erosion in the 1970s–1980s, triggering or increasing erosion exemplifies this point. Shabica *et al*. (2004) gave an opposite viewpoint of a groyne field located well inside a Lake Michigan surf zone, finding no long-term downdrift effects. Positive results were attained at isolated groynes at East Hampton, New York, U.S.A., where the gross longshore transport was far larger than the net one: accumulation on both groyne sides made the structures behave like headlands creating crenulated shorelines on both sides (Bokuniewicz, 2004). Some U.S. coastal states have even enacted stringent coastal zone management guidelines that severely restrict, or prohibit, groyne construction, *e.g*., South Carolina. Groyne fields have even been removed—virtually unheard of in 1911, *e.g*., at Sandy Hook, New Jersey, U.S.A., due to its great impact on downdrift coastal sectors (Nordstrom and Allen, 1980).

A further consideration concerns stakeholders' acceptance, not taken into account by the RCCEA (1911), but pertinent for the 21st century. Gòmez-Pina (2004) argued that their unattractive aspect makes them unpopular, and special care must be paid to their aesthetics, but Williams *et al*. (2005) showed that beach users really liked them. Today, modern groynes are frequently built with a crest walkway to allow easy, nondangerous access, transforming defence structures into promenades (Figure 3b); that was unheard of in 1911 when they were simply coastal protection structures. Additionally, the RCCEA (1911) report was a study of the U.K. coast's geomorphology and protection measures in place, so no consideration was given to groyne rip current formation (Short and Masselink, 1999). Rips are of great concern today, not only for the sediment loss (Silvester and Hsu, 1993), but also for beach safety issues (Leatherman, 2013).

For centuries, in parallel with traditional rock groynes, wood permeable groynes were used (Figure 2d), but now are considered a "soft" groyne version. They slow down longshore currents, favouring sediment deposition without offshore deflection. Updrift elevation occurs at all groynes, and scouring, indicating a current velocity increase, is invariably present at the tip (Trampenau, Oumeraci, and Dette, 2004). Nevertheless, permeable groyne adoption remains limited to its origin area, with few Mediterranean but many U.K. applications, *e.g.*, 89 permeable between Trimingham and Happisburgh (13.6 km).

DISCUSSION

The above has given a spine to the findings relating to seawalls/groynes. Within the past 100 years, there has been a mushrooming of innovative techniques relating to coastal protection that was unheard of in 1911. Stepped seawalls had been introduced, but physical/numerical modelling, extensive monitoring, reefballs, geotextiles, *etc*. now appear to be mandatory considerations for many coastal protection projects. Similarly, the basis of 1911 coastal protection was the safety of coastal settlements and roads, now aesthetics also plays an important role.

The Main Differences

If RCCEA members could visit the coast today, they could see many differences regarding coastal structures; the most evident being the material used: once natural rocks were prevalent (except in seawalls where concrete was increasingly used, although often covered by rocks), now concrete precast elements of different shape are frequent (dolos, tetrapods, accropods, *etc*.), but behind this sounder differences exist. Two of the main differences between groyne and seawall research within the last century have undoubtedly been laboratory testing and explicit field studies. A third, based on new concepts and techniques, is dealt with later in this paper. Today, engineers, developers, and coastal planners need qualitative/quantitative descriptions and models of seawall effects on coastal environments in order to make intelligent decisions about when/where protection structures are appropriate.

Early laboratory seawall testing studies were conducted during World War II, *e.g.*, Dorland (1940), concluding that the main wave action force did not necessarily cause seawall base scour but placed material in suspension and removal by currents. This is as true today as when first written, but a scaling problem existed in these early experiments. Sawaragi and Kawasaki (1960) found the maximum scour depth is approximately equal to the incident (deep water) wave height. Xie (1985) showed that for fine sediments, maximum scour was at standing wave system nodes in front of the seawall, where velocities are highest. For coarse sediments, maximum scour was between node and antinode, but different scouring patterns were found for regular and irregular waves. Sato *et al*. (2014) from physical and numerical studies showed that some deposition can occur in front of a seawall.

A deficiency in most field studies was an absence of description of concurrent changes in waves, currents, *etc*. through storms, which obscures relationships between cause and effect on beach changes and equilibrium profile development. If a beach profile is close to equilibrium, storm arrival may result in no change or erosion—Dean's (1991) approximate principle. However, most profiling depths are not normally taken to the depth of closure (Phillips and Williams, 2007), so erosion/deposition refers mainly to the visible beach and not to the total active profile. Plant and Griggs (1992, p. 183) showed that in mild conditions, minor effects occurred but concluded "that increasing wave energy would increase the differences in responses between natural beaches and those protected by seawalls."

Protection emphasis was put on groynes in the RCCEA (1911) report, but since then a lot of water has passed under the bridge, but basic questions remain. The difference today is that based on many built and monitored structures and the availability of sophisticated physical/numerical models, answers are no longer based only on experience but also on a sound theoretical basis. However, the coastal system variables and the structures themselves are so large that, similar to other defence devices, a comprehensive solution of all aspects is still not possible, *e.g.*, "Few quantitative studies of groyne functioning have been conducted. . . . little field monitoring has been done. Most moveable physical models were performed at small scale and may not be reliable in all aspects" (Wang and Kraus, 2004, p. 342). Past century studies on permeable groyne efficiency, wave tank experiments, and numerical models have resulted in "design criteria and guidance for groyne length and permeability, pile depth and spacing, and groyne field characteristics such as multiple groynes and spacing versus double width groynes" (Poff *et al*., 2001, p. 238). In this way an old intuitive structure has been elevated to the status of a scientifically based device after one century.

What definitely has changed from 1911 to the present is seawall design. Their evolution was driven by the need to reduce seawall height, *e.g.*, from a cost or landscape impact viewpoint, but maintaining efficiency in shore protection, prevention overtopping, and reduction of backwash toe velocity to limit scouring. This is the rationale for the different seawall profiles resulting from numerical equations and physical studies that continue today (Anand, Sundar, and Sannasiraj, 2011). Nevertheless, "Results from the use of these equations are very approximate at best. If determination of overtopping rates is important in coastal project design, considerations should be given to the conduct of model studies" (Sorensen, 2010, p. 237). Research (both laboratory and field) in the area of wave run up and overtopping has been exhaustively documented by, amongst others, van der Meer *et al*. (2006), Hoffmans *et al*. (2008), van der Meer (2011, 2015), and Le Hai Trung *et al*. (2010).

The Societal Debate

Whether hard stabilisation is worth the cost is still an ongoing debate. Cost and technological solution sustainability are critical factors, as seawall cost effectiveness in order to protect coastlines is now being questioned (Cipriani, Pelliccia, and Pranzini, 1999; Wiegel, 2002). There is also an issue of cost/benefit timeframes—the immediate problem of private property falling into the sea is easily seen, but the long-term effects of seawalls on public property are less tangible. In communities facing imminent coastal hazard threats that directly affect beachfront residents, local councils tend to focus on the false economy of an immediate "quick fix" (usually a seawall) that looks reassuringly solid and is thought to protect threatened private property, remove liability claims, *etc*. (Jacobson, 2004).

For example, over the past 25 years erosion has claimed some 405 ha (1,000 acres) of barrier island in South Carolina, U.S.A. In 2014, the South Carolina House Natural Resources and Agriculture committee voted 17:1 to advance a bill allowing Debordieu Beach, Pawleys Island community to reconstruct the old relict seawall despite a 26-year-old statewide ban on seawall building (Fretwell, 2014).

Sometimes, a seawall is an absolute necessity, especially in coastal urban centres, *e.g.*, the stepped seawalls of Rhyl, Wales, and the recent aforementioned $11 million seawall and groyne construction, Towyn, Wales (Figure 1d). These are good examples of modern coastal protection. When RCCEA (1911) was written, most seawalls were simply an almost vertical wall or stepped, although some more sophisticated structures did exist in U.K., such as the Hastings seawall (Figure 1a).

In his 1987 paper, Dean (1987b) commented on the fact that whilst "passive" erosion—erosion which would occur without the seawall—can occur; "active" erosion—associated with erosion caused by the seawall—does not, and is widely quoted to favour hard structures in recreational areas. A key point is whether any seawall is partially or fully exposed to waves, and it is prudent to remember that "the best gauge of the likely success or environmental impact of coastal engineering . . . is the historical experience on that beach" (Cooper and Pilkey, 2004, p. 642). On this score, it is a salutary thought that at one of the most iconic and historic places in the U.S.A.—Jamestown, Virginia—"if it hadn't been for Colonel Yonge's sturdy stone and concrete bulwark that has withstood the erosive waters of the James for a century, there would be no reason to visit Jamestown at all" (Tucker, 2002, p. B3). The Association for the Preservation of Virginia Antiquities has a plaque there that reads:

> Col. Samuel H. Yonge (1843–1935) designed and built, during the early years of the 20th century, the stone and concrete seawall at Jamestown that successfully stopped the erosion of the historic island, thereby preserving it for posterity.

Some Innovative Concepts and Schemes for Coastal Protection, post 1911

Several new concepts and schemes have been developed since RCCEA (1911), and some older concepts have been adapted/improved to address new societal and environmental requirements not considered 100 years ago, *e.g.*, a larger attention to aesthetics and its impact on the surrounding landscape; reduction of possible impact on water quality and local hydrodynamic conditions (*e.g.*, for swimmer safety); and attention to long-term and large-scale issues (*e.g.*, sea-level rise). There is now a deeper ecological awareness that motivates coastal engineers to design coastal structures following a "Building with Nature" principle. Other examples are oyster reefs or the use of plants as nearshore wave reductors (Cheong *et al*., 2013). These concepts are nothing else than a newer version of the old sea-wall and breakwater schemes in that the principles of wave energy dissipation are essentially the same despite reefs/vegetation being used rather than concrete. The premise of using engineering structures to enhance biological/ecological diversity is very different from traditional Victorian approaches to coastal protection.

Firth *et al*. (2014) reported on work carried out on the design of coastal defence structures in the THESEUS project (2009–2014), which aimed to conserve/restore native species diversity. They manipulated biodiversity on defence structures through various interventions, *e.g*., artificial rock pools, pits and crevices on breakwaters; tested the use of various rock sizes in gabions; used a precast habitat enhancement unit; gardened native habitat-forming species, *e.g*., threatened canopy-forming algae on coastal defence structures. Strong evidence exists that concrete structures are poor surrogates for natural rocky shores, often supporting assemblages with lower species abundance and diversity (Coombes *et al.,* 2015). Their findings indicated that texture had a significant effect on colonisation. Smoothed tiles supported significantly fewer numbers of barnacles; intermediate roughness (grooved concrete) supported significantly greater numbers. Early colonists, *e.g*., barnacles on marine concrete, are helped by manipulating surface heterogeneity at a millimetre scale.

Submerged breakwaters, which reduce a structure's visual impact, are now often used instead of standard breakwater schemes. Recirculation and water quality can also improve when these structures are replaced. These come in many formats acting as sills to retain sand and have had mixed reactions, *e.g*., Beachsaver reef^{TM}, Double T-sill (Basco, 2008; Morang, Waters, and Stauble, 2014). In Tuscany and Emilia-Romagna (Italy) a number of old high-crested breakwaters have been lowered and combined with nourishments and monitored for a 10-year time window (Preti *et al.,* 2011; Figure 3c). The experiment was successful (*i.e*. lower visual impact, improvement of water and seabed quality, beach widening), although costs increased due to nourishment maintenance. However, design of submerged structures is a more complex task than for standard structures. Therefore, numerical (and possibly physical) modelling usage is really required (see next section). An experimental submerged breakwater project at Palm Beach (Florida, U.S.A.) showed that when no proper preconstruction detail studies were carried out, then structures can lead to increased erosion due to longshore current formation—developed because bottom currents cannot overpass the reef—behind the structure. Here volumetric erosion rates doubled after construction, and the experiment was concluded with the structure's final removal (Dean, Chen, and Browder, 1997).

Macro tides have significant impacts on sediment transport processes, especially on high-crested breakwaters producing larger yearly changes, whilst low crested ones form salients and embayments at a much reduced rate (Pan *et al*., 2010). Wave overtopping has a significant impact on waves and currents in these embayments (van der Meer, 2011). The most successful sustainable beaches on sediment starved coasts can be associated with nearshore attached breakwaters, where the beaches are filled with sand before mitigation (Pan *et al*., 2010).

Submerged groynes not mentioned in the 1911 report are recent and present only in the Mediterranean. Those rooted to the dry beach, frequently with a buried segment, enter the sea at the swash zone and run offshore with a 1–2 m high crest (Berriolo and Sirito, 1973). built with rocks, concrete precast

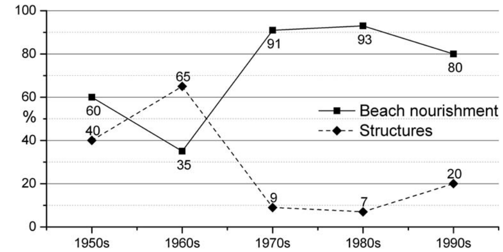

Figure 4. Shift from hard to soft engineering alternatives by the U.S. Army Corps of Engineers (from Hillyer, 1996).

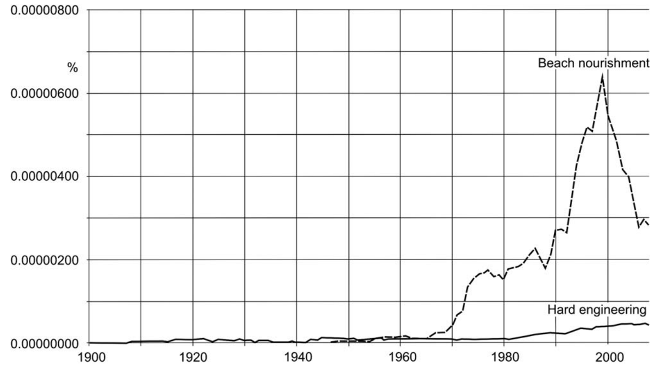

Figure 5. Hard engineering *vs*. beach nourishment: the contribution by published books from 1800–2010 (www.googlengrams).

elements, sand bags or geocontainers filled with sand or concrete, they trap sediments moving longshore, triggering updrift side ramp formation. Sediments are deposited downdrift due to current velocity reduction after passing the groyne crest. Postconstruction beach monitoring and numerical model runs showed tip structure scouring as in permeable groins (Aminti *et al*., 2004).

A coastal engineering practice little known in Great Britain at the time of RCCEA (1911) was large-scale nourishments (Figure 3d), and a sound account of the European experience is given by Hanson, Brampton, and Capobianco (2002). Increasing environmental awareness together with recent predicted sea-level rise scenarios has also led to upscaling of standard nourishment volumes, an extreme example being the "Sand Engine," in southern Holland (Stive *et al*., 2013). This mega-nourishment has a sand volume of approximately 21.5 million m^3, and advanced monitoring and modelling techniques were crucial for its design. Figure 4 shows how much soft engineering has largely replaced hard engineering, and this is also exemplified in the literature (Figure 5).

Increasing environmental attention is also driving designers to use multifunctional structures, *e.g*., those favouring fishing *via* artificial reefs (Lokesha and Sannasiraj, 2011; Miles, Russell, and Huntley, 2001; Morang, Waters, and Stauble, 2014) composed of precast elements acting as wave attenuators (*e.g*., Tecnoreef® modules, Reef Balls, Wave Attenuation Devices).

Beach dewatering has been applied in many places, *e.g*., Sweden, Denmark, Great Britain, France, but independent comprehensive monitoring has been performed only at Alassio, Italy, and showed inconclusive results (Bowman, Ferri, and Pranzini, 2007). Ciavola, Vicinanza, and Fontana (2008) analysed beach response at several Italian installations and was critical of its efficiency in limiting erosion. The Pressure Equalization Module©, *i.e*. vertical drains connecting upper sand layers with deeper ones, appears to be even more ineffective (Walstra, Brière, and Vonhögen-Peeters, 2014).

Therefore, although many new technologies have occurred, seawalls, groynes still form the majority of nonharbour defence projects present along most of the world coasts. Currently, along with the question of negative fallouts on adjoining coastal sectors of traditional hard projects, there exists a growing environmental concern plus awareness of the natural landscape's economic value, which has moved designers toward softer shore protection strategies. Protection of natural landforms, including cliffs, beaches, and spits, should not "freeze" their morphologies but allow process reshaping, possibly reducing erosion rates.

The Role of Monitoring and Physical/Numerical Modelling after 1911

Advances in coastal engineering practices would have never been possible without development of monitoring, physical modelling, and numerical modelling techniques (Figure 6), *e.g*., Ozasa and Brampton (1981). Monitoring has a long history, but most measurements carried out in the past mainly focused on development of the coastal profile's dry portion. In the Netherlands, for example, yearly data of dune foot position, mean low- and high-water line existed for every alongshore kilometre of the entire coastline from the middle of the 19th century. Although very valuable to study long-term morphological trends, these data did not provide information about nearshore zone morphological changes, *e.g*., due to interaction with coastal engineering structures. Moreover, shoreface interventions, *e.g*., nourishments, submerged breakwaters, could not be implemented because there was no means of measuring their efficiency. Consequently, shoreface breakwaters were difficult to implement as long as there were only limited means of measuring efficiency. A combination of long-term data from the dry beach (since 1900) with comparatively short-term (50 years) profile data of the shore face can provide useful results on the morphological development of the coast itself and related morphological processes (Kunz, 1997; Ladage and Kunz, 2002).

Much concern relates to single events or experiments, which might have no bearing over periods of 1 or 2 years to even decades (Pilkey *et al*., 1980), *e.g*., projects developed using physical models, but interlaboratory calibration projects tend to demonstrate the inaccuracy of small-scale experiments (De Rouck *et al*., 2007). McDougal, Kraus, and Ajwibowo (1996) using a numerical model and rewriting the standard SBEACH model, compared results with those obtained from SUPER-TANK experiments and found that the influence of reflection on a seawall profile was minor. Seawall inclination was important, with erosion being roughly proportional to the reflection coefficient, vertical walls giving the largest scouring values (Schiereck, 2001). Laboratory tests proved that the

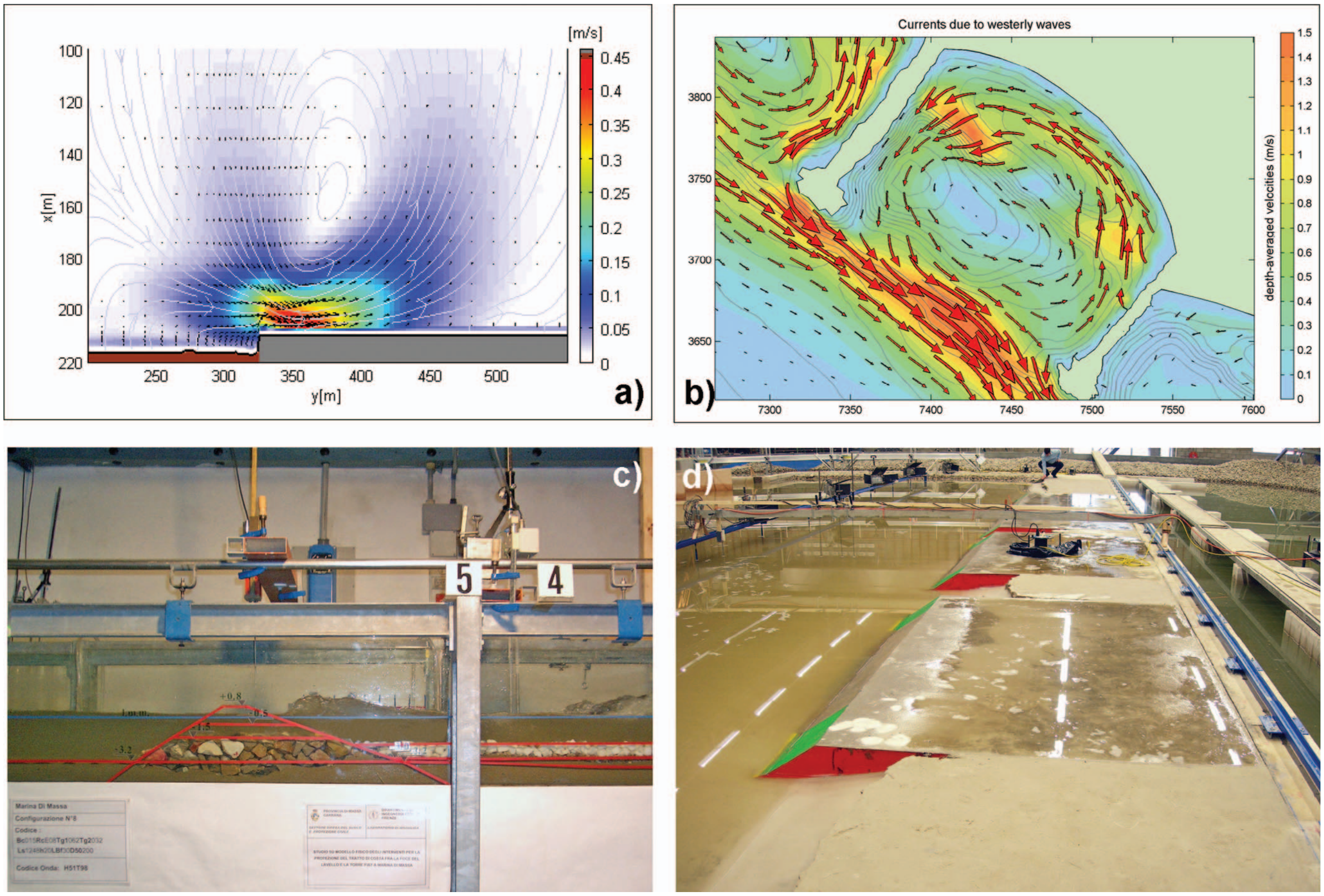

Figure 6. Examples of numerical and physical models used today to design and validate shore protection projects. (a) Mean velocity field in front of a dune–dike system for obliquely incident waves from the right (Van Geer, *et al*., 2012). (b) Modelled wave-induced currents within a groyne field at Deltares. (c) Testing submerged breakwater efficiency in a wave channel (DICEA, UNIFI). (d) Physical modelling of erosion at a dune–dike connection (Boers, Van Geer, and Marcel, 2011).

transition between hard structures/soft defences is also a very critical point, as downdrift of seawall increased beach erosion may occur (Komar and McDougal, 1988).

Morphological modelling (Brøker *et al*., 2007) and physical modelling of erosion processes in a seawall breach and the junction between dike (Netherlands name for coastal seawalls) and unprotected dune have been extensively carried out at Deltares (Boers, Van Geer, and Marcel, 2011; Figure 6d). Experiments showed that these structures can promote a significant dune erosion increase of between 27% for a connection between dune and dike and 88% for a dike breach. Van Geer *et al*. (2012) used the same dataset to validate the X-Beach numerical model, showing that generally the main dune set back processes are well captured by numerical model results. Many laboratory experiments relate to breakwater design, *e.g*., Kramer *et al*. (2005), and for wave flumes and basins, "the waves and the wave processes during wave-structure interaction are simulated correctly using a Froude scale" (van der Meer, 2015, p. 2).

In the last few decades, monitoring techniques have received a large boost, *e.g*., EU projects, remote sensing techniques to monitor morphological changes (*e.g*., satellite imagery, Airborne LIDAR Bathymetry, ARGUS cameras), and techniques to measure wave activity and hydrodynamic conditions, all frequently used in theoretical and applied studies (Pranzini and Wetzel, 2008). Those techniques set boundary conditions for development of innovative methods for coastal protection. In the Netherlands, for example, with the JARKUS monitoring programme, yearly measurements from the first dune row to approximately the –8 m contour has become available with an alongshore resolution equal to 250 m (Giardino, Santinelli, and Vuik, 2014). This on-going programme was started in 1963 by Rijkswaterstaat (Ministry of Infrastructure and the Environment). The dataset derived by this programme was the basis for implementation of the large nourishment policy, which commenced in 1990, and the shift from the use of standard beach nourishments towards shoreface nourishments.

Owing to increasing computation power, numerical modelling techniques are now widely used in different design phases of coastal engineering protection schemes (Chiranjeevi and Mani, 2005). One-dimensional coastal evolution models are generally used in feasibility studies to assess coastal evolution in the reference situation and after solutions are implemented. Two and three-dimensional models are applied in the detail design phase to optimize the design schemes and to assess their behaviour on the short and long term. A sound overview has been given by Van Rijn (2011). Some geologists/geomorphologists are partly still sceptical about the value and accuracy of numerical models (Cooper and Pilkey, 2004), but if correctly used and calibrated, they have proved to be extremely powerful, flexible, and relatively cheap systems to assess design efficiency and to choose the one that is most effective (Figure 6b). However, difficulties exist in using empirical relationships to predict beach response in meso- and macro-tidal coasts (Shabica, Michael, and Nagelbach, 2010), but remote sensing monitoring and process algorithms are powerful tools for studying the morphology and hydrodynamics.

CONCLUSIONS

In this paper, progress in coastal protection measures during the last century has been discussed. The reference document (RCCEA, 1911) investigated the state of coastal erosion and resulting protection measures in the U.K. The present paper focuses on "traditional" coastal defence measures (*i.e.* seawalls and groynes), widely used at the time of RCCEA (1911), together with new concepts and schemes that were completely unknown when RCCEA (1911) was written.

What has actually changed in terms of coastal protection measures during the last century? Was this a "century of change" as the paper title suggests?

The first important difference relates to the "what" and "why" coastlines are being protected today, which is different than a century ago. Coastal protection measures are much more widespread because of the larger human pressure on coasts (*e.g.*, development of new settlements, infrastructures, harbours, tourism, *etc.*). Therefore, large coastal stretches, which were unprotected one century ago, now need protection, and the pros and cons of different solutions have been categorised and widely distributed internationally.

Much new knowledge and experience has become available, followed by design and monitoring of these new coastal protection structures. The "why" question relates to the recent coastal protection measures objectives. A century ago the main function was (short-term) safety of coastal settlements and roads; nowadays new objectives play an important role on optimal coastal erosion design measures, *e.g.*, an Italian 1907 law was approved with the aim of making large financial resources available for defending coastal towns. This objective was partly achieved, but the result was many urban beaches were lost. This, in principle, would not be admissible anymore in the present situation.

Also, awareness for a landscape's aesthetic value has boosted development of designs that are not only "functional" but also "beautiful." Large coastal restoration projects are now the result of multidisciplinary studies involving landscape architects, engineers, geologists, and ecologists, a collaboration almost unknown a century ago, so that groynes with very diverse shapes have been designed—and they even act as tourist pathways.

A factor that was completely disregarded a century ago is climate change/sea-level rise. While discussions are ongoing on sea-level rise rate and change in storminess, it is widely accepted that mean sea level is on average increasing. Many studies and projects are being implemented to design structures that are more resilient to climate change in coastal areas, which can be flexible to account for the uncertainties underlying predictions. Large sand nourishments, almost unknown a century ago, are a very good example because they integrate well with the surrounding landscape and because they can easily adapt by changing nourishment volumes.

As new technologies appear, different solutions and designs become possible. Shoreface nourishments are now implemented, and monitoring techniques extend to the underwater bathymetric profile. Also, the large increase in sand and gravel usage in combination with traditional "hard" structures is now possible thanks to dredging sector improvements, which makes it possible to reach sediment resources at larger depths at competitive prices.

Finally, improvements in numerical modelling (next to the traditional physical) have allowed optimization of traditional schemes, unknown a century ago, but designed and based on experience (*e.g.*, groyne fields). This is one reason that hard structures, so poorly evaluated by researchers, environmentalists, and stakeholders in the second half of the 20th century, have been recently reconsidered, in combination with "soft" types of solutions, *e.g.*, groynes and revetments combined with nourishments, use of hard structure in combination with vegetation. Recently there has been a quantum shift towards ecology as a value and, associated with this, a judgement/assessment of coastal areas, seemingly without taking into account natural forces. Retreat options have become feasible and, along with the primary "safety" targets, an enhanced resilience (biophysical and socio-economic system) in coastal regions is demanded for integrated coastal zone management. However, there remain coastal sites where "hard" types of solutions are the only alternatives.

Can all this be called a "century of change" in coastal engineering? Perhaps it is more appropriate to talk about a continuous and integral improvement in approach, methodology, and technology. Definitely, RCCEA (1911) members would be very positively surprised by modern coastal protection projects. Or would they? Whatever one's view is on coastal erosion and protection, the shoreline is an area where sometimes, "the rocky shore beats back the envious siege/Of watery Neptune" (Shakespeare, Richard II), but sometimes anthropogenic help is needed. This paper started with a quote by Bascom (1964) so fittingly it ends with, "for the short span of human interest . . . the first and most valuable lesson one can learn about the sea is to respect it" (Bascom, 1964, p. 256).

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