Old breakwaters - What did we build, how well have they lasted, and what happens when they collapse?

27 November 2015

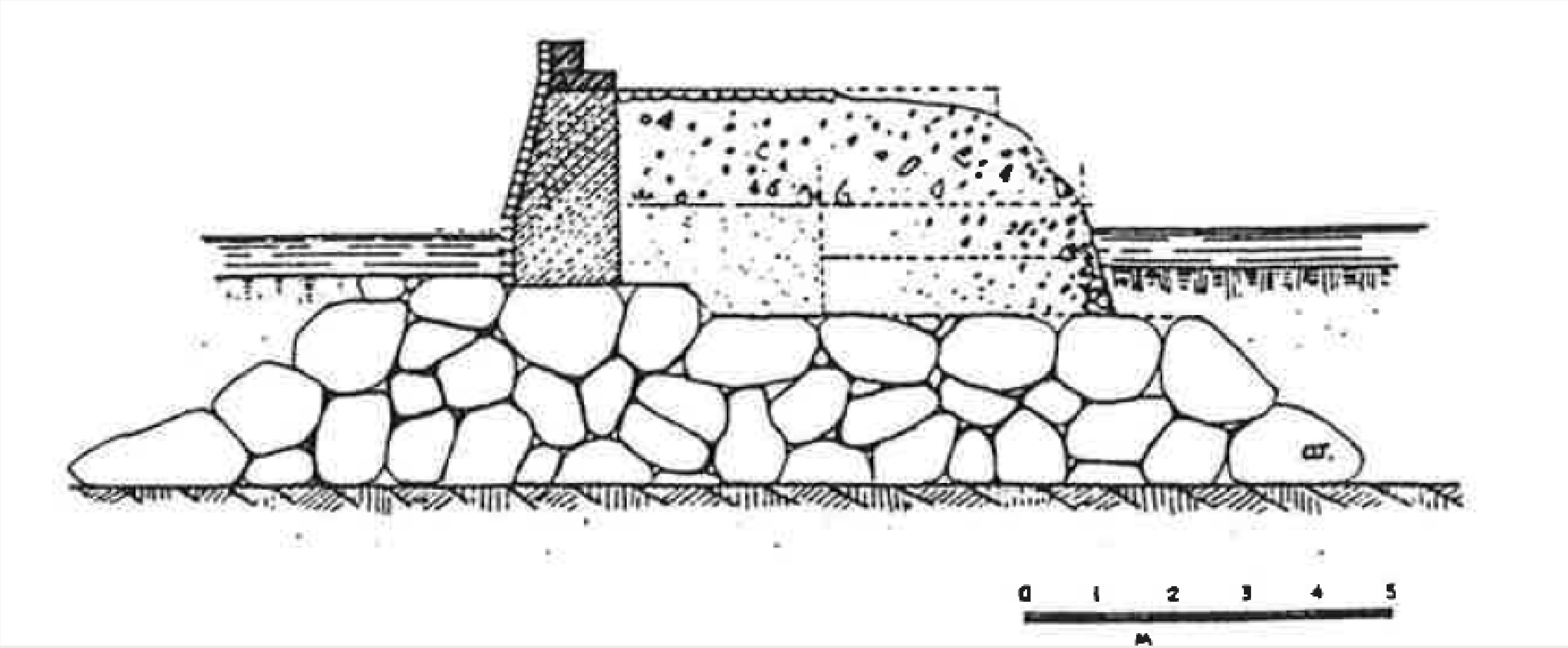
William Allsop - HR Wallingford; Southampton; UCL; Edinburgh

Historical context

"Italy is often considered as a mother country of vertical breakwaters for harbour protection ... the technology of vertical concrete walls was introduced 2000 years ago by the Roman harbour engineers in contrast with the Greek tradition of rubble mound breakwaters."

Franco L. (1994) *Vertical breakwaters: the Italian experience*, Coastal Engineering, Vol. 22, pp31-55, Elsevier Science, Amsterdam.

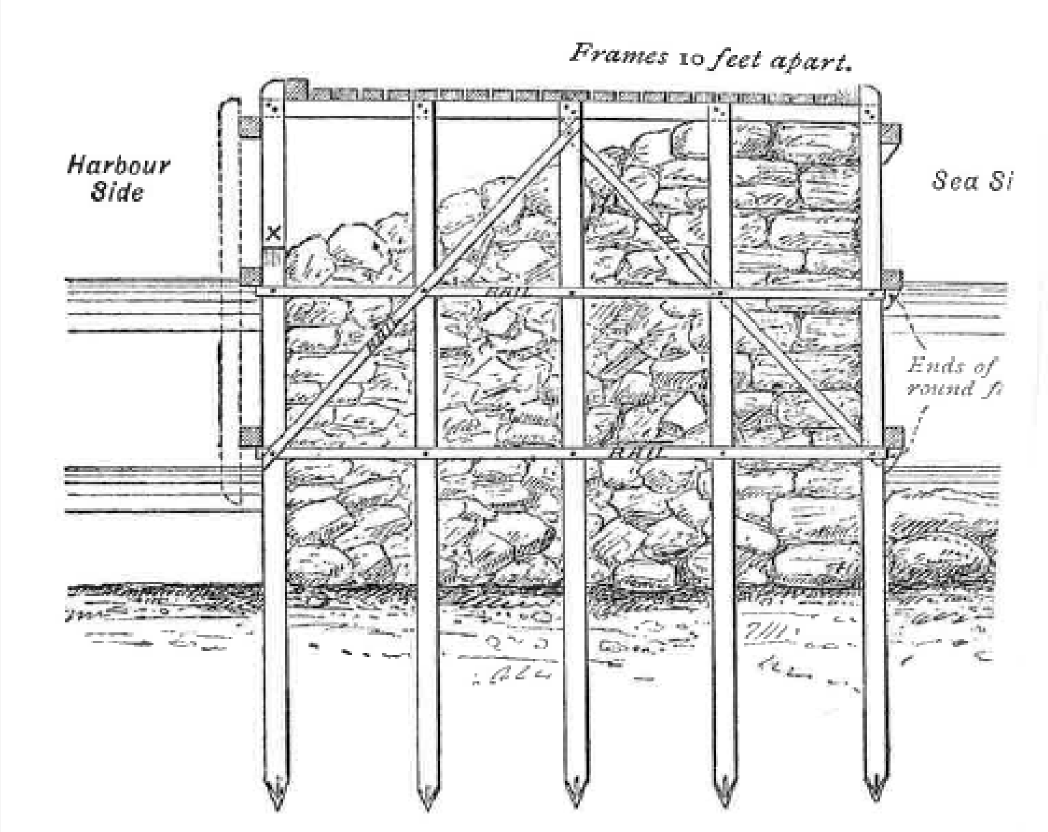
Classic “vertical” breakwaters



Composite breakwater at Claudius Port (Rome) with concrete superstructure using ship hulls as lost forms

Classic “vertical” breakwaters

The “Cob” breakwater at Lyme Regis, 16th C, Braye & Tatham (1992)



Typical timber frame with rubble hearting, Braye & Tatham citing Shield (1895)

History – some key technical steps

1661-83	Breakwater at Tangiers (1661); use of timber caissons (1676), abandoned (1683)
1757	Smeaton experiments with lime / pozzolanic mortar, used at Eddystone
1773	Steam engine fitted to lighter to dredge sand
1774	Smeaton started Aberdeen North Pier
1795	Boulton & Paul making steam engines commercially
1803	Maiden voyage of Charlotte Dundas, steam powered tug
1813	Rennie used diving bell for foundations at Ramsgate
1824	Aspdin patented Portland Cement, OPC commercialised from approx. 1845
1825-33	Stonehaven and Cockenzie by Stephenson
1837	Siebe starts production of diving helmets and suits
1851	Alderney started; Great Exhibition showcases new technologies
1862	Messent makes 40t concrete blocks for Tyne piers
1871-72	Alderney complete, then outer end abandoned; Failure at Wick
1875	Dyce Cay 50t concrete bags at Aberdeen; 104t bags at Newhaven (1885)
1892	Titan crane placing 50t concrete blocks at Peterhead
1909	Dover harbour completed

Masonry Breakwaters

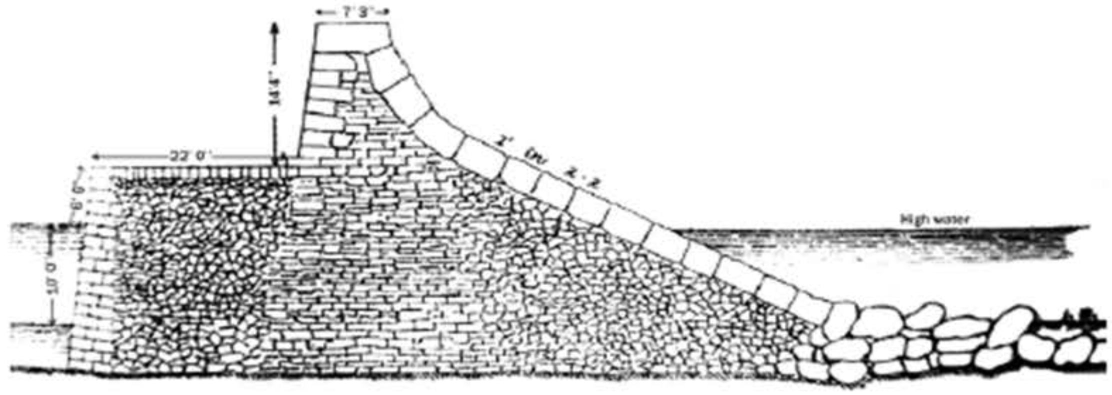


Figure 3.69 The Old Pier, Wick, 1823 (courtesy A Stevenson)

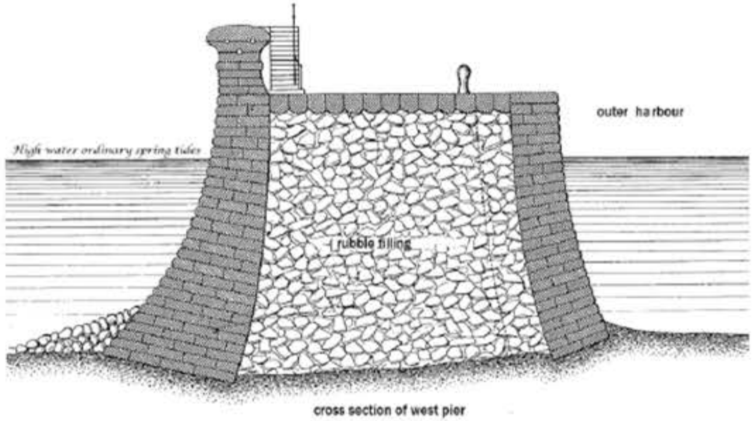


Figure 3.73 The West Pier, Whitehaven, 1831 (from Williams, 1879)

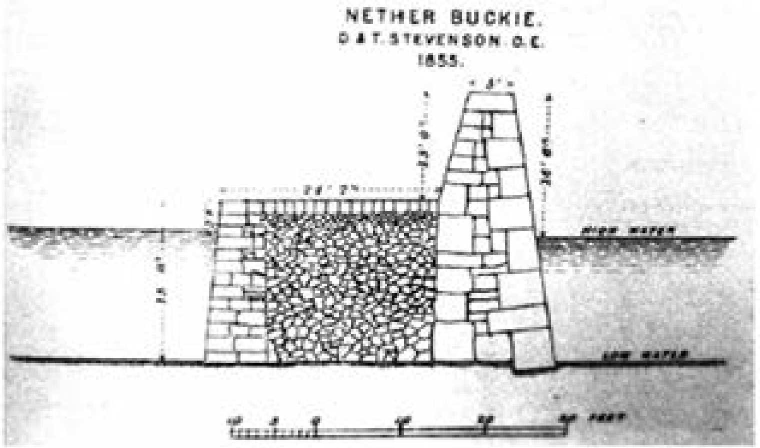
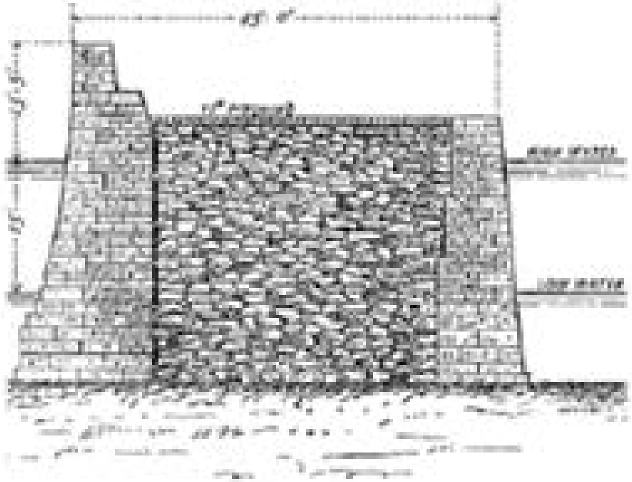


Figure 3.68 The pier at Nether Buckie, 1855 (courtesy A Stevenson)



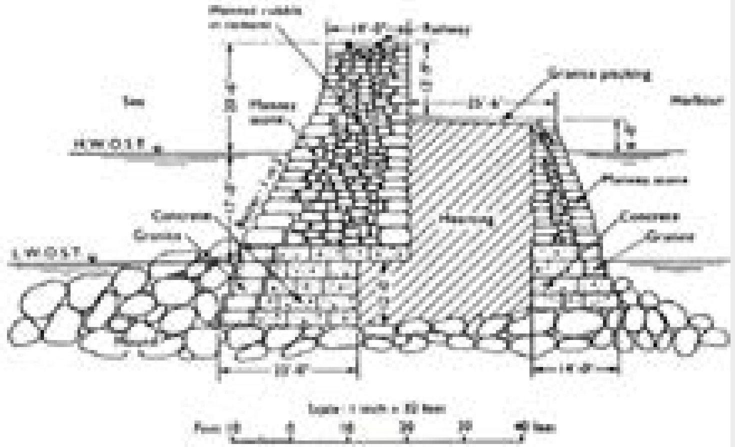


Figure 3.88 Section through breakwater, Alderney, 1851–1864 (from King and Bishop, 1951)

Masonry Breakwaters

Use of concrete blocks and/or fill

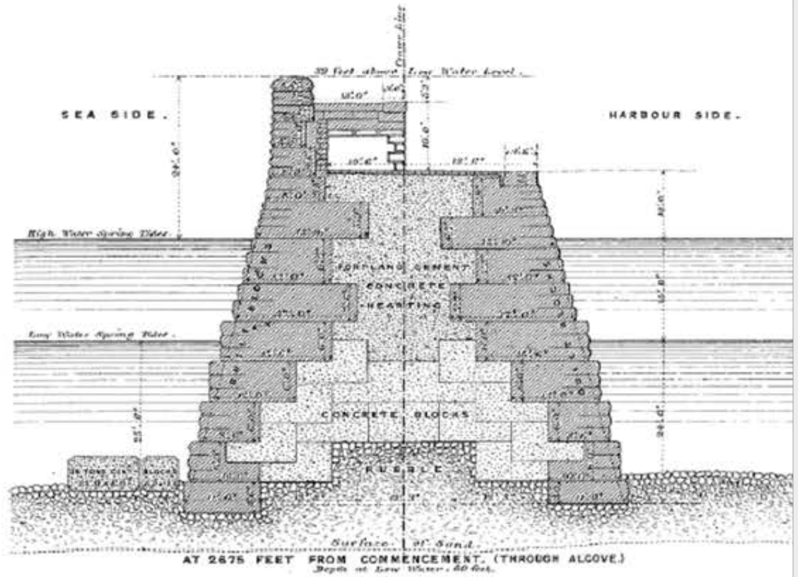


Figure 3.76 Piano blockwork used in the breakwater, North Tyne, 1855–1895 (from Coode et al, 1886)

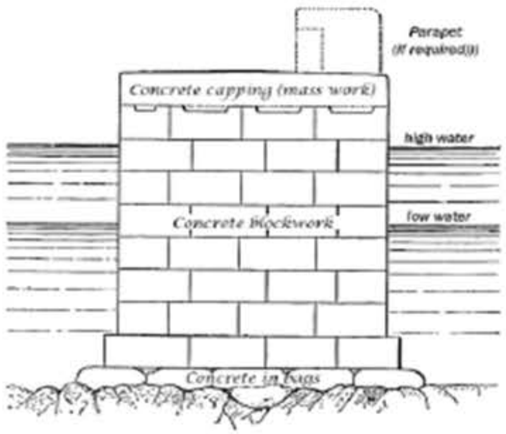


Figure 3.82 Breakwater formed of concrete blocks with foundation bag work keyed into rock (from Shield, 1895)

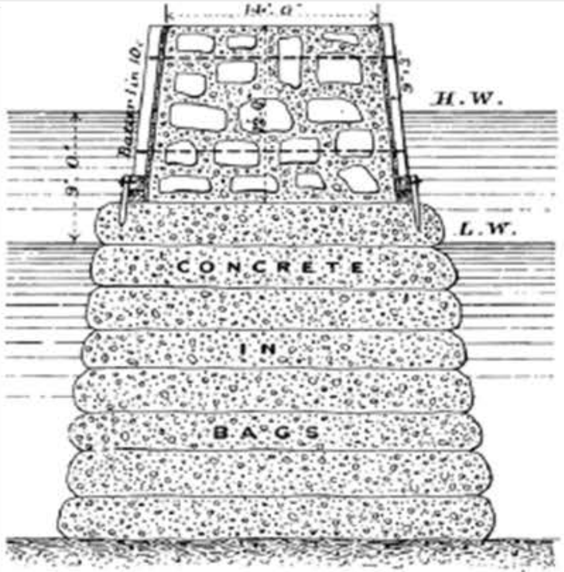


Figure 3.83 The outer portion of the breakwater, Ardrossan, 1892 (from Robertson, 1895)

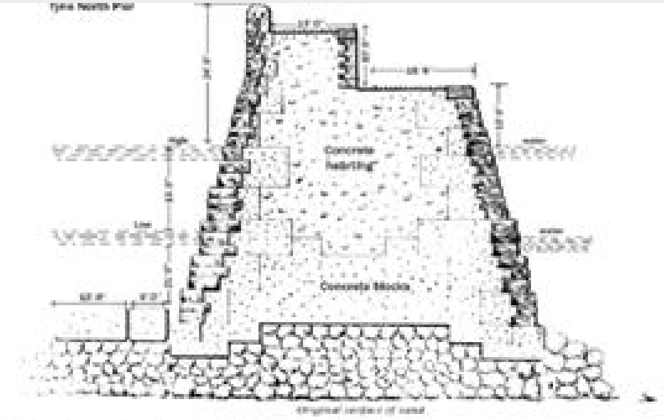


Figure 3.74 The North Pier, Tyne, 1855–1895 (courtesy A Stevenson)

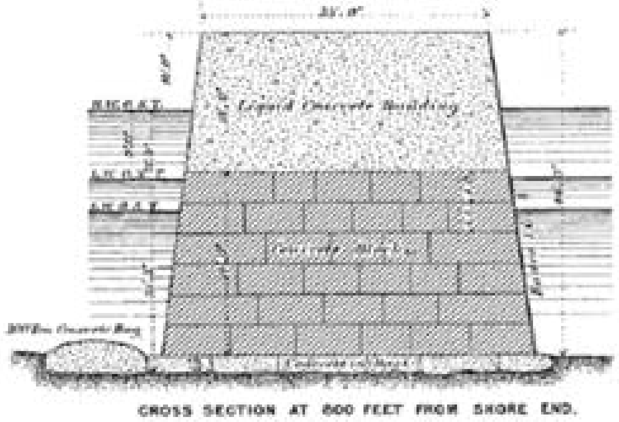


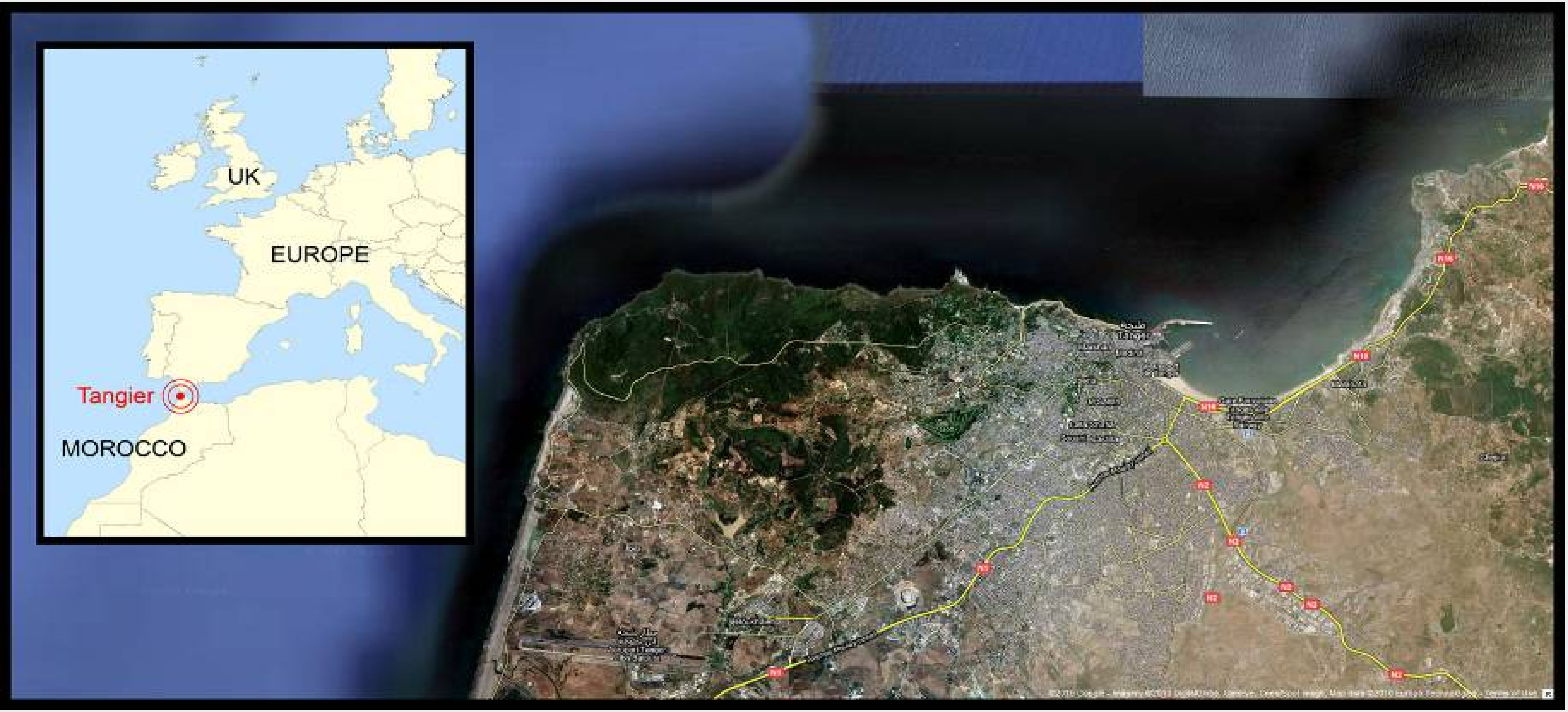
Figure 3.90 The south breakwater, Aberdeen, 1873 (from Cay, 1874)

Tangier Breakwater, 1661-1684

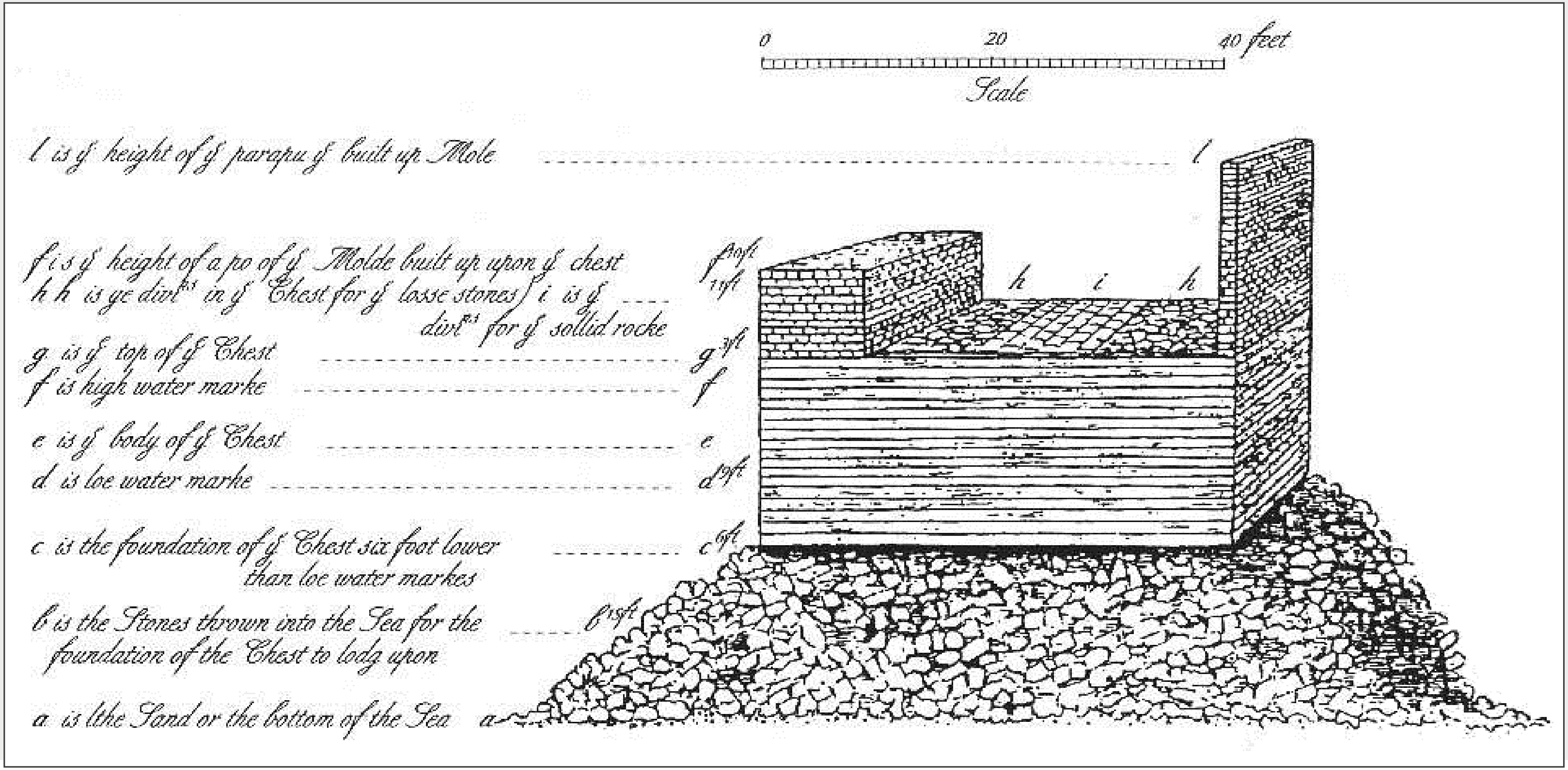
"The story of the English Occupation of Tangier would be incomplete without some account of the building of the Mole, the greatest engineering work till then attempted by Englishmen."

Routh EMG (1912) *Tangier: England's lost Atlantic outpost, 1661-1684,* (Chapter 17: The Mole and Harbour), John Murray, London.

Tangier breakwater, 1661-1684



The revised caisson design, 1677, after Routh (1912)



Samuel Pepys' diary, Jan / Feb 1663

"12 January… So … we spent all this night attending to Sir J. Lawson's description of Tangier and the place for the Mole[1] of which he brought a very pretty draught.

[1] In April, 1663, … the charge for 1 year's work was £13,000.

[In March 1665, £36,000 had been spent . ….]

6 February…where at the Solicitor Generals' I found Mr Cholmely and Creed reading to him …the contract for the Mole at Tangier, which is done at 13s the cubic yard, though upon my conscience not one of the Committee, besides the parties concerned, do understand what they do therin, whether they give too much or too little.

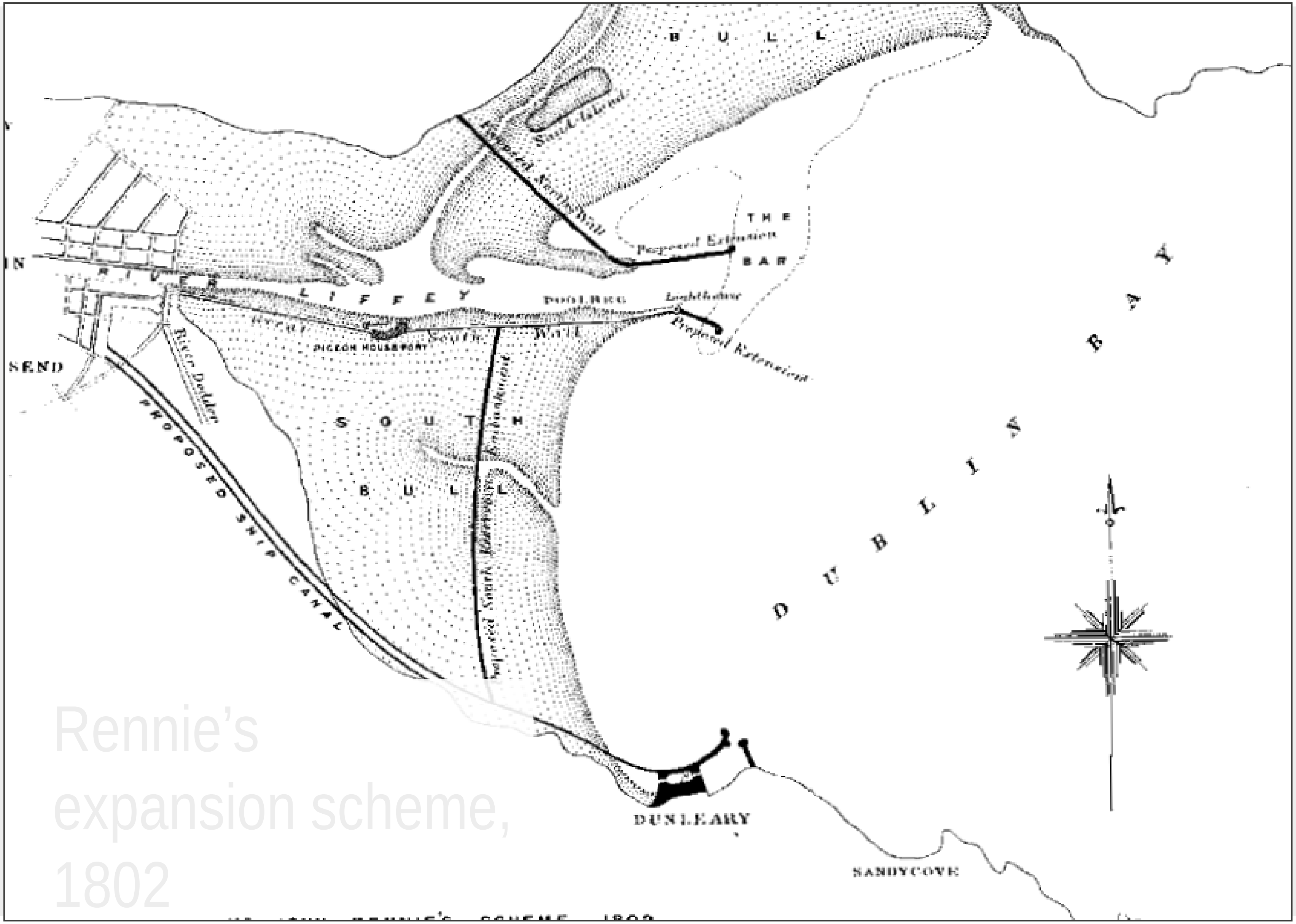
Dublin Great South Wall

Constructed 1716 – 1786

from Ringsend out to Poolbeg

Dublin Great South Wall

Dublin Great South Wall



Rennie's expansion scheme, 1802

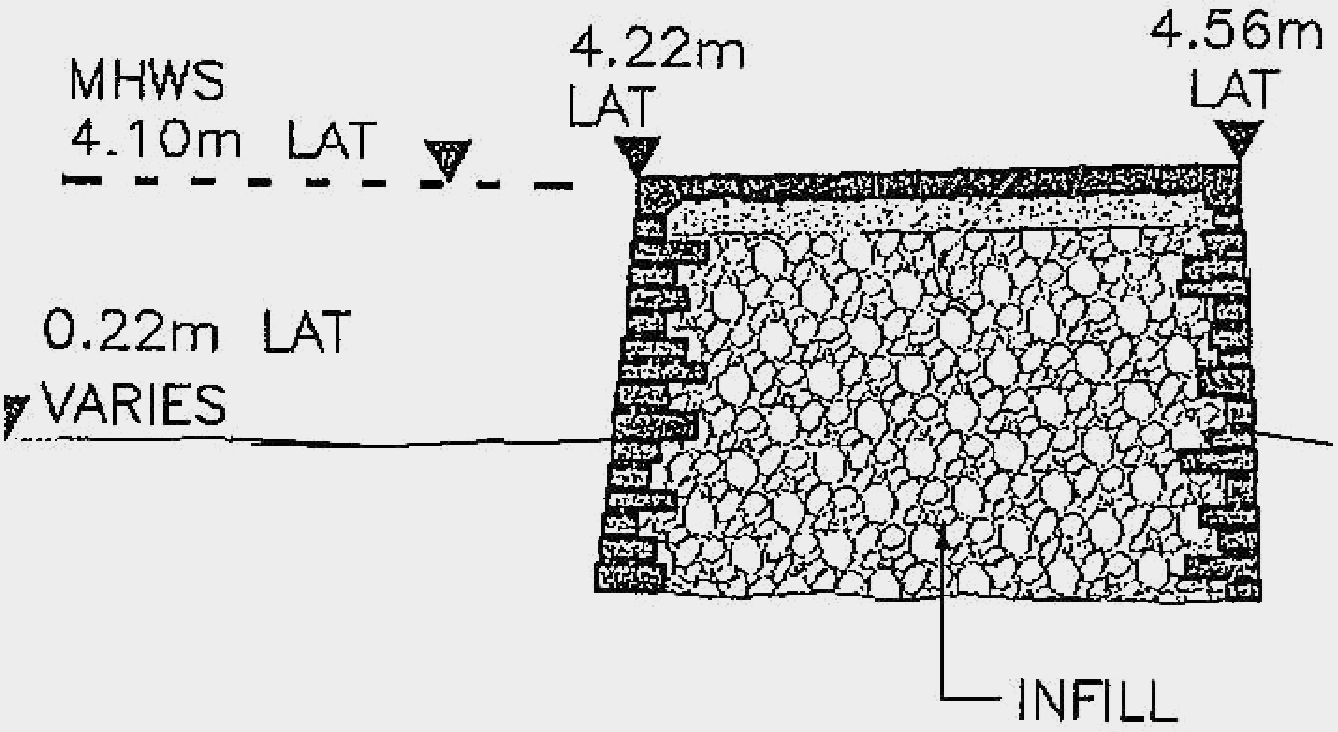
Dublin Great South Wall

High water, views from North side

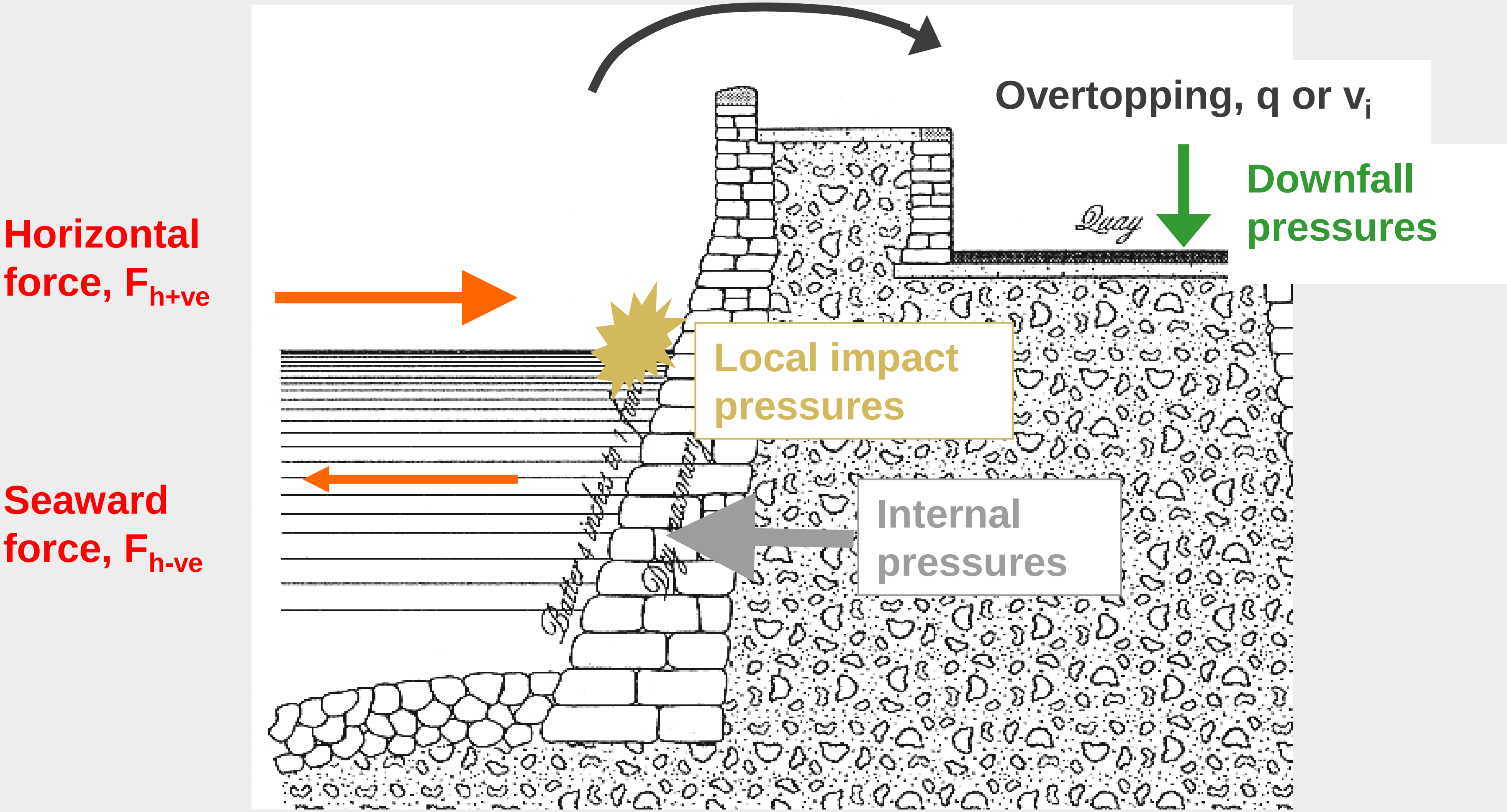
Views from the South

Dublin Great South Wall

Indicative cross-section through Great South Wall



Wave effects on vertical structures



Wave loads / responses for vertical, battered or composite walls.

Context for determination of wave loads

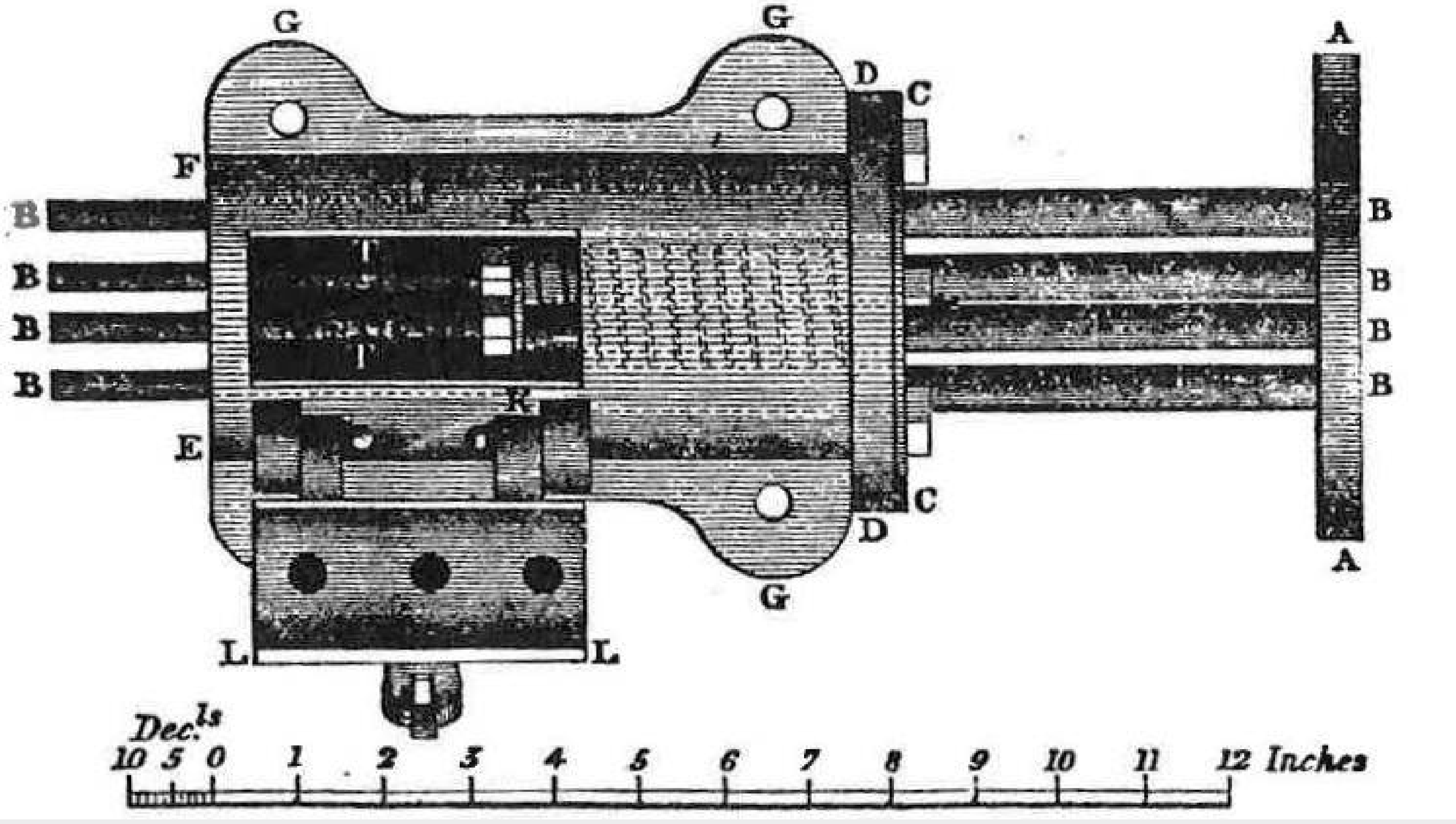
"*Perhaps it may be considered rather hard by the young engineer, that he should be left to be guided entirely by circumstances, without the aid of any one general principle for his assistance*."

Scott Russell J.(1847) *On the practical forms of breakwaters, sea walls and other engineering works exposed to the action of waves*, Proc. ICE, Vol VI, pp135-148.

"*In forming designs of marine works, the engineer has always a difficulty in estimating the force of the waves with which he has to contend….. The information … derived from local informants … is not satisfactory. I shall explain the construction of this simple self-registering instrument*…"

Stevenson T. (1849) *Account of experiments upon the force of the waves of the Atlantic and German oceans*, Proc. ICE, pp23-32 (reported by David Stevenson)

Wave effects on vertical structures



T. Stevenson's wave force Dynamometer, circa 1845

Wave forces

Wave forces

$$F_{h,imp(1/250)} = C_r^{\alpha} \cdot \rho g \cdot H_{m0} \cdot L(h_s) \cdot \left(1 - \frac{|h_b - d|}{d}\right) \quad (21)$$

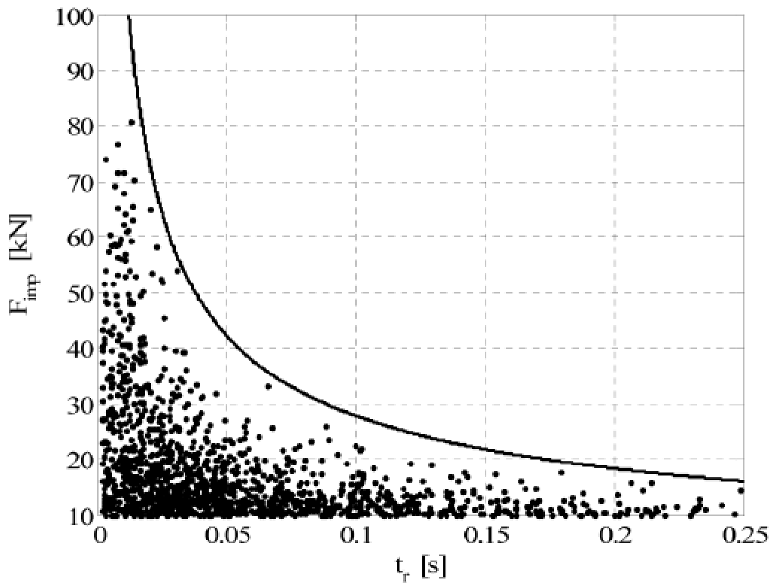
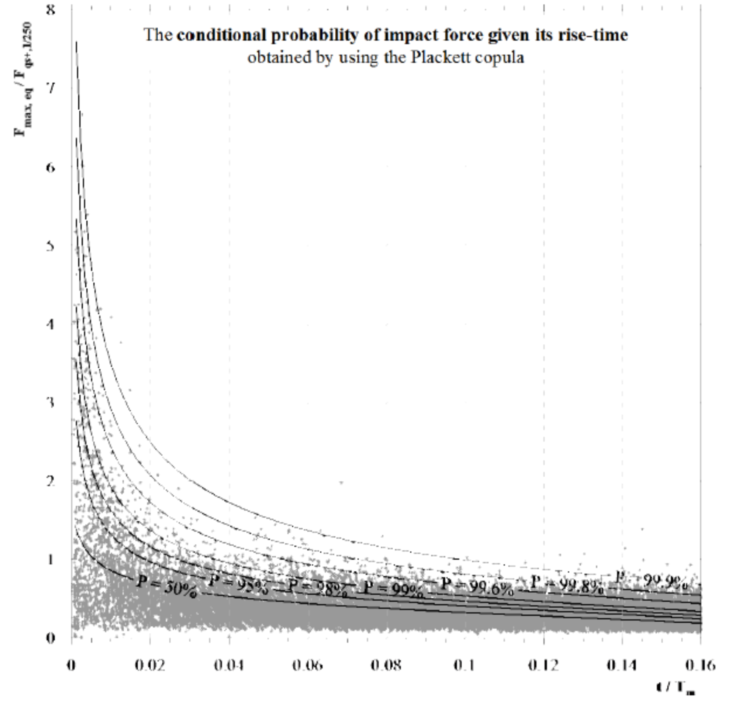


Figure 19 Impact force maxima and rise times recorded during physical model tests; solid line obeys Equation 24 with a =7 and b =-0.6.



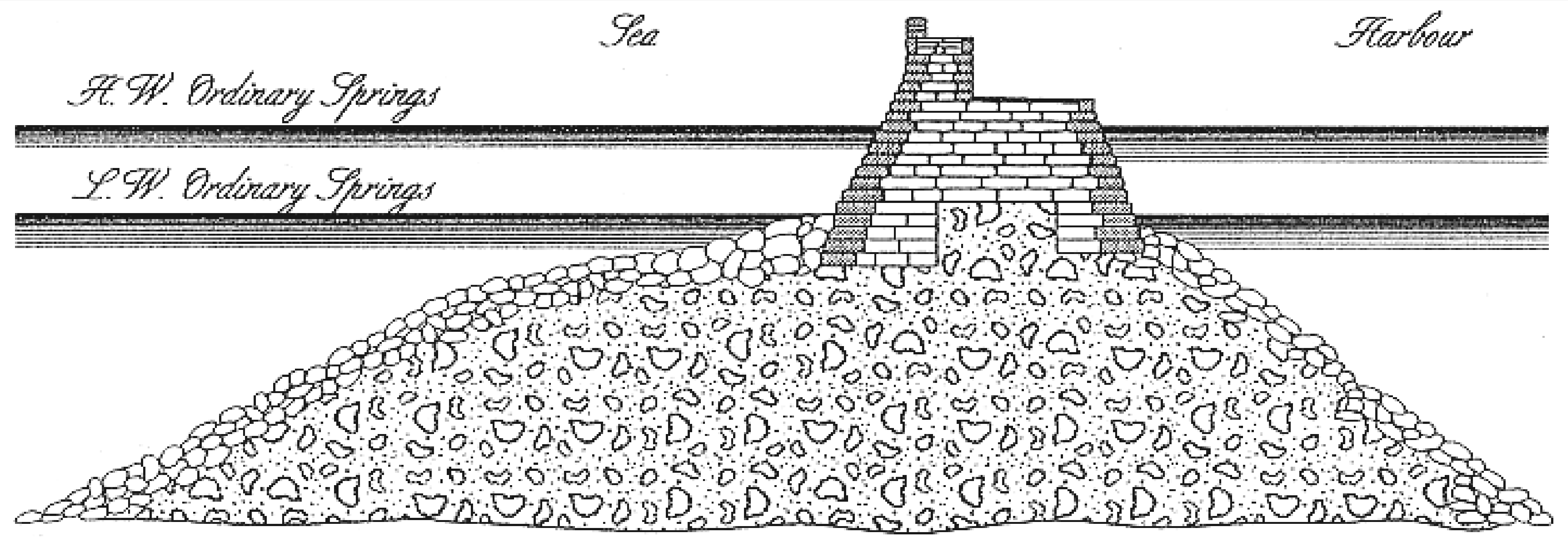
$$F_{imp} = a \cdot t_r^{b} \quad (24)$$

Admiralty Breakwater, Alderney

1847-present

Admiralty breakwater, Alderney

Classic "vertical" breakwaters



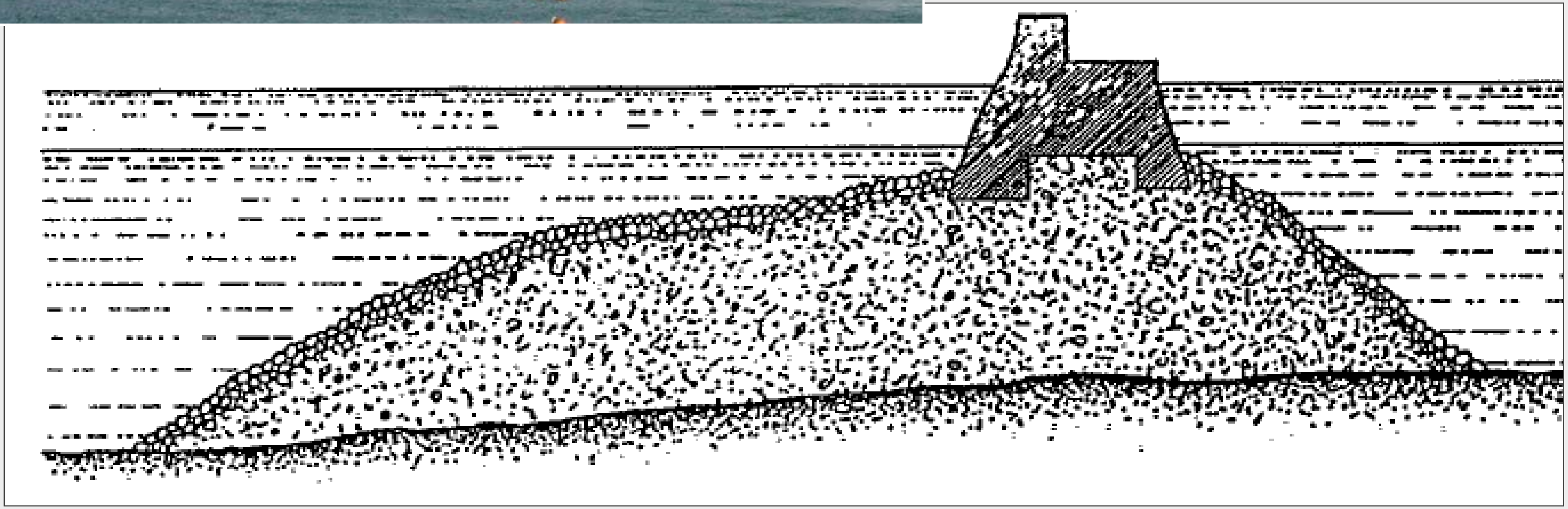
Alderney (c. 1845), showing foundation mound up to just below low water, stone blockwork walls, un-cemented fill.

Note – mound has already been enlarged on the seaward face.

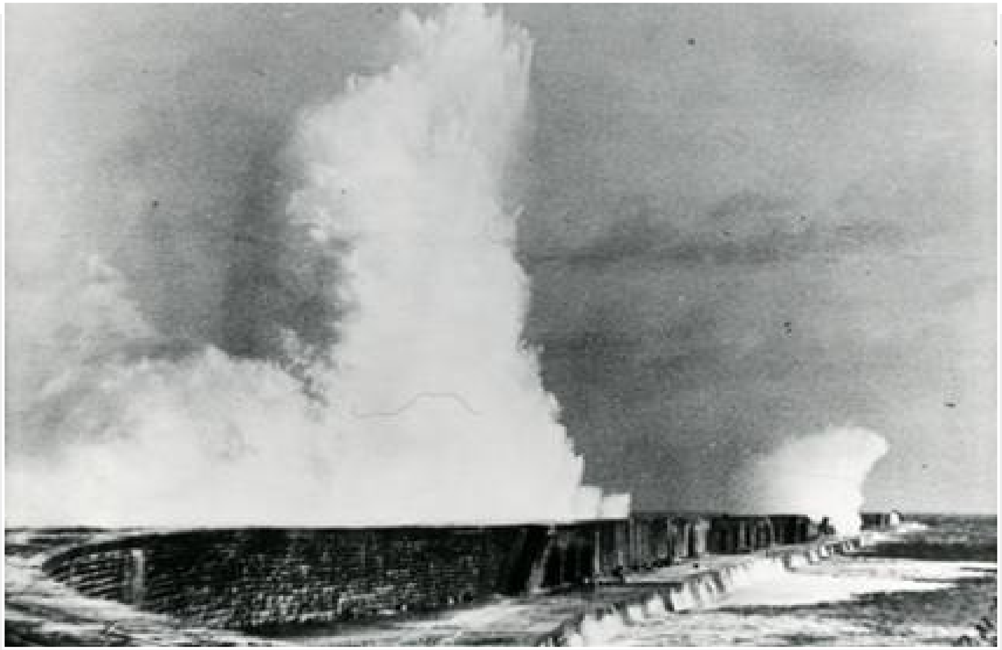
Admiralty breakwater, Alderney

Admiralty breakwater, Alderney

High mound causes (longer) waves to shoal up and break impulsively against the upper wave wall



Alderney Breakwater under storms

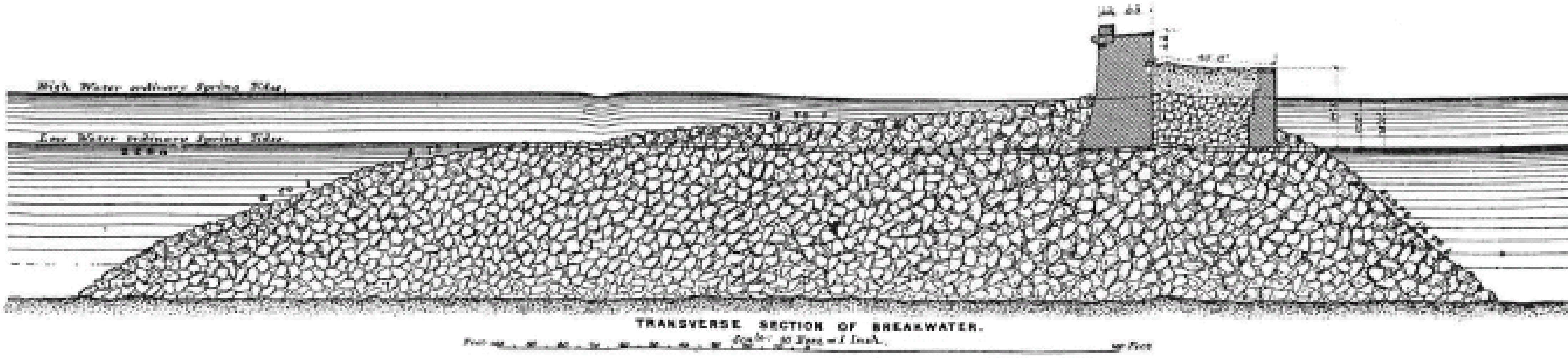


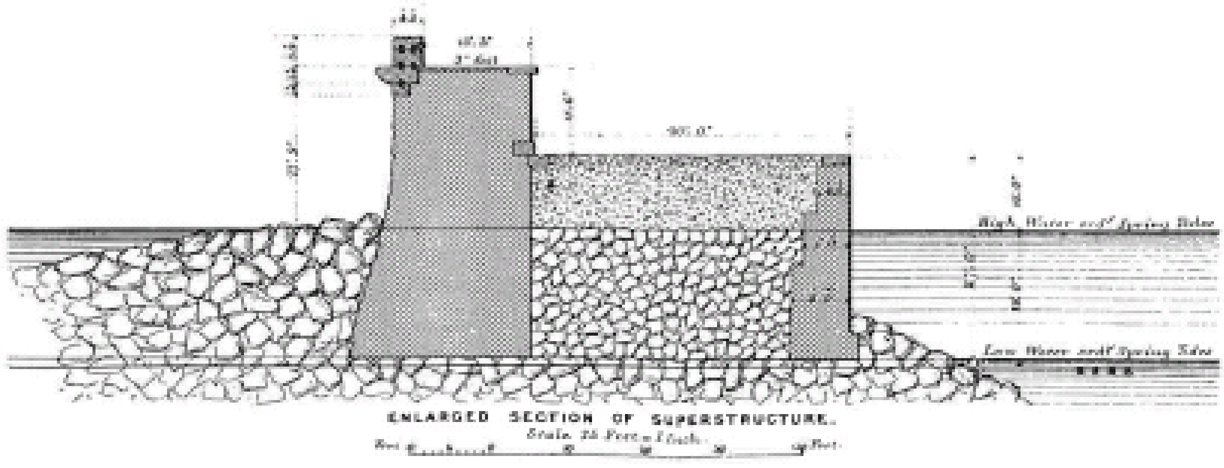
Alderney Breakwater – damage repair

Port Logan – blockwork failure

Port Logan, Rhinns of Galloway. Failure of close fitting blockwork armour (low permeability) over ungrouted rock fill.

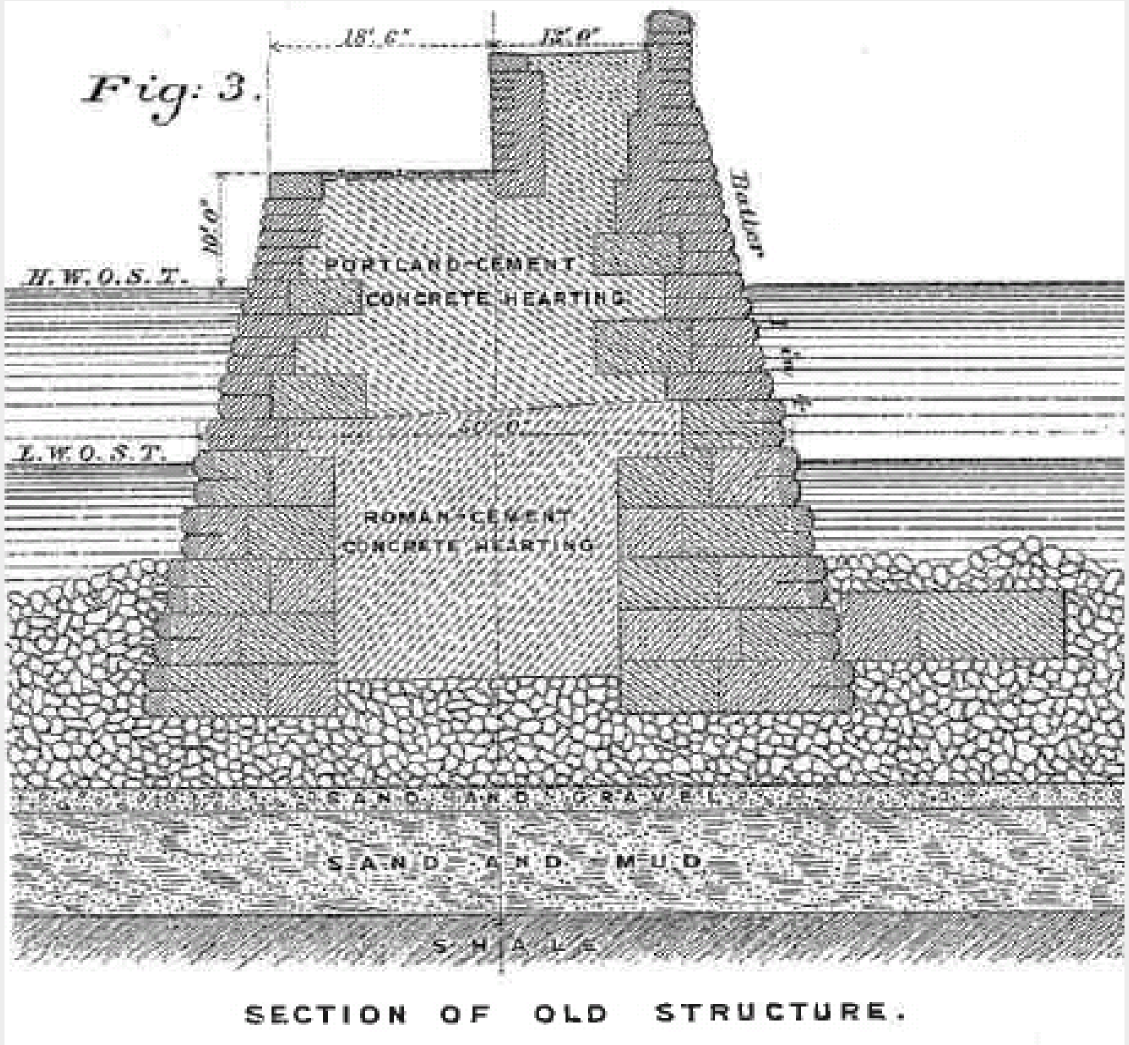
Classic "vertical" breakwaters

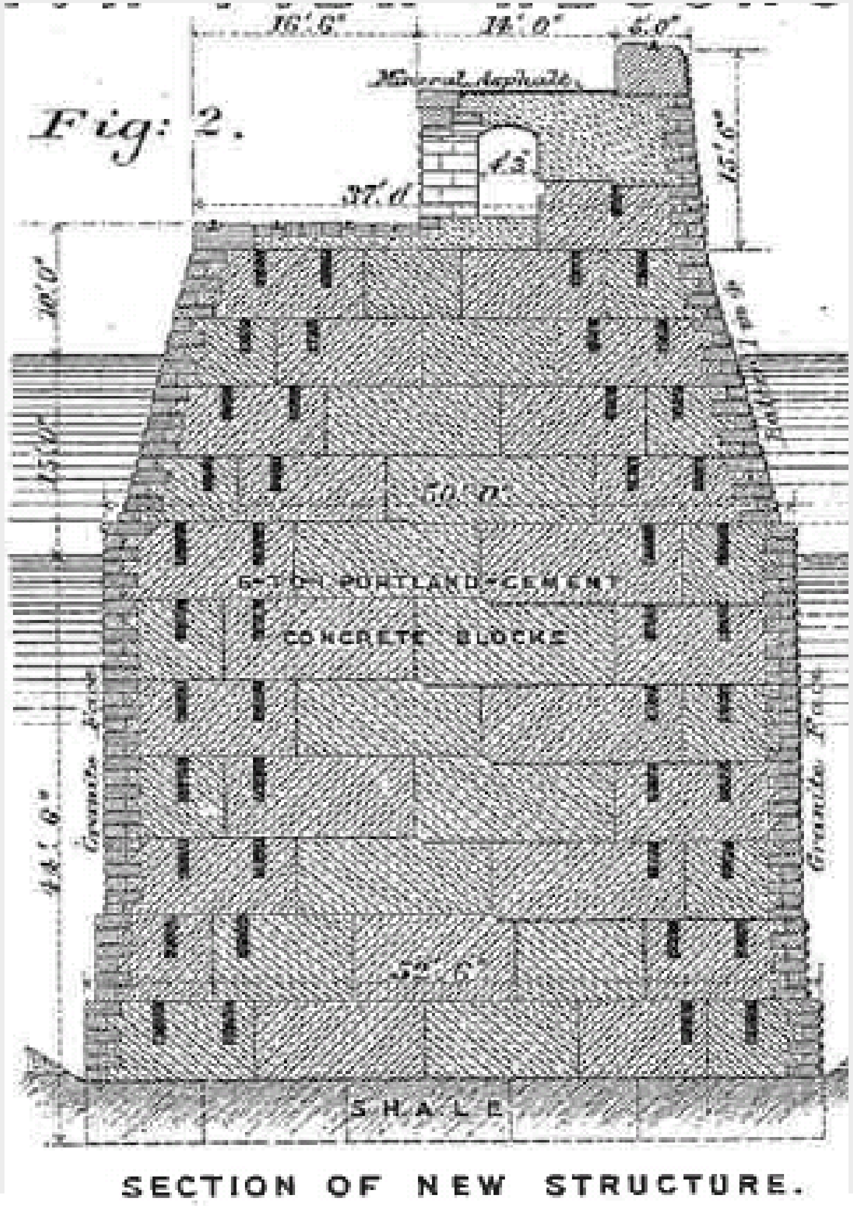




Wide mound to break waves before hitting the wall, but high mound can cause (longer) waves to shoal up and break impulsively against the wave wall

Classic “vertical” breakwaters



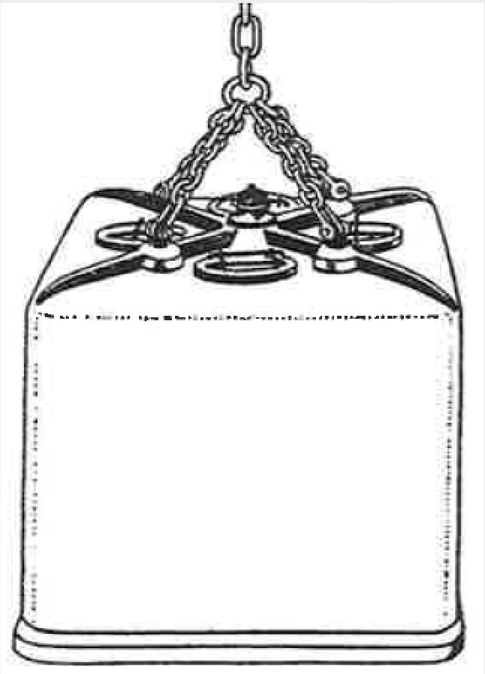


New Tyne North Pier, 1899

Construction methods, mid / late 1800s

"Titan" cranes for block placement, here used at Peterhead South Breakwater.

Diving bell used for foundation preparation and setting toe blocks.

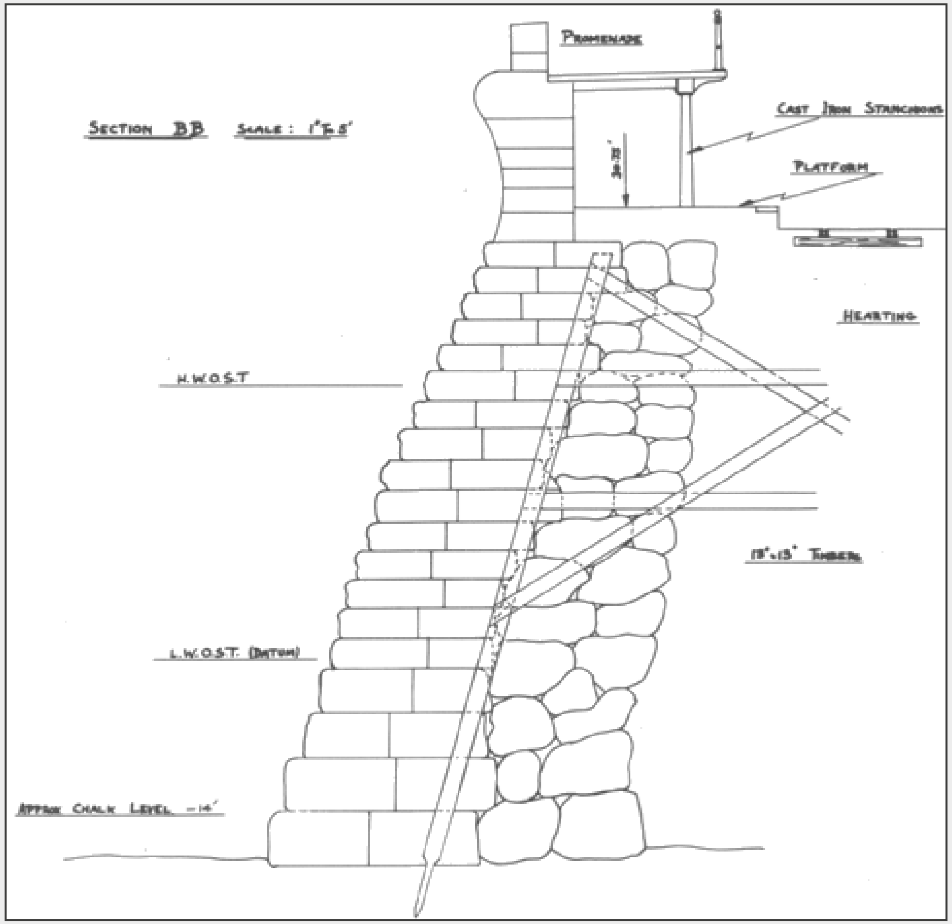


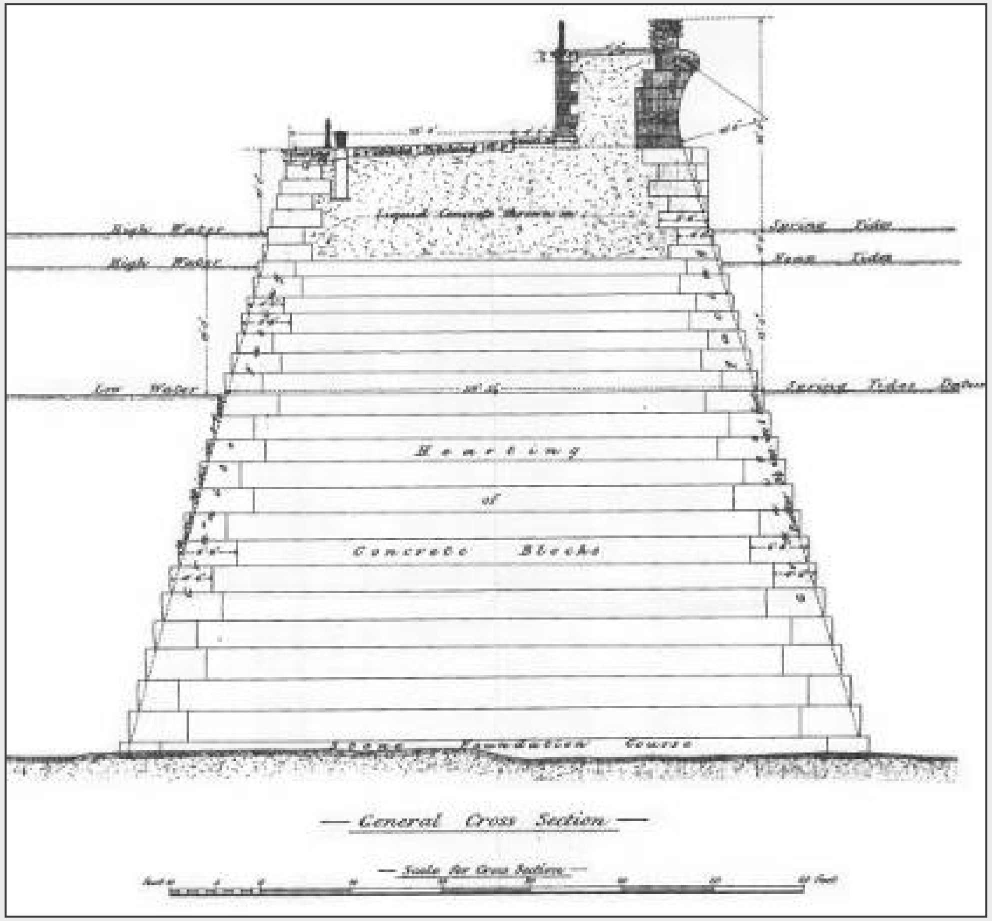
Dover Breakwaters (Admiralty and Western)

1880-1900

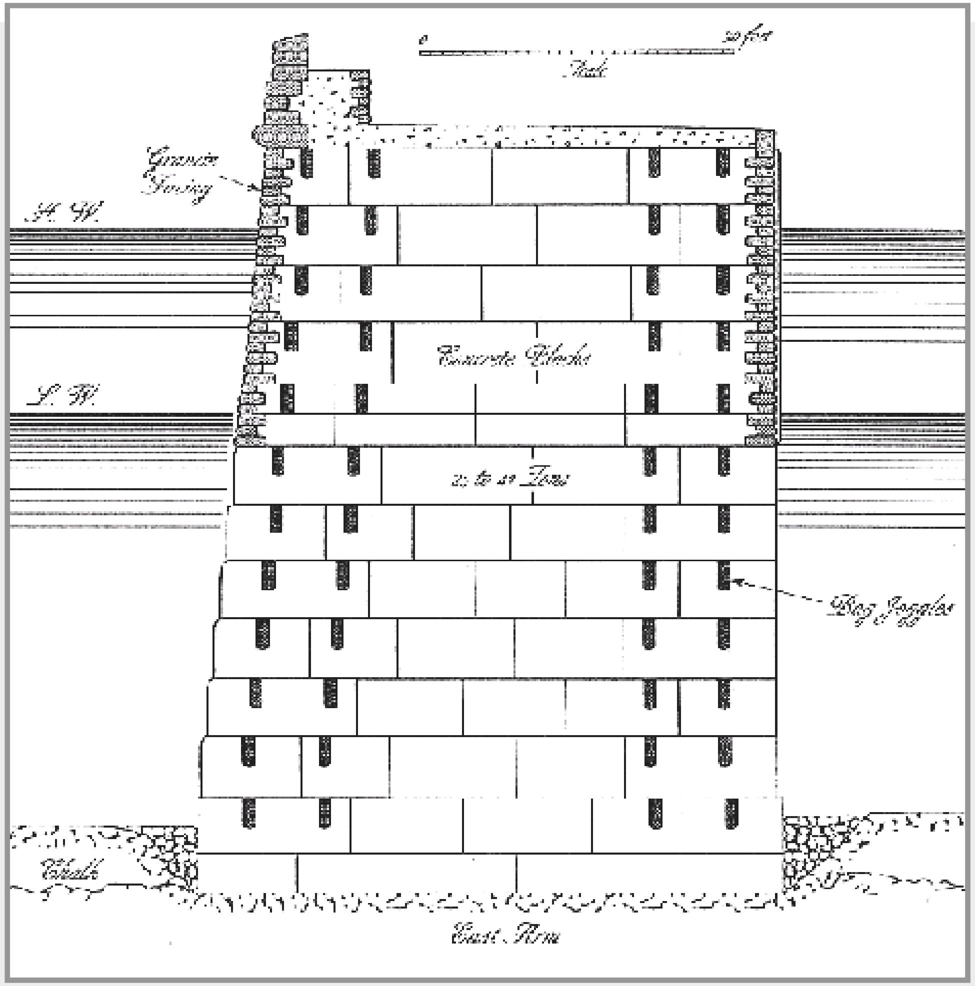
Dover harbour, 1880 - 1900

Dover harbour, 1880 - 1900





Dover harbour, 1880 - 1900



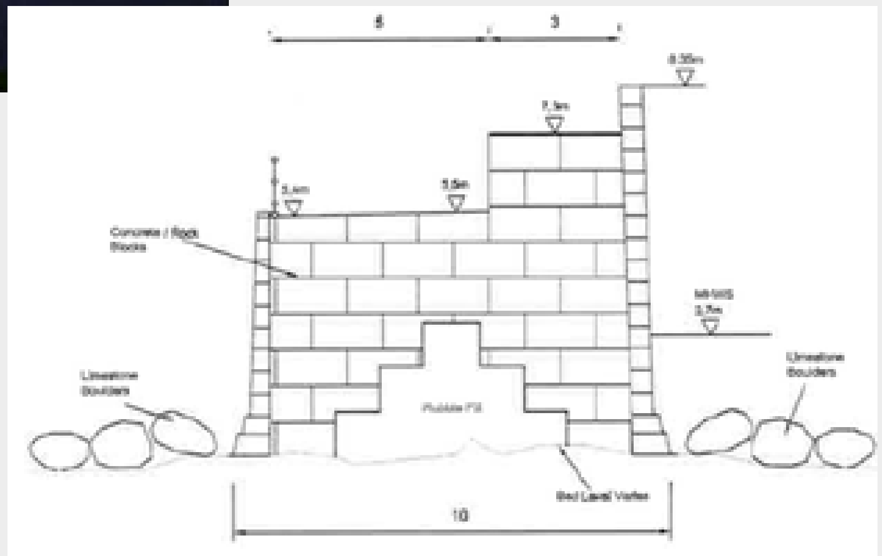
‘Orphan Breakwater’ tests

Orphan Breakwater testing

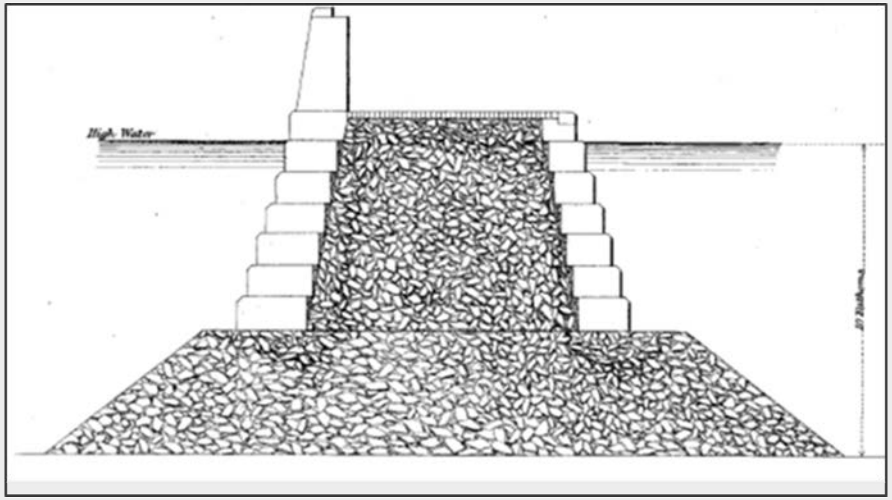
2D physical model tests on collapse and wave transmission,

supported by ICE R&D Enabling Fund, summer 2015

Design of ‘Orphan Breakwater’ tests



Design of ‘Orphan Breakwater’ tests



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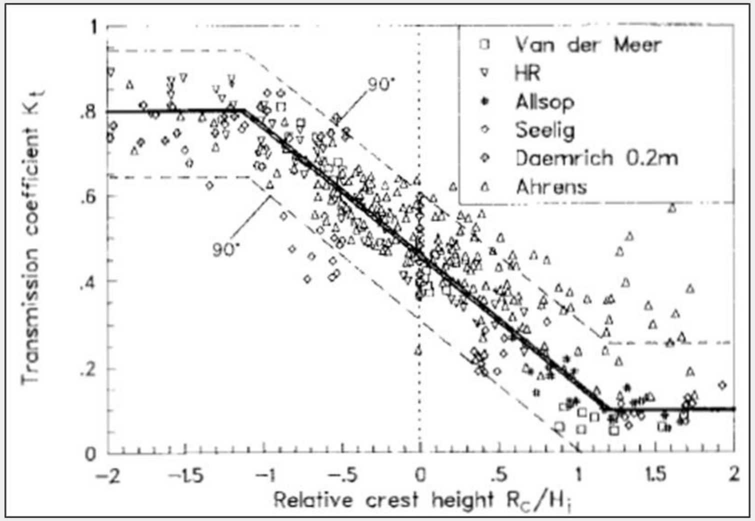

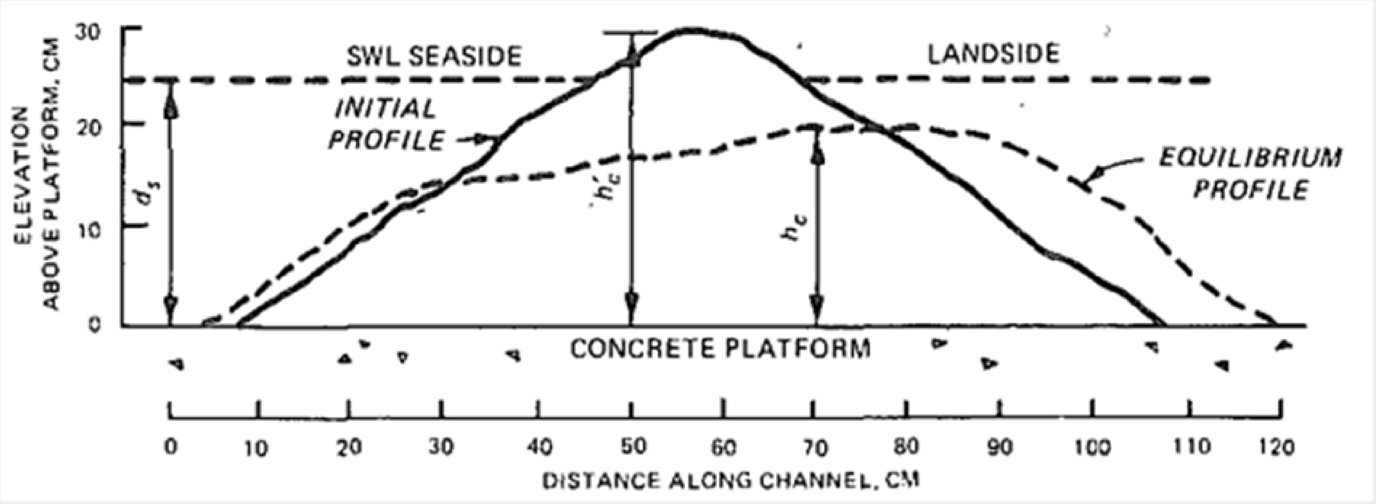

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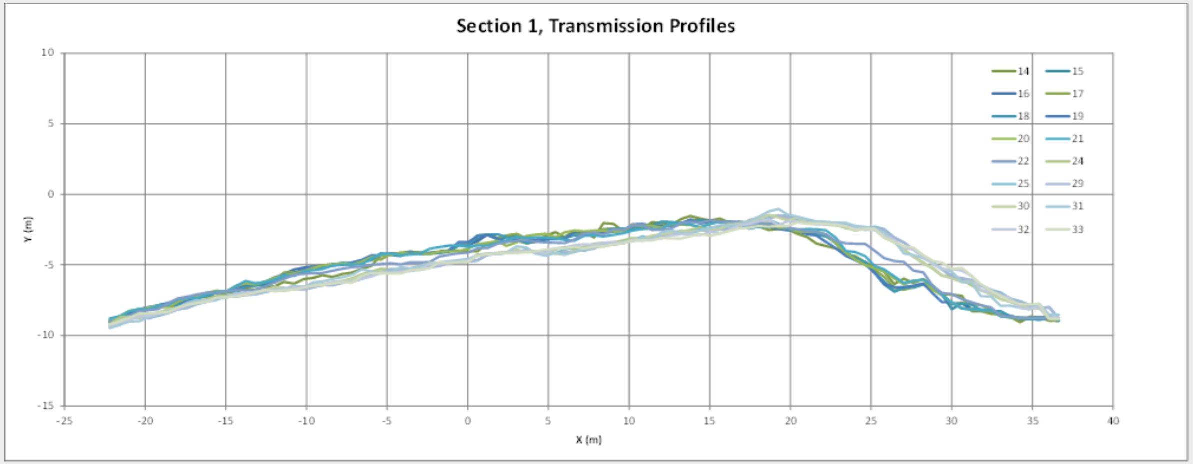

HR Wallingford
Working with water

Suggestions

Some initial (and partial) comments:

- Nearly all structures before 1900 were designed on the basis of vernacular design ‘rules’, primarily informed by (trial and error) experience. No wave forces could be predicted.
- Guidance on waves and their effects by Shield (1895) is markedly more advanced and clearer, although still incomplete, than that by Vernon-Harcourt (1885).
- Key materials and construction plant improved rapidly 1840-1890.
- Stability of (external) blocks depends critically on the permeability / mobility of the fill within, but no reliable / robust prediction methods.
- Toe scour may allow wash-out of internal fill, but extending toe berms or mounds (as at Dawlish?) may NOT provide a safe panacea.
- Collapsing breakwaters are unlikely to ‘evaporate’, so the remaining rubble ‘heap’ will still provide (quantifiable) levels of protection.

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Dr Tom Bruce

Dr Stephen Richardson

Dr Jane Smallman

