Portencross Castle

Review of Extreme Sea Level Frequencies

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Dr Robin Wardlaw
Institute for Infrastructure and Environment
School of Engineering and Electronics
University of Edinburgh
Crew Building
King's Buildings
Edinburgh EH9 3JN

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1. Introduction

This report has been prepared at the request of the "Friends of Portencross Castle". It summarises the results of an investigation of sea level frequencies at Portencross, and the possible impact of future sea level rise on the castle.

2. Historic Sea Levels

2.1 Relevant Tidal Records

The closest tidal station to Portencross is at Millport. This station is part of the UK National Tide Gauge Network and is run by the Tide Gauge Inspectorate. Unfortunately no details for Millport are available from the NTSLF web site, but it is understood that the record is not long. Long term tidal records do exist for Greenock, and a good relationship exists with both astronomical tides and tidal surge beween Millport and Greenock. A comparison of predicted high tides on 4th February indicated high tides of 3.2 m at both stations for the first tide and 3.6 m at both stations for the second tide. The chart datum at each site is -1.62 m.

Detailed analyses of tidal records at Greenock have recently been carried out by the Babtie Group (2002). Babtie carried out a regression analysis of peak sea levels recorded at Millport and at Greenock, and found these to be very well correlated. The following relationship was fitted:

$$Y = 1.1115X - 0.0866$$

where, Y = Greenock sea level
X = Millport sea level

The coefficient of correlation for the above relationship was 0.9888. It is clear that Greenock sea levels can be used as a basis for determining peak sea levels at Millport and by association, Portencross.

2.2 Sea Level Frequencies at Greenock

Glasgow City Council have recently funded two studies that have included detailed analysis of sea level extremes at Greenock:

"Glasgow Harbour Area Tidal Inundation and Siltation Study", September, 2001, Babtie group.

"Tides, Surges and Extreme Still-Water Level Estimates at Greenock, Renfrew and Glasgow (Broomielaw)", D L Blackman, Proudman Oceanographic Laboratory, April 2002.

The Babtie study presented a thorough analysis of historic sea level extremes at Greenock. Data were analysed for the 1907 – 2000 period. Trend analysis of the historic record indicated that the relative mean sea level at Greenock has been rising at a rate of 1.5 mm per year since 1907. Babties carried out frequency analysis of maximum sea levels using both partial duration series (largest 5 events per year) and the annual maximum series. Analyses were carried out on the historic record, and on a trend adjusted historic record. In the trend adjusted analysis, historic values were raised by an amount calculated by the number of years before 2000 multiplied by 1.5 mm. This results in a record for frequency analysis that represents present conditions. The results of the Babtie analysis are presented in Table 1.

Table 1
Babtie estimates of sea level frequencies at Greenock

Return Period (years)	Annual Maximum Sea Level 1907 – 2000 (no trend)	Annual Maximum Sea Level 1907 – 2000 (trend adjusted)
2	2.83	2.89
5	3.04	3.10
10	3.17	3.23
50	3.48	3.54
100	3.62	3.76
500	3.97	4.10

Note. Levels are in mOD

In the studies carried out by the Proudman Oceanographic Laboratory, a different approach was adopted. In the POL studies, astronomical tidal frequencies and storm surge frequencies were calculated independently, and then combined. The Babtie analysis was in effect a High Water Surge analysis, and the sample may not truly reflect the risk of coincidence of the peaks of storm surge and astronomical tides. The POL estimates of extreme sea level frequencies at Greenock are given in Table 2.

Table 2
POL estimates of sea level frequencies at Greenock

Return Period (years)	Annual Maximum Sea Level (GEV distribution, no trend)	Annual Maximum Sea Level (Joint Probability)
2	2.90	3.03
5	3.11	3.26
10	3.22	3.43
20	3.32	3.59
50	3.42	3.76
100	3.48	3.86
250	3.56	3.98

The GEV estimates (Generalised Extreme Value Distribution) are most comparable to the estimates produced by Babtie. Babtie fitted a General Logistic distribution, and the choice of distribution explains the differences between Tables 1 and 2. The joint probability analysis carried out by POL was based on relatively short records (analysis of 15 minute tidal records between 1998 and 2001), that included a significant surge in 1998. Indeed in the report POL conclude on the joint probability analysis that *"…computed surge distributions may not be as representative of the long-term surge distributions and raises uncertainty in any estimates derived from it"*.

It is considered that the most appropriate estimates of sea level frequencies at Greenock are the trend adjusted records produced by Babtie. These may be considered to be representative of present conditions.

2.3 Sea Level Frequencies at Portencross

Sea level frequencies at Portencross have been estimated from those at Greenock using the regression relationship between Millport and Portencross presented in section 2.1. The Babtie trend adjusted estimates at Greenock have been used. Estimated sea level extremes at Portencross are given in Table 3 below.

Table 3
Estimated sea level frequencies at Portencross

Return Period (years)	Annual Maximum Sea Level (mOD)
2	2.68
5	2.87
10	2.98
50	3.26
100	3.46
500	3.77

The above estimates are of still water levels and do not include wave effects.

3. Impacts of Sea Level Rise

3.1 Approach to Estimation of Sea Level Rise

Estimates of sea level rise as a result of global warming are made on the basis of results produced from General Circulation Models (GCMs) of the world's climate. Changes in global average sea levels (eustatic sea level) are a serious consequence of global warming, and result in part due do thermal expansion of the oceans and in part due to the melting of land based ice. To estimate relative sea level rise at any particular coastal location, estimates of eustatic sea level rise are combined with estimates of change of the land levels locally as a result of geological uplift or subsidence (isostatic change).

There is a number of organisations internationally who are involved in climate research and in forecasting the impacts of climate change. The Inter Governmental Panel on Climate Change (IPCC) reviews research findings and has produced a number of reports consolidating scientific findings and results. The most recent of these reports was published in 2001. In the UK, the Department for Environment, Food and Rural Affairs (DEFRA) funds the UK Climate Impacts Programme (UKCIP). The latest report under this programme was published in 2002 (UKCIP02), and presents the full range of expected climate impacts in the UK, including sea levels rise.

3.2 Global Average Sea Level Rise

The UKCIP02 and IPCC have used the same green house gas emissions scenarios. The UKCIP02 is based on the results of the Hadley Centre models (HadCM3), while the IPCC use a range of different models, with different representations for the atmosphere and ocean and for the mass balance of land based ice. The result is a range of sea level changes influenced by a combination of emissions uncertainty, and scientific uncertainty. Table 4 presents the estimates of global sea level change, relative to the 1961-90 average, published by the UKCIP02. The figures in brackets are the range of estimates for the same emissions scenarios presented by the IPCC.

Table 4
UKCIP02 global-average sea level change (cm) relative to the 1961-1990 average.

UKCIP02 Scenario	2020s (cm)	2050s (cm)	2080s (cm)
Low Emissions	6 (4 – 14)	14 (7 – 30)	23 (9 – 48)
Medium-Low Emissions	7 (4 – 14)	15 (7 – 32)	26 (11 – 54)
Medium-High Emissions	6 (4 – 14)	15 (8 – 32)	30 (13 – 59)
High Emissions	7 (4 – 14)	18 (9 – 36)	36 (16 – 69)

Note. IPCC range in brackets.

The UKCIP02 results lie below the mid-range in the IPCC results and do not exhibit significant variation between emissions scenarios.

For the purposes of the investigation of future sea levels at Portencross, the above data have been adjusted to present changes relative to the year 2000, as this was the date to which sea level frequencies at Greenock were trend adjusted. The adjusted data are presented in Table 5.

Table 5
UKCIP02 adjusted global-average sea level change (cm) relative to 2000

UKCIP02 Scenario	2020s (cm)	2050s (cm)	2080s (cm)
Low Emissions	3 (2 – 7)	11 (4 – 27)	20 (6 – 45)
Medium-Low Emissions	4 (2 – 7)	12 (4 – 27)	23 (8 – 51)
Medium-High Emissions	3 (2 – 7)	12 (5 – 27)	27 (10 – 55)
High Emissions	4 (2 – 7)	15 (6 – 33)	33 (13 – 66)

Note. IPCC range in brackets.

3.3 Isostatic Change

The Clyde estuary is experiencing geological uplift as a result of de-glaciation. In the UKCIP02 report, the estimate of isostratic uplift for southwest Scotland was 1.0 mm/year. Scottish Natural Heritage have recently published a review of coastal processes and management of Scottish estuaries (2002). Their review of the literature on uplift indicated that uplift in the vicinity of Portencross is in the range of 0.8 – 2.2 mm/year. A more recent paper by Shennon et al (2002) indicates that a rate of isostatic uplift of 1.5 mm/year would be appropriate for north Ayrshire.

3.4 Relative Sea Level Change at Portencross

Adopting a rate of isostatic uplift of 1.5 mm/year, a range of relative sea level changes at Portencross have been produced. These are presented in Table 6.

Table 6
Relative sea level change (cm) at Portencross, relative to 2000

UKCIP02 Scenario	2020s (cm)	2050s (cm)	2080s (cm)
Low Emissions	-1 (-2 – 3)	3 (-4 – 19)	7 (-7 – 32)
Medium-Low Emissions	0 (-2 – 3)	4 (-4 – 19)	10 (-5 – 38)
Medium-High Emissions	-1 (-2 – 3)	4 (-3 – 19)	14 (-3 – 42)
High Emissions	0 (-2 – 3)	7 (-2 – 25)	20 (0 – 53)

Note. IPCC range in brackets.

The UKCIP02 report indicates that regional differences in sea-level rise will occur because warming of the ocean water will not occur uniformly. There is, however, little agreement between different models as to where these differences will occur. They do point out, however, that regional differences can be as much as ±50% of the change in global average.

On the basis of the above, it would be prudent to work with an upper bound relative sea level rise at Portencross of 19 cm by the 2050's, and 42 cm by the 2080's, based on the medium-high emissions scenario.

3.5 Changes in Storm Surge

Storm surge cannot be modelled directly in either GCM's or regional climate models. Meteorological outputs have, however, been used with a separate model of the shelf seas around the UK for the UKCIP02. The indication of this modelling is that the height of a storm surge with a return period of 50 years could increase by 0.2 m in the vicinity of the Clyde estuary. However, the UKCIP02 report clearly states that *"We have relatively little confidence in these patterns and magnitudes of change in storm-surge height"*. For the purposes of this report, possible changes in storm surge height have been ignored.

3.6 Change in Wave Climate

The UKCIP02 report indicates that "*Changes in offshore wave climate and wind direction are not well quantified and we present no quantitative estimates in this report*". There is thus no basis for attempting to quantify and change in wave climate.

A brief review of the wave climate in the Clyde estuary has been presented by Firth and Collins (2002) in their report for SNH. The indication is that in the inshore region, waves rarely exceed 1.2 m in height.

3.7 Estimated Future Sea-Level Extremes at Portencross

On the basis of the data presented in Tables 3 and 6 estimates of future sea-level extremes at Portencross have been made and are presented in Table 7. These estimates are considered to be upper envelope values, being based on the upper limit of the range of IPCC forecasts of global average sea-level change.

Table 7
Upper envelope of annual maximum sea-levels at Portencross (mOD)

Return Period (years)	2000	2020's	2050's	2080's
2	2.68	2.71	2.87	3.10
5	2.87	2.90	3.09	3.29
10	2.98	3.02	3.21	3.40
50	3.26	3.29	3.48	3.68
100	3.46	3.49	3.68	3.88
500	3.77	3.80	3.99	4.19

5. Sea Levels Relative to the Castle Walls

Figures 1 and 2 show photographs of the Portencross Castle, with levels at key points indicated. The door level for the castle is only exceeded by an event with a return period of 500 years by the 2050's, but is not exceeded by an event with a 100 year return period in the 2080's.

The southwestern wall of the castle is most exposed to the prevailing seas, but the levels here are significantly higher than the still sea level under extreme conditions. Even with wave heights in excess of 1.2 m, the extreme levels only start to approach the base of the walls. Wave energy will be dissipated significantly in the run up to the castle, and significant damage is unlikely. The northwestern wall of the castle is lower than the southwestern wall, and waves are likely to run along this in extreme events, but again with much dissipated energy.

Refracted waves will run through the harbour during storm surge, but will have a lower amplitude than those in the inshore region. Water proof doors on the castle entrances would be sufficient to prevent the ingress of water under extreme surge conditions.

6. Conclusion

This brief analysis indicates that with upper envelope predictions of future sea level rise, still sea levels during extreme surge events will not exceed the base of the castle walls, except on a small section of the northwest wall, until after the 2080's. The door level of the castle is not exceeded by a event with a 1% annual probability in the 2080's on the upper limits of the medium high sea level rise scenario. Actual rates of relative sea level rise at Portencross are expected to be significantly less than those adopted for the preparation of Table 7. By taking upper envelope values, there may be some confidence that the levels given will not be exceeded. Even under this upper envelope analysis, waves reaching the southwest wall during an extreme surge will have had much of their energy dissipated before reaching the base of the wall. Waves are likely to run along both the lower parts of the northwest and northeast walls during an extreme event, but will be refracted and be lower than experienced in the inshore region. It would be prudent to use waterproof exterior doors on the castle to prevent any water slopping round doors in an extreme event as a result of waves. The analysis indicates that global sea level rise is very unlikely to present any significant threat to the fabric of the castle exterior over the next 100 years.

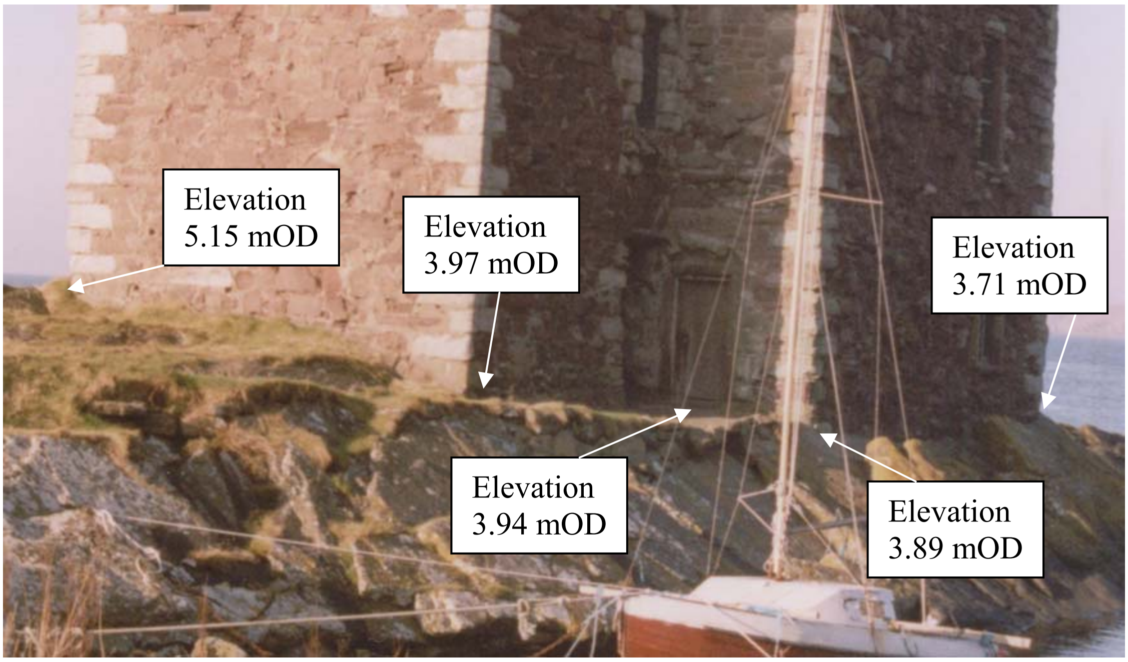

Figure 1 Levels at base of southeast and northeast walls of castle

Figure 2 Levels at base of southwest wall of castle

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