Controls of Shore Platform Width: the Role of Rock Resistance Factors at Selected Sites in Japan and Wales, UK

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ABSTRACT


Shore platform widths in the Glamorgan Heritage Coast, Wales, UK (21 sites) and the Kii (14 sites) and Izu Peninsulas (19 sites), Japan, were analysed with respect to rock strength parameters. Specifically, uniaxial compressive strength (from Schmidt hammer readings), joint density and bed thickness, were measured at cliff base and high, mid and low tide locations. Platform width values were derived from telemetric field measurements and in the case of the Glamorgan Heritage Coast, augmented by LIDAR values. Analysis of the data indicated a significant and consistent correlation between platform width and the Schmidt hammer readings derived from the more resistant, dry, unweathered rocks exposed at high tide and cliff base sites, with $R = 0.35$ at Glamorgan, 0.42 at Kii and 0.41 at Izu. This suggests that a high proportion of the platform width variation could be related to this specific rock resistance parameter (uniaxial compressive strength). No significant relationship was evident between joint density and platform width. This was unexpected and may reflect the difficulty of objective measurement of this parameter in the field. In the case of some of the Japanese sites, no jointing was apparent (within some of the massive volcanic series). Similarly, no consistent relationship was found between platform width and bed thickness.

ADDITIONAL INDEX WORDS: Geotechnical parameters, compressive strength, Glamorgan Heritage Coast (Wales), Izu and Kii Peninsulas, (Japan).

INTRODUCTION

Sea level has been relatively stable at its present level since completion of the Holocene transgression some 3000 years ago in the case of the N. Hemisphere and 6000 years ago in the case of the S. Hemisphere. Marine processes have acted upon exposed hard rock masses to develop the characteristic morphology of such coastal zones i.e. shore platforms and cliff faces; the former is the concern of this study. Platforms can be differentiated into two types: ‘Type A’, lacking a significant seaward step and ‘Type B’ with a step and consequent offshore increase in water depth.

Shore platform development is a reflection of interactions between a large number of dependent and independent variables and, in general terms, variation in morphology is a reflection of wave assailing forces ($F_w$) and rock resistance factors ($F_R$). Platform development ceases when the resistance of the cliff mass equals the assailing forces of the waves.

In storm wave environments such as the North Atlantic, mechanical wave erosion usually dominates platform development with water hammer, shock pressure of breaking waves and air compression in joints and crevasses being the most important processes, (EVERARD et al. 1964). In addition, the effect of pebble abrasion on a cliff face, still needs to be resolved.

TRENHAILE (1987; 1997) demonstrated a strong positive correlation between platform gradient ($\beta$) and spring tidal range ($T_i$) for linear platforms extending below low tide level, suggesting that:

$$\beta = 0.26 T_i$$

where $\beta$ is in degrees and $T_i$ is in metres giving a maximum platform width in the order of 220m.

In contrast, STEPHENSON and KIRK (2000a) showed wave erosion to be ineffective for shore platform development in New Zealand. Chemical and salt weathering, and repeated wetting and drying played important parts in the formation of quasi-horizontal platforms in Japan (SUNAMURA, 1992) and New Zealand (STEPHENSON and KIRK 1998, 2000b).

Whilst it is difficult to substantiate the pattern of evolution of platforms through field measurement and experimentation, TRENHAILE (2000) showed through mathematical modelling, using wave transformation equations, that platform width increased through time to reach static equilibrium. Simulated platform width increased with tidal range and decreased with the rate of submarine erosion, rock resistance, roughness of the platform surface, the amount and persistence of cliff foot debris and wave period. TRENHAILE (2000) showed that platform width increased in an essentially linear fashion with the rate of increase gradually declining with time and, in some cases, reaching equilibrium. The predicted profiles were similar to those found in field conditions.

Further understanding of the dynamics of platform development is likely to depend upon improved understanding of wave forces and the controls of rock resistance. Advances have been made in both contexts, e.g. SUNAMURA (1992), stressed the importance of quantifying the wave assailing force ($F_w$), defined as:

$$F_w = A p g H$$

where, $A$ is a constant, $p$ = the density of water, $g$ = the acceleration due to gravity and $H$ = the height of the largest waves.

Field measurements suggest that the bore of plunging breakers generate the highest pressures and TRENHAILE (2000) has incorporated water depth and type of breaking wave to define the surf force at the waterline ($S_f$) by using a decay function:

$$S_f = 0.5 p_s (H/0.78)^{1/3}W_s$$

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where $W_S$ = width of the surf zone and $k$ = rate of surf energy attenuation. The equation can be used to calculate the proportion of the breaker wave that reaches the surf-rock interface. Additionally, the tide duration factor and hourly number of waves of each type can determine the excess surf force for erosion at the head of the surf zone (TRENHAILE, 2000).

SUNAMURA (1992) derived an equation for rock resistance ($F_R$):

$$F_R = BS^c$$

where, B is a constant and $S^c$ the compressive strength of the rock in question.

TSUJIMOTO (1987) showed that where $F_R$ exceeds 3000 tonnes/m$^2$ (300kg/cm$^2$) platforms do not develop and plunging cliffs dominate the coastal zone. Therefore, platforms seem only to develop in rocks, which erode easily. Evidence, suggests an inverse relationship between platform width and rock resistance, (TRENHAILE, 1987; 1999a), though this is not always apparent because of the influence of other factors. TRENHAILE (1972, 1999a) has examined the influence of e.g. rock dip and strike and he also showed that platform width decreased with cliff height and that a bare cliff foot, or possibly one with a pebble beach, was the most favourable for development of wide platforms.

In addition, the possibility of inheritance of morphological properties from interglacial stages cannot be ignored. Using evidence from sediments, platform gradients and palaeosols in NW Spain (TRENHAILE, et al. 1999b) and from mathematical modelling (TRENHAILE, 2000, 2001), it has been shown that contemporary marine processes may be modifying shore platforms formed in the Pleistocene.

With some notable exceptions e.g. TSUJIMOTO (1987), STEPHENSON and KIRK (2000a and b), specific geotechnical controls have often been excluded from studies of platform genesis and currently, little attempt has been made to analyse variations in platform width in terms of measured, geotechnical parameters. This is not unexpected, since SUNAMURA (1992) believes that $F_R$ is a much more problematic factor to quantify than $F_W$.

The objective of the current study was to examine the significance of the $F_R$ factor through field measurement of a number of geotechnical parameters at selected macro, micro and meso-tidal shore platform at selected sites in Wales and Japan. Specifically, it was to analyse the effects of variation in rock strength, joint density and bed thickness as controls of platform width.

The Glamorgan Heritage Coast, Wales, UK

Platforms occur along almost 70% of this coastline in south Wales, UK. Twenty-one, regularly spaced sites, were selected for study within the Liassic limestone exposures between Southerndown and Llantwit Beach. It is macro-tidal, with spring tides in the range of 9 - 12 metres, generating tidal currents of up 2m/sec. In addition, storm wave conditions frequently occur with dominant and prevalent waves approaching from the southwest. Wave energies are high with typical values in the order of $68 \times 10^{3}$ Jm$^{-2}$ crest width (WILLIAMS and DAVIES, 1987).

Platforms have been cut into the almost horizontal Liassic limestone and shale rock of the angulata and bucklandi subdivisions. The strata dips to the southeast with a maximum value of 3°. Joint spacing ranges from >1.0m to <1.0cm$^{2}$. Platforms at the selected sites varied in width from 42m to 264m, and sloped gently seawards at an angle of 2°-3°. They can be described as 'Type A' platforms using the SUNAMURA (1983), terminology (Figure 1). Cliff recession rates were found to be circa 6-10cm per annum, sufficient to suggest that a high proportion of the present platforms are contemporary features i.e. developed in the last 3000 years or so of stable sea level (BELOV et al., 1999; WILLIAMS et al., 2002).

Kii Peninsula, Honshu, Japan

This study area was located some 200km south of Osaka, between Inami and Arito, covering a coastal section of 65km; 14 sites were selected for analysis along the SW orientated section of the peninsula with ease of access a determining factor. The coastal zone is a micro to meso-tidal (range 0.22 - 6m), swell wave environment with a mean wave height of 1.7m for swell waves and 1.1m for wind waves. Platforms occur along one third of this coastline and are developed typically in Miocene sedimentary rocks of Miro and Tanabe Group age. The Miro Group consists of an alternating sequence of sandstones, mudstones, and siltstones of varying thickness with some intercalated pebble conglomerates.

The Tanabe Group overlies the Miro Group unconformably and the Middle Miocene rocks consist of siltstones, conglomerates and massive sandstones.

Most platforms have low gradients (< 1°) and terminate in low tide cliffs i.e. usually the 'Type B' platforms of SUNAMURA (1983; Figure 2). Measured widths varied from 55 - 250m with the widest platforms showing a preferred orientation to the southwest i.e. corresponding with the approach of the most powerful waves generated by cyclones and typhoons approaching from the south-west. The annual average wave energy for the Kii Peninsula is 2.1 kw/m with a significant wave height of 1.18m (Corc 1990). SUNAMURA (1992) suggested a negative correlation between platform width and tidal range for this area.

Izu Peninsula, Honshu, Japan

The 19 selected sites were within a 20km section of the southeast coast of the Izu Peninsula between Ryyugu and Minato, some 300 km. southwest of Tokyo. Site selection was mainly determined by coastal accessibility and the existence of...
Sunamura’s profile surveys of 1978 (Figure 3). This coastal section is mainly developed in Shirahama Group volcanic rocks of Tertiary age reaching up to 300m in thickness. Andesites, volcanic breccias, tuff breccias and tuffaceous sandstones and siltstones dominate with rapid alternation of the rock types.

The submarine slope has gradients between 1/10 and 1/50 and waves under typhoon storm conditions can reach 8 - 9m in height with periods of 14 - 18 sec. Southerly waves dominate, though typhoon generated waves can move inshore from a variety of directions depending on the track of the storm event. Annually averaged wave energy data is 9.7kw/h and the significant wave height is 0.52m (TRENHAILE, 1990). Tides along this section of the coast have a mean range of 1.2m.

The shore platforms are nearly horizontal, ranging from 17 to 150m in width and are almost swept clear of rock debris with few surface blocks and rock fragments. They range in height from 1.2 - 3.7 m (SUNAMURA, 1978), and descend steeply on their seaward margin with water depths reaching 2 - 11m though, some have a small seaward step structure. Local crustal movements have affected platform elevation and SUNAMURA (1978) identified a relative displacement of 1.5m, the predominant tectonic displacement occurring in 1703.

SUNAMURA (1978) concluded that breaking waves at the seaward edge of the platform are the most effective agent of platform genesis. Based on the width of the small seaward edge steps, he estimated annual growth of the platforms along this coastline to be 0.4 - 0.8cm / yr.

**METHODOLOGY**

Platform width is defined as the shore normal distance between the foot of the cliff and the low spring tide level. In the case of the Kii and Izu Peninsulas, widths were measured using telemetric equipment and tapes. LIDAR based measurements to mean low tide level together with ground survey profiles were employed in the case of the Glamorgan Heritage Coast.

Geotechnical data was obtained in the field with rock strength data derived from Schmidt hammer (type ‘N’) rebound measurements. This source of data, with its known limitations, was selected because of the ease of measurement in the field and due to the restrictions of time and logistics available for the study. At least two sets of data, (15 readings for each set), were collected at high, mid and low tide locations at all investigated sites. Measurements were taken on dry, unweathered surfaces and therefore, represent the maximum readings for rock types exposed at the specific sites. Representative sampling was particularly difficult at some steeply dipping, rapidly alternating rock sequences of variable resistances along the Kii Peninsula. Data was plotted as Schmidt hammer rebound values (Figures 4 and 5) and some have been converted within the text into uniaxial compressive strength values (MPa).

Bed thickness, where possible, was measured in centimetres.

**RESULTS AND DISCUSSION**

Discussion of specific geotechnical controls of platform width must be seen within the context of TRENHAILE’S (1999) general conclusions i.e. the widest platforms are found on the most exposed coasts with high wave energy and that usually, platform width increases with decreasing rock resistance. The present study aims to make a contribution to the debate on the rock resistance controls of platform width whilst recognising that the relationship is complex. As TRENHAILE (1999) stressed, physical hardness may not be the main measure of rock resistance especially if the rock is well jointed and / or bedded.

**Relationship between Platform Width and Rock Resistance (Uniaxial Compressive Strength)**

Platform width varied from 55 - 250m for the Kii Peninsula sites, 17 - 150m for the Izu Peninsula sites and 42 - 264m for the Glamorgan Heritage Coast sites. Schmidt hammer readings varied from 19 (weakest siltstone) to 64 (gritstone), 26 - 240 MPa respectively, for the Kii Peninsula; from 18 (tuffaceous sandstone) to 57 (breccia clasts), 25 - 200MPa respectively, on the Izu Peninsula; and from 10 (the weakest shale) to 65 (the hardest limestone), 17 - 250MPa respectively, for the Glamorgan Heritage Coast. The three study areas show a

- **Figure 3.** Shore platform at Tenjinzaki, Kii Peninsula, Japan.
- **Figure 4.** Relationship between platform width and averaged Schmidt hammer readings sites at the Kii Peninsula, Japan.
- **Figure 5.** Relationship between platform width and Schmidt hammer readings for surveyed sites at the Glamorgan Heritage Coast.
similar relationship between platform width and the averaged uniaxial compressive strength values for the most resistant rocks exposed at each sampling location.

In general terms, platform width increased as compressive strength decreased. The highest Coefficients of Determination were found for averaged high tide and cliff base data sets for the most resistant rocks exposed and were significant at the 95% level with $R^2 = 0.42$ (Kii), $R^2 = 0.41$ (Izu) and $R^2 = 0.35$ (Glamorgan). This suggests that a significant proportion (35-40%) of the variation in platform width is related to this rock resistance indicator. As rock strength increases platform width decreases, a finding in keeping with the conclusion of Tsujimoto (1987), that increasing rock resistance limits platform development, with the feature ceasing to exist when rock strength reaches >3000 tonnes/m². With respect to weaker rocks such as interbedded shales, no relationship was apparent from the data collected.

However, rocks such as thinly bedded and closely jointed shales were extremely difficult to sample using the Schmidt hammer and such data sets, and any conclusions drawn, must be treated with caution. It might be expected that weathering and erosion of weaker inter-bedded material would undermine the more resistant strata leading to block detachment. This in turn should influence erosion rates and platform width. Such a correlation was not apparent from the data available.

It was the similarity of the $R^2$ values for the three locations that gives confidence to the conclusion that platform width decreases as compressive strength of the more resistant rocks exposed increases.

Relationship between Platform Width and Joint Density

Glamorgan and Kii have a similar relationship between joints density per metre and platform width. The correlation was unexpectedly low, with values of $R^2 = -0.06$ and $R^2 = -0.02$ respectively.

Many studies (e.g. Trenhaile, 1987) have stressed the importance of air compression in joints as a mechanism in platform development, a conclusion with which the authors would concur from general field evidence of undercutting and joint block detachment on platforms. Nevertheless, a strong relationship between platform width and joint density was not reflected in the data sets of the surveyed sites. It is less important than the intact resistance of the rock type.

Joint density was extremely difficult to assess in the thin inter-bedded shales of the angulata and bucklandi sequences of the Glamorgan Heritage Coast. Perhaps assessment of this factor awaits a more objective and consistent technique of joint density measurement. Certainly, a larger sample base is required before one can draw conclusions with regard its impact on platform width.

There is some evidence from the data that the highest Schmidt Hammer readings were obtained from more massive strata with widely spaced joints. Consequently, there is a possibility that the Schmidt hammer readings reflect joint density and bed thickness as well as the intact strength of the rock. This is worthy of further investigation.

Joint density measurements were not relevant to the Izu sites where the platforms were cut, primarily, in volcanic ejecta material and where jointing did not exist.

Relationship between Platform Width and Bed Thickness

The Glamorgan and Kii shore platforms widths demonstrated contrasting strengths of correlation with bed thickness. Platforms along the Glamorgan Heritage Coast show a low positive correlation, $R^2 = 0.09$, whilst the Kii data has a much stronger positive correlation with $R^2 = 0.35$.

Whilst one might have expected more massively bedded rocks to offer greater resistance to erosion and to allow only narrower platforms to develop, this relationship is not apparent for the data sets from the Glamorgan Heritage Coast sites. In addition, bed thickness was more variable along the Kii Peninsula, and true bed thickness could not be determined at four of the Kii sites. Consequently, conclusions with regard to this factor must be treated with caution. Bed thickness data was not relevant to the volcanic material at Izu sites as it was impossible to measure this parameter.

CONCLUSIONS

1. Within the array of rock strength parameters analysed, uniaxial compressive strength appeared to be a significant control of variation in platform width in macro and micro/meso-tidal environments.

2. Platform width decreased as the uniaxial compressive strength of the rock increased. The strength of the rock exposed at high tide and cliff base locations, i.e. where cliff recession and platform extension is occurring, was particularly important. Both Type 'A' and Type 'B' platforms showed a similar relationship. The correlation was comparable for the Kii and Izu sites in Japan and only slightly lower for the Glamorgan Heritage Coast sites. The link between shore platform width and this specific geotechnical parameter is a useful finding and can be expressed with a measure of confidence.

3. Where more than one rock type was exposed at the shore platform surface, it was the rock with the highest compressive strength, which had the dominant control over platform width. For example, limestone was more significant than inter-bedded shale in explaining width variations in the case of the Glamorgan Heritage Coast. Within the gently dipping strata of this area, expanses of limestone rather than thinly bedded shale dominate the surface of the shore platform and Schmidt hammer readings will be biased toward limestone related values. Whereas shale undercutting may be a mechanism involved in platform development, it seems that the properties of strata exposed over the greatest surface area, in this case the limestone, which has the greater influence on resistance to breaking wave processes and consequent development of the equilibrium width.

4. In spite of the frequently expressed claims for the importance of joint discontinuities in the wave quarrying process, variation in joint densities produced an unexpectedly weak correlation with platform width. The well-jointed Liassic sequence in Glamorgan should have been an appropriate site to test this widely held belief. However, joint density was an extremely difficult and subjective parameter to measure in the field. An increase in sample size and improved field measurement technique will be required to further test the significance of this parameter.

No joint measurements were possible in the case of the Izu Peninsula and were only available at some of the sites in the Kii Peninsula.

5. Changes in bed thickness did not seem to influence platform width in Glamorgan Heritage Coast sites but showed a stronger positive correlation in the case of the Kii Peninsula sites. Theoretically, increases in bed thickness might be expected to increase rock mass strength and therefore, platform width should reduce as bed thickness increases. Further data collection is required and as indicated above, bed thickness was difficult to ascertain at the Kii Peninsula sites and strata thickness could not be determined for the volcanic series at Izu.

6. A multivariate approach to data analysis will be necessary to give a more complete explanation of platform width variation and additional parameters should be measured e.g. water depth. Only bi-variate analysis was possible with the measured data sets of the current study. Integration of the findings of this study with the work of Trenhaile (1999, 2001) at similar locations could give a more comprehensive analysis of the controls of platform width but was not possible within the time limitations available for this study.
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LITERATURE CITED


