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*Recent sea-level changes in Hong Kong and their implications**

ABSTRACT

An analysis of data collected from tide gauges has indicated that the Hong Kong area is undergoing uplift at a rate of about 1 mm/year. However, in coastal land reclamations under the influence of long term ground settlement, the rate of subsidence may exceed the rate of uplift resulting in an apparent relative sea-level rise. Consequently, reclaimed land affected by large amounts of ground settlement are susceptible to marine inundation during storm surges generated by typhoons. In order to assist future coastal development, it is recommended that continuous monitoring of long term ground settlement is carried out on the reclaimed land using state-of-the-art surveying methods including satellite altimetry and laser ranging. This is needed to provide warning on subsidence problems so that measures including sea defence by dykes and flood pumping stations may be used to address the problem of flood damage.

Introduction

Global warming through increases in energy production is expected to result in a future sea-level rise. The impact of this on densely populated low-lying coastal mega-cities is a matter of universal concern. However, are the global rates of future sea-level rise which are predicted applicable to different parts of the world? In the present study, the local evidence for recent sea-level changes in the city of Hong Kong is reviewed followed by an assessment of the implications.

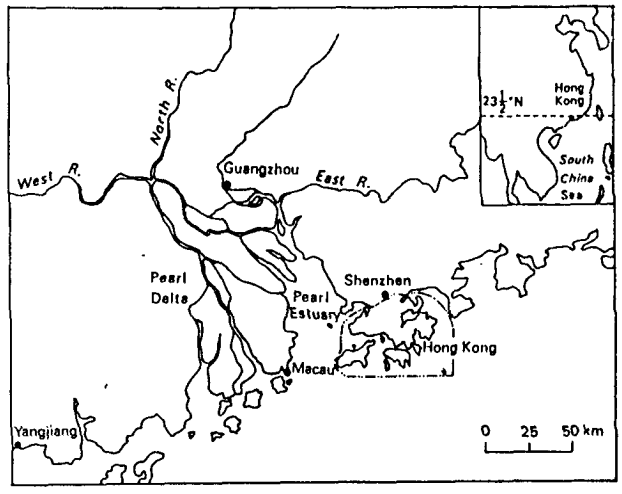

Figure 1 Map of Hong Kong and the Pearl Delta.

Hong Kong is situated near to the mouth of the Pearl River estuary on the northern coast of the South China Sea (Figure 1). Although southern China is regarded as a passive continental margin by Taylor and Hayes (1980), earthquakes up to a Richter scale of 6.4 have occurred within 280 km of the territory at Yangjiang. The western part of the territorial waters of Hong Kong is influenced by discharges from the Pearl River Delta which is advancing rapidly in a southerly direction at an average rate of 50 to 60 m/year (Huang, 1984). The total land area of Hong Kong is about 1,100 km^2 with close to 10 % consisting of coastal land reclamations (Peart and Yim, 1992). It has a total population of just under 6 million with about 60 percent concentrated in the Victoria Harbour area (Figure 2). Because the upland areas are difficult to develop and are prone to landslides, much of the densely populated existing urban areas are

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Figure 2 Oblique air photograph of Victoria Harbour showing extensive areas of coastal land reclamations on both sides of the harbour including most of the Kai Tak International Airport.
(Reproduced with permission from the Director of Building and Lands, Hong Kong Government).

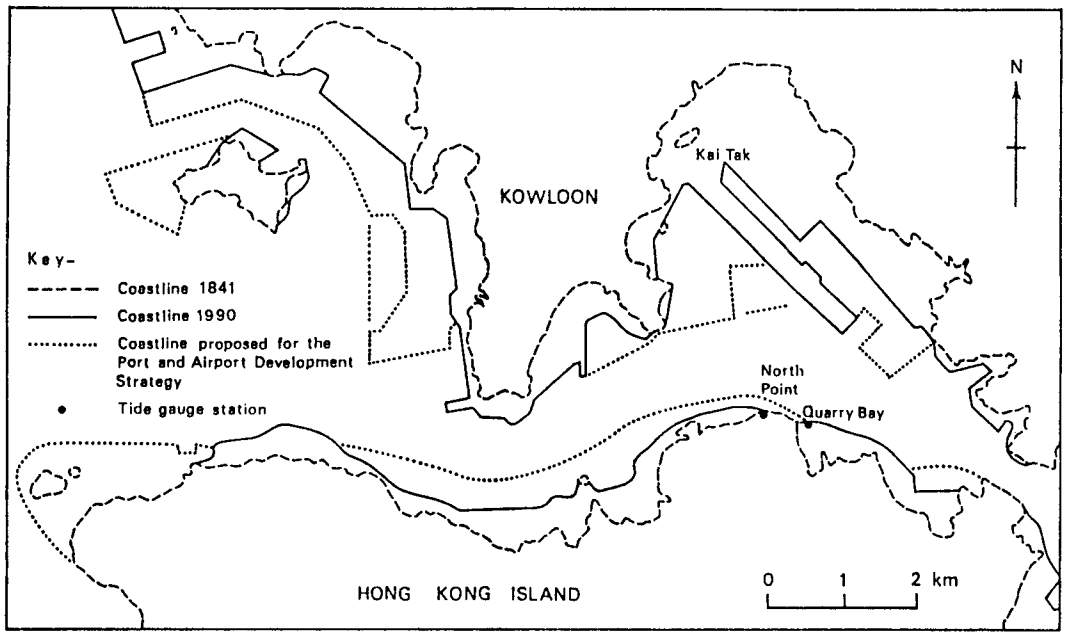

Figure 3 Map of Victoria Harbour showing the position of the coastline during 1841, 1990 and the coastline proposed for PADS. Because the reclaimed land is low-lying, it is prone to flooding during rainstorms and storm surges.

low-lying land created through coastal land reclamations in the past 100 years. Since 1841, dramatic changes of the coastline have taken place within Victoria Harbour (Figure 3). New reclamations are currently being constructed and are being planned for the Port and Airport Development Strategy (PADS). A common feature of the reclaimed land is that it does not normally exceed 6 m above Principal Datum (P.D. - the local reference datum which is about 1.15 m above mean sea level.

Evidence for recent sea-level changes

The evidence for recent sea-level changes in Hong Kong was examined previously by Yim (1991a; 1991b; 1992 and 1993). Based on the results of the analysis of tide gauge stations, Yim (1992) concluded that the ground stability of stations located on coastal land reclamations warranted attention. The longest running tide gauge station at North Point (Figure 3) was operated for 34 years before it was replaced by the Quarry Bay station. Both stations are located on reclaimed land. Surveying checks made on the North Point station and benchmarks from 1954 onwards permitted the correction of sea-level elevations against ground settlement (Yim, 1991a; 1991b and 1992). Between 1954 and 1983, a total settlement of 16.3 cm or a rate of 5.4 mm/year was found (Yim, 1991b). When the average rate of ground settlement is deducted from the annual mean sea level, no rising sea-level trend can be found. Furthermore, if comparisons are made between the corrected annual mean sea levels at the North Point and Quarry Bay stations with other stations in Hong Kong which have been found by check surveying to be unaffected by ground settlement, crustal uplift is indicated. Although the rate of uplift is difficult to quantify accurately, comparison of graphical plots of annual mean sea levels for tide gauge stations with the longest record showed a figure in the region of 1 mm/year (Yim, 1991b). This is similar to the rate of 0.6 mm/year obtained by repeated precise levelling over a 16-year period from 1960-1975 for the Shenzhen area bordering Hong Kong (C. Yang, *personal communication*). Because the North Point and Quarry Bay stations are both located on reclaimed land, the ground has subsided at rates exceeding that of crustal uplift.

High sea levels of short duration are caused by storm surges associated with the passage of typhoons close to Hong Kong. The highest predicted astronomical tide level is only 2.7 m P.D. but the maximum sea level during major typhoons in some parts of the territory may

exceed this elevation by more than 3 m. The elevation of sea level attained at different localities appears to be largely related to the coastal configuration (Yim, 1993). Within the area of Hong Kong, large differences are possible due largely to the irregular natural coastline. During the passage of a typhoon, sea levels at different localities also vary with time as a result of changes in wind direction. The sand bars present in many embayments such as at Pui O on Lantau Island in western Hong Kong can be attributed to a storm beach and/or blown sand origin (Meacham and Yim, 1983). They are considered to be relic features formed by high sea levels associated with storm surges.

Implications

It can be seen from the previous section that notwithstanding the belief that global warming will result in a worldwide future sea-level rise, local factors such as crustal uplift and subsidence must be taken into account for the accurate prediction of sea-level change. In the case of Hong Kong, allowance for the greenhouse effect in engineering design (Kwok, 1990) cannot be justified on the basis of local evidence. The record of tide gauge stations has failed to show a rising sea-level trend but relative sea level has been found instead to be falling due to crustal uplift. However, at least some of the coastal land reclamations was indicated by the North Point tide gauge site to be subsiding through long term ground settlement at rates exceeding crustal uplift. Therefore there is an apparent relative sea-level rise in the areas affected.

Reclaimed land affected by high rates of ground settlement are the most susceptible to marine inundation during storm surges generated by typhoons. This is of the greatest concern in all low-lying coastal areas. In addition to sea flooding, rainstorm flooding resulting from changing hydraulic gradients consequent upon reclamation may also increase the flood hazard (Peart and Yim, 1992). Flooding is also exacerbated by the "trough-effect" created by old reclamations which have settled between the upland areas and the new reclamations which have higher elevations.

Ground elevations of reclaimed land in Victoria Harbour available from topographic maps show many areas including seawalls to be below 4 m P.D. These areas are prone to overtopping by waves and sea flooding during storm surges. The increase in elevation of seawalls to 4.5 m P.D. in the newer coastal land reclamations would provide better protection including the effects of possible long term ground settlement. However, rainstorm flooding is exacerbated because the reclaimed land has very little gradient available for gravity drainage.

According to Yim (1991b) the causes of long term ground settlement in coastal land reclamations are attributable to a wide range of factors including:

1) Diagenetic compaction of soils including the release of gas.
2) Surcharge loading including piling.
3) Blasting through quarrying and tunnelling.
4) Regional and local earthquakes.
5) Mudwaves generated by coastal land reclamations.
6) Tunnelling within coastal land reclamations.
7) Erosion through leakages from water supply and drainage pipes.
8) Excavation particularly when dewatering is carried out.
9) Mass movement generated by the removal of fill deposits on the sea bed.
10) Rapid drawdown.

Coastal land reclamations formed of granular aggregates are susceptible to spontaneous liquefaction induced by earthquakes, blasting and other vibrations particularly when they are not well compacted after emplacement. In addition, when reclamations are extended offshore into deeper waters, a greater thickness of soft marine muds is usually encountered (Yim, 1991c). Because of this, there are likely to be higher rates of long term ground settlement. In order to monitor ground settlement and sea-level changes, it is necessary to make use of state-of-the-art surveying methods including satellite altimetry and laser ranging (known collectively as the global positioning system, GPS) as well as the establishment of new bedrock benchmarks for checking tide gauge levels. Regular check surveying would provide data to permit the estimation of the rate of crustal uplift and the rate of subsidence of tide gauges located on reclaimed land. In Hong Kong, benchmarks founded on bedrock have been installed adjacent to all tide gauges to permit continuous monitoring of possible ground settlement. This installation programme was completed in 1991 (H.H. Choy, *personal communication*). While the use of GPS is under consideration by the Hong Kong Government, some evidence has been found for tide gauge levels to be influenced by moderate scale regional earthquakes (Yim, 1991d). Without GPS, it will not be possible to estimate the rate of crustal uplift accurately.

Conclusions

This study shows the importance of using local evidence for determining recent sea-level changes in Hong Kong. For planning future coastal development, it is misleading to use a global rate of predicted sea-level rise without making adjustments for local rates of uplift and subsidence. Coastal land reclamations are targeted areas of concern because of possible long term ground settlement. In view of the lack of available records and the problem of applying records when available to sites where the soil conditions and the construction methods differ, large scale monitoring work is needed urgently to provide warning on apparent relative sea-level changes. It is based on these findings that subsidence problems may be recognised and addressed using measures including sea defence by dykes and the installation of flood pumping stations.

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