SOME POTENTIAL PROBLEMS ASSOCIATED WITH BOAT HARBOURS AND MARINE STRUCTURES ON CORAL REEFS

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INTRODUCTION

Expansion of tourism in the Great Barrier Reef region has resulted in the development of many new tourist resorts as well as the upgrading and expansion of existing resorts. Virtually all such resorts provide for holiday experiences which emphasise the idyllic tropical island paradise or the unique natural environment of the Great Barrier Reef. Essential to both concepts is the marine environment as both a recreation area and a spectacle to be observed and enjoyed.

For these. reasons, as well as the need to provide access to the resort, most island resorts require various marine facilities, including jetties, boat harbours and marinas, beaches and lagoons for water activities. Furthermore, space for marine service areas, helipads and even airstrips, often can only be provided by reclamation of portions of the foreshore.

When there is a coral reef, either as a fringing reef adjoining a continental island or the mainland or a platform reef on which the coral cay is situated, the provision of these marine facilities and structures usually involves construction on or in the coral reef. This paper discusses some of the problems associated with such projects.

FRINGING REEF ENVIRONMENTS

The principal factors that all fringing reefs have in common are that they adjoin the shoreline of a continental island or section of mainland and that coral and biogenic sediments constitute a significant proportion of their surface and upper substrate (1). In other aspects they can be very different. Three examples are given to indicate this diversity.

1. Norfolk Island (Figure la)

   This island lies in the Pacific Ocean between New Zealand and New Caledonia. On its southern shore it has a short, narrow, exposed reef located about 50m offshore from a sandy beach. There are several narrow gaps in the reef which connect to a narrow lagoon and to a small bay at one end of the reef. This reef is subjected to heavy breakers from the continuous swell as well as storm waves from several directions. Wave-induced currents are well developed with strong current outflows through the various gaps in the reef The wave-induced circulations dominate over tidal circulations (2).

2. Hayman Island (Figure lb)

The northernmost island of the Whitsunday group,. lying within the Great Barrier Reef lagoon, Hayman Island has a wide comparatively, sheltered reef. on its southern shore. Tidal and wind induced circulations dominate. Local "wind waves' are small except during occasional cyclones. The reef is predominately 'formed, of coral and biogenic sediments, overlying an earlier'reef of Pleistocene age (3).

3. Nellie Bay, Magnetic Island' (Figure lc)

Another comparatively sheltered reef subjected to local wind waves and some' low ocean swell, again with occasional cyclones. Significant input of terrigenous sediments from a creek at one end dilutes the biogenic reef-derived sediments (4). The nature, of the reeef substrate is not known but could be largely terrigenous sediments with corals and reef derived materials confined to the surface layers. Several fringing reefs in North Queensland have this type of structure (1).

BOAT HARBOURS AND MARINAS

Basic Requirements

Boat harbours or marinas form an essential part of many island resorts particularly in sheltered waters such as in the Whitsunday area. These facilities are required where it is desired to anchor vessels for considerable periods of, time. Where only a short stay is required, for. instance for commuter traffic, day trips or inter-island transfer, an open unprotected jetty may be adequate, although even in this case some dredging of the reef surface may be necessary.

The basic requirements of a boat harbour,. are a navigable entrance, a sheltered mooring area, suitable landing structures, such as pontoons or jetties, and adequate space for services and storage. Provision of the entrance may involve dredging an access channel from the edge of the reef, while the mooring'area may also have to be dredged out of the reef. Breakwaters or submersible bund walls may be required to provide'the necessary shelter at all stages of the tide. Jetties will involve driving piles into the reef surface and reclamation of part of the reef flat may be required to provide service areas. Navigational aids such 'as lights and beacons will of necessity be located on the reef in most areas.

Environmental Effects,

The're are 'many potential environmental effects which can result from a major disturbance to the reef flat such as dredging a boat harbour.. Some of the more obvious ones are given here as examples, of what can happen. It is not intended to be a discussion of all possibilities.

Firstly, the dredging of the boat harbour and its access channel may alter current and wave patterns. Moreover the consequences of these alterations will be modified if the dredged basin is surrounded by a breakwater or bund wall. An unprotected basin may fill up with sediments from the adjoining reef flat or from a stream discharging into or close to it (Figure 2a and b). Some of the sediments may be carried out through the entrance channel and completely removed from the reef surface*. A basin protected by a breakwater or bund wall should not fill with sediment but the wall may deflect the current seawards and still cause removal of sediment from the reef surface (Figure 2c). Moreover, the breakwater may change wave directions on the reef flat and shelter portions of the beach, causing changes to the beach alignment.

Secondly, during dredging a surface layer of reef rock may be broken through and underlying loose material exposed. This material may slump into the basin, effectively causing sedimentation additional to that described above. Continued removal of this material may weaken reef surface areas surrounding the dredged area and cause foundation problems.

Thirdly, disposal of dredge spoil may be a problem if it is not required or is unsuitable for reclamation purposes.

ARTIFICIAL LAGOONS AND RECLAMATIONS

Some resorts may need a shallow protected lagoon for water activities, such as swimming, wind surfing, paddle boats, etc. Such an area could be provided by enclosing a portion of the reef flat with a low flat bund wall (Figure 3a). The effect of the bund wall is to raise the low tide level over the reef flat while still allowing some tidal movements at high tide (Figure 3b). Such a project will require extensive investigation to ensure that problems such as pollution, changed ecology and sedimentation are minimised. For instance, pollution can be minimised by the continual tidal inflow over the top of the wall at the higher tide levels and discharge through sluice at low tide from time to time as required. However, tidal inflow creates the possibility of reef sediments being carried over the bund wall into the lagoon during periods when waves are stirring up sediments on the reef flat outside.

Design of the enclosing bund poses various problems associated with its appearance and safety for visitors walking on it, as well as the basic engineering problems of location, stability and water-tightness. The nature of the reef surface and its substrate is again important with regard to both their ability to support the bund wall and drainage structures and also their permeability which determines the amount of subsurface leakage from the lagoon.

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*This situation exists at Heron Island in the Capricornia region of the Great Barrier Reef. There, a dredged boat harbour and access channel provide a channel for tidal outflow to remove sediments from the reef and cay into deep water (5,6). A satisfactory and economical solution to this problem has yet to be devised.

Reclamations on reef flats may have settlement problems as the reef substrate consolidates. Moreover, the location and extent of the reclamation may cause changes to the current,circulations and beach.,, alignments similar to those caused by breakwaters. 'When "the reclaimed area is close to the reef edge, for example,' the end of an airport runway, special protection structures may. be required to dissipate wave energy (Figure 3c).

STRUCTURES ON REEFS

Foundations

Coral reefs generally do not make good foundations for structures (7) . Certainly structures should not be founded on sand cay or sand banks unless the foundation is taken down onto a firm substrate at or below reef surface level.

The variable nature of the reef structure makes design of foundations difficult (Figure 4). Bearing capacity and pile skin friction for calcareous sands are lower than for quartz sands and settlements tend to be greater (8,9). Piles have a habit of disappearing into unconsolidated sediments'which often underlie a 'thin hard surface of reef rock. In these cases raft foundations are preferable but more expensive (10).

Design Water Levels

Normal water levels are determined by the tides. Even if these are not known at a specific location, they can usually be estimated by interpolation from predictions for nearby locations*. If necessary, their measurement is simply a matter of installing a suitable recorder and operating it for a suitable time period.

Storm tide levels are another matter altogether. Cyclonic storm surges may result in substantial water'level increases offshore from the reef depending upon the intensity and direction of 'approach of the cyclone. Coastal topography can also significantly affect the storm surge height. At Townsville numerical modelling predictions indicate that the storm surge from the 1 in 50 year cyclone would be about 3.m above predicted tide, whereas' the 1 in 500 year cyclone would produce a surge of, almost 4 m (11). The height of these surges could be further increased as they travelled over the shallow reef flat, On the' other hand the probability of the occurrence of very high storm tide levels is reduced because this depends upon the surge arriving at or near the predicted astronomical high tide.

Selection of design water levels clearly must be made taking account of both the probability of occurrence of a given storm tide level and the expected consequences in terms of loss of life and damage to faciltities.

Wave Impacts

Structures located on reefs are subjected to wave action. Under normal conditions the waves are not very large and create few problems. During cyclones large waves may break on the edge of the reef. Intense plunging breakers may cause destruction of coral at the reef edge as well as the formation of ramparts or berms of coral rubble and shingle some short distance shoreward of the reef edge. The breaking waves are transformed into turbulent bores which travel, for several wave lengths across the reef before the waves reform into smaller oscillatory waves which continue to move landwards (Figure 5a). At low tide virtually all wave energy is dissipated at the reef edge although water levels on the reef flat may be increased (Figure 5b).

The'zone of intense disturbance and aeration varies in width with the. size of the waves and the depth of water over the reef. For typical conditions in the Great Barrier Reef lagoon, say waves of 3 m height and 6 s period in 3 m water depth, this zone is about 100 m wide (12). For extreme waves, it might be 200 m wide. Clearly wave impacts on structures will be much lower if the structures are located away from the reef edge. Furthermore, while the largest waves reaching a structure, such as a bund wall located well back of the reef flat, will occur at the highest water level, these largest waves will not be caused by the largest waves offshore. The largest waves that actually reach the structure are those which just cross the reef edge without breaking and hence, with minimal previous energy loss, break directly upon the structure itself (Figure 5c).

Knowledge of wave action on reef platforms is not very extensive. However, the following points should be considered by designers:

(i) Structures should be located back from the edge of the reef outside the initial breaker zone to minimise wave impacts.

(ii) The largest waves to'reach a structure on the reef will be those which just pass over the reef edge at high tide level without breaking.

(iii) The height of reformed waves on a horizontal or very flat reef platform does not normally exceed 0.55 times the water depth (13,14).

(iv) Waves breaking at the edge of the reef will increase the water level on the reef flat by an amount of the order of 10% of the offshore wave height. The wave set-up decreases with increasing tide level.

(v) The prediction of cyclonic wind waves have been improved in recent years and a numerical model, which has been tested in northern Australian environments, has been developed (15,16).

Construction Materials

Stability of breakwaters, and bund walls may be difficult to achieve with available methods and materials., Coral rubble may be too small or unavailable; in sufficient quantities, nor may there be a convenient, economical and environmentally acceptable source of rock on the island or adjoining mainland. New alternative construction methods need to be developed to cope with such situations. such methods might involve the electrodeposition of calcuim and magnesium salts from seawater (17), or biological approaches involving the cultivation of corals or algae to bind material together, or controlled formation of beach rock in specified locations.

BEACHES BEHIND REEFS

Beaches behind fringing reefs tend to be formed of a relatively steep upper beach at the shoreline, the base of which is between mean tide level and low tide level. A lower beach of much flatter slope may exist on the landward side of the reef flat with exposed coral shingle. and living coral further offshore (Figure 6a). The upper beach will normally be formed of medium to coarse sand of either biogenic or terrigenuous origin, generally with a mixture of both types of sand., The lower beach will tend to be finer in size.

Generally waves reach the beach only at tide levels above mean tide level, the largest waves occurring at high water as explained previously. The general alignment of the beach is determined by the dominant wave direction with sand movement along the beach in either direction as wave directions fluctuate about the dominant one. In some cases ocean swell from outside the outer reef may have a different effect to local wind waves (Figure 6b). Significant changes to the beach only occur during cyclonic conditions when beach recession of 10 m or more can occur. The timing of the cyclonic waves and surge with the tide is crucial,.

> If the cyclone occurs at low tide there is little effect on the beach.
> If the cyclone occurs at high tide there is significant erosion and recession of the shoreline.
> If the cyclone occurs at high tide plus storm surge there is a disaster.

Where the beach is inadequate or has been badly eroded, beach replenishment may be contemplated. In some cases this may be achieved by mechanical or hydraulic movement of sand from accreted areas back to eroded areas. Where sand has been permanently lost from the beach-reef system or where it is desired to improve an existing beach, it will be necessary to bring sand from a source outside the immediate beach-reef system. Such material should be selected with care and should have properties as close as possible to those of the existing stable beach; The evironmental effects of its removal from the source area will also have to be considered.

SUMMARY AND CONCLUSIONS

1. The characteristics of a given fringing reef system depend upon a combination of geological, climatological, oceanographical and ecological factors. Every reef is different from its neighbour and an understanding of the particular characteristics of a given reef is essential if substantial engineering works are to be constructed on it with minimal environmental disturbance.

2. Substrate conditions of reefs are very variable and can present significant problems when either firm foundations or water-tightness are required.

3. Normal wave climate on the fringing reefs of the Great Barrier Reef is relatively mild but tidal effects are significant in most areas.

4. Extreme wind and wave conditions are infrequent but the possible effects of cyclonic waves and surges can be catastropic.

5. Ecological considerations will almost certainly be more significant than in normal mainland beach environments.

6. Very little specific data is available concerning water circulations and, more particularly, wave action on the reefs of the Great Barrier Reef. Furthermore, some concepts. and design formulae commonly used by engineers in other coastal environments may not be applicable.

7. As a consequence of the above facts the investigation and construction costs for projects located on fringing reefs are likely to be greater than for an equivalent project on a reasonably accessible mainland beach but may not be as great as for a coral cay environment in exposed water.

AN IDEA FOR RESEARCH

There is a need for interaction between reef scientists and engineers in defining useful applied research projects. For example,, the design of breakwaters and bund walls might be improved if new methods for stabilising their materials could be developed. Perhaps marine biologists could determine how to cultivate corals or algae from the reef rim to provide a natural binding of an artificial mound. Geochemists could develop a means of rapidly producing beach rock. The latter would be particularly, helpful in stablising breakwaters and bund walls on reef flats in relatively sheltered areas which are only occassionally subjected to strong wave action.

REFERENCES

1. Hopley, D., Slocombe, A.M., Muir, F. and Grant, C. 'Nearshore Fringing Reefs in North Queensland. Coral Reefs; Vol.1, pp.151-160, 1983.

2. Gourley,. M.R. Wave Generated Currents - Some Observations made in Fixed Bed Hydraulic Models,: Univ. Qld, Dept. Civ. Engng, Bull. No.7, Nov. 1965.

3. Hopley, D., McLean, R.F., Marshall, J. and Smith, A.S. Holocene-Pleistocene Boundary in a Fringing Reef: Hayman Island, North Queensland. Search, Vo1.9, No. 8-9, Aug-Sept. 1978.

4. Smith, A. Case Study: Magnetic Island and its Fringing Reefs. In Hopely, D. (ed) Geographical Studies of the Townsville Area. James Cook Univ. Nth. Qld, Geog. Dept. Occ. Pap.2, pp. 59-64, 1978.

5. Gourlay, M.R. and Flood, P.G. Impact 'of Coastal Engineering Works upon a Coral Cay: Heron Island. Preprints: Conference on Environmental Engineering, Townsville, 8-10 July 1981. Instn. Engrs. Aust. Nat. Conf. Publ. 81/6, pp. 159-163, 1981.

6. Gourlay, M.R. Interaction between Natural Processes and Engineering Works on the Leeward, Side of a Coral Cay: A Case Study of Heron Island on the Great Barrier Reef. Proceedings: International Conference on Coastal and Port Engineering in Developing Countries, Colombo 20-26 March 1983, vol. 2, pp. 1468-1482, 1983.

7. Bock, H. Founding Structures on Coral Reefs. Preprints. Conference on Environmental Engineering, Townsville, 8-10 July 1981. Instn. Engr, Aust. Nat. Conf. Publ. 81/6, pp. 51-56, 1981.

8. Poulos, H.G. Engineering Properties of Bass, Strait Sediments. In Recent Sediments in Eastern Australian - Marine Through Terrestrial. Geol, Soc. Aust. Abstracts No. 13, pp. 8-11, Feb. 1985.

9. Poulos, H.G. and Chua, E.W. Bearing Capacity of Foundations on Calcareous Sand., Univ. Sydney, School Civ. & Min. Engng. Res. Rep., No. R515,Jan. 1986.

10. Ramsbotham, J.F. The' Lighting of the 'Great Barrier Reef, North of Cooktown, Queensland.', Trans. Liverpool Engng. Soc. Vol. 40, 1919.

11. Harper,, B.A., Sobey, R.J. and Stark, K.P. Numerical Simulation of Tropical Cyclone Storm Surge along the Queensland Coast - Part VI Townsville. James Cook Univ. Nth. Qld, Dept. Civ. & Systems Engng, Nov.1977.

12. Nelson, R.C. and Lesleighter, E.J. Breaker. Height Attenuation over Platform Coral Reefs. Preprints: 1985 Australasian Conference on Coastal and Ocean Engineering, Christchurch, N.Z., 2-6 Dec. 1985, vol. 2, pp. 9-16, 1985.

13. Nelson R.C Wave Heights in Depth Limited Conditions: Trans. Inst. Engrs., Aust. - Civ. Engng. Vol. CE27, No.2, pp. 210-215, May 1985.

14. Nelson, R.C. Design Wave Heights on.Very Mild Slopes. Univ. N.S.W. Aust. Defence Force Acad., Univ. Col., Dept. Civ. Engng, Res. Rep. No. R3, 1986,

15. Young, I.R. and Sobey, R.J. The Numerical Prediction of Tropical Cyclone Wind Waves. James Cook Univ. Nth. Qld., Dept. Civ. & Systems Engng, Res. Bull. CS-20, July 1981.

16. Sobey, R.J. and Young, I.R. Predictive Model for Hurricane Wind Waves. Proceedings: Specialty Conference on Computer and Physical Modelling, Chicago, Aug. 1980. Am. Soc. Civ. Engrs, Hydr. Dvn, pp. 334-344, 1980.

17. Stark, K.P. and Johnston A.J. A Marine Building Material of the' Future. Preprints: 1985 Australasian Conference on Coastal and Ocean Engineering, Christchurch, N.Z., 2-6 Dec. 1985, Vol. 2., pp.257-268, 1985.

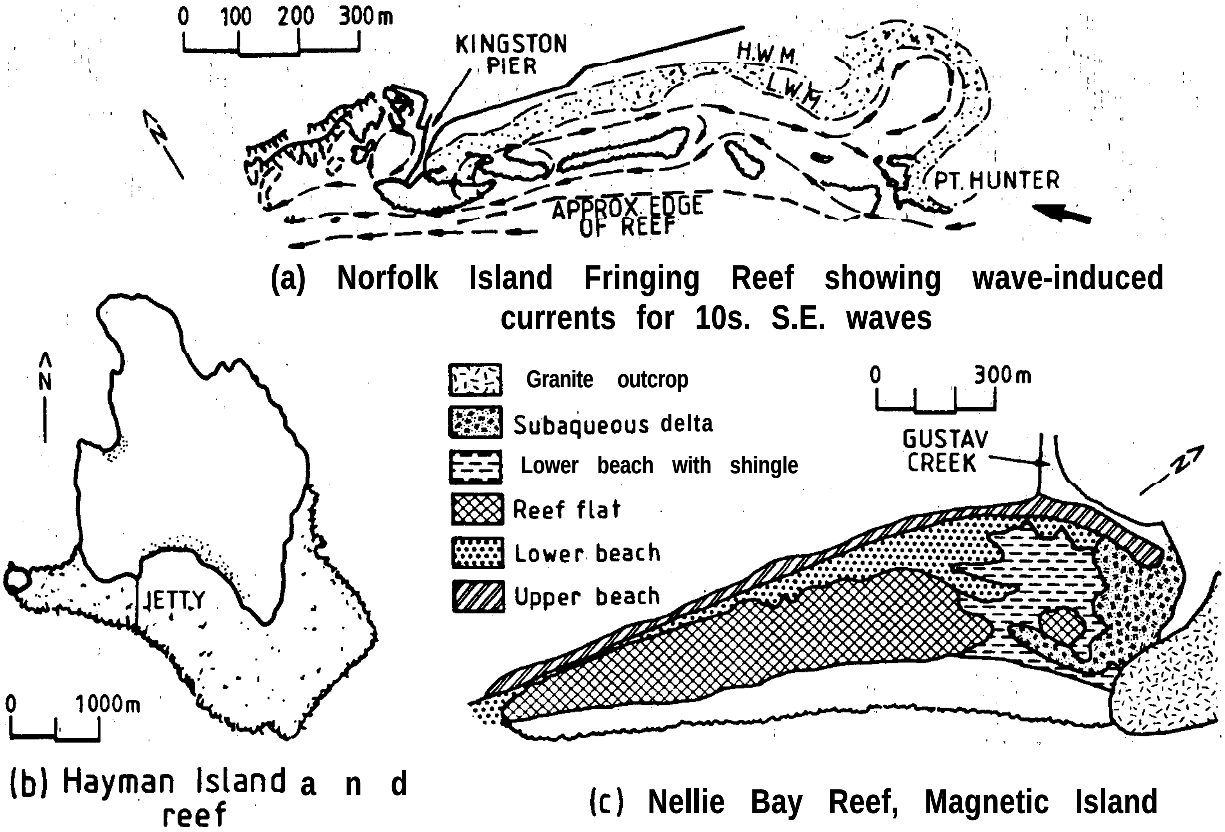

Figure 1. EXAMPLES OF FRINGING REEFS

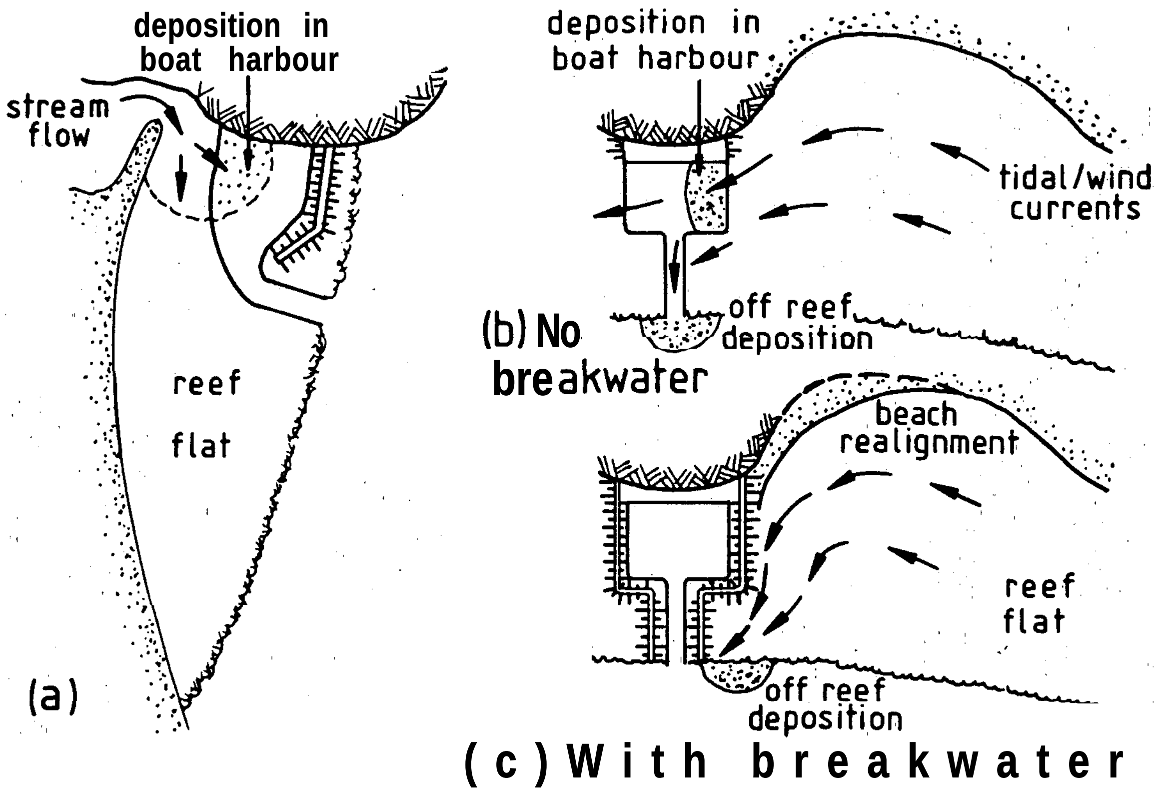

Figure 2. SEDIMENTATION IN BOAT HARBOURS

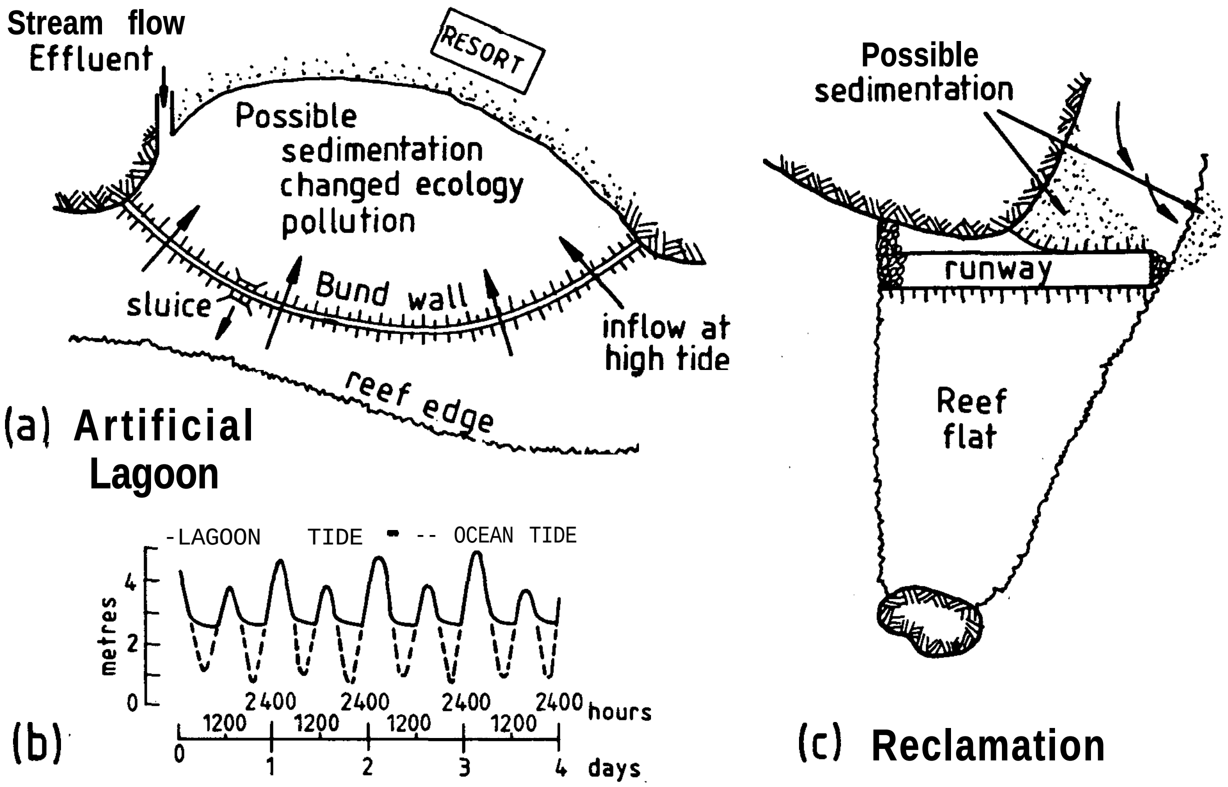

Figure 3. ARTIFICIAL LAGOONS AND RECLAMATION

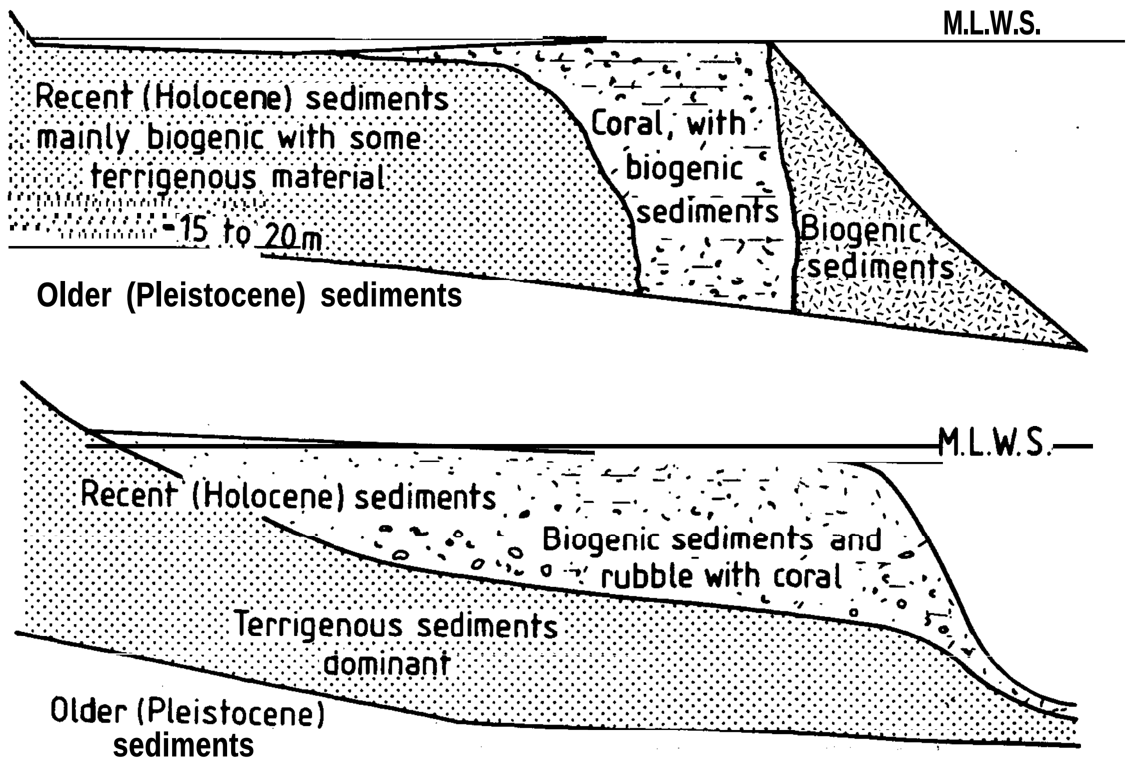

Figure 4. TWO TYPES OF REEF STRUCTURE

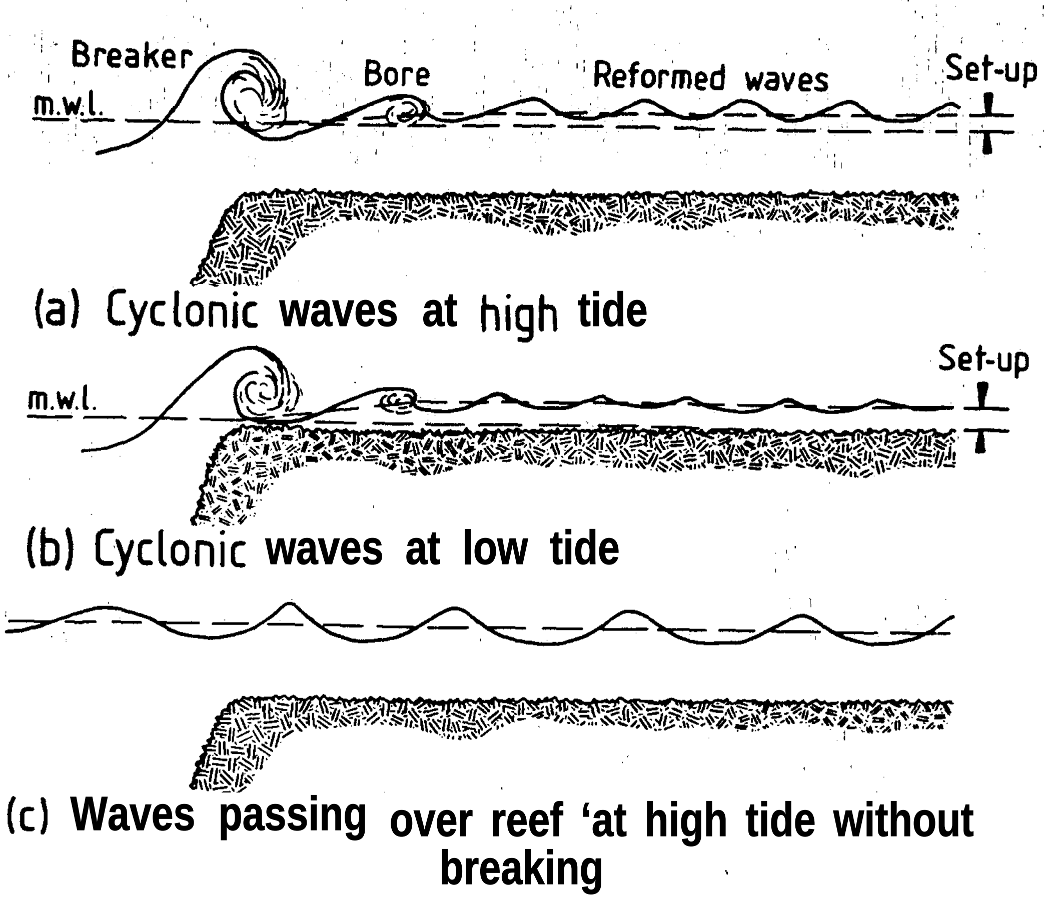

Figure 5. WAVES ON CORAL REEFS

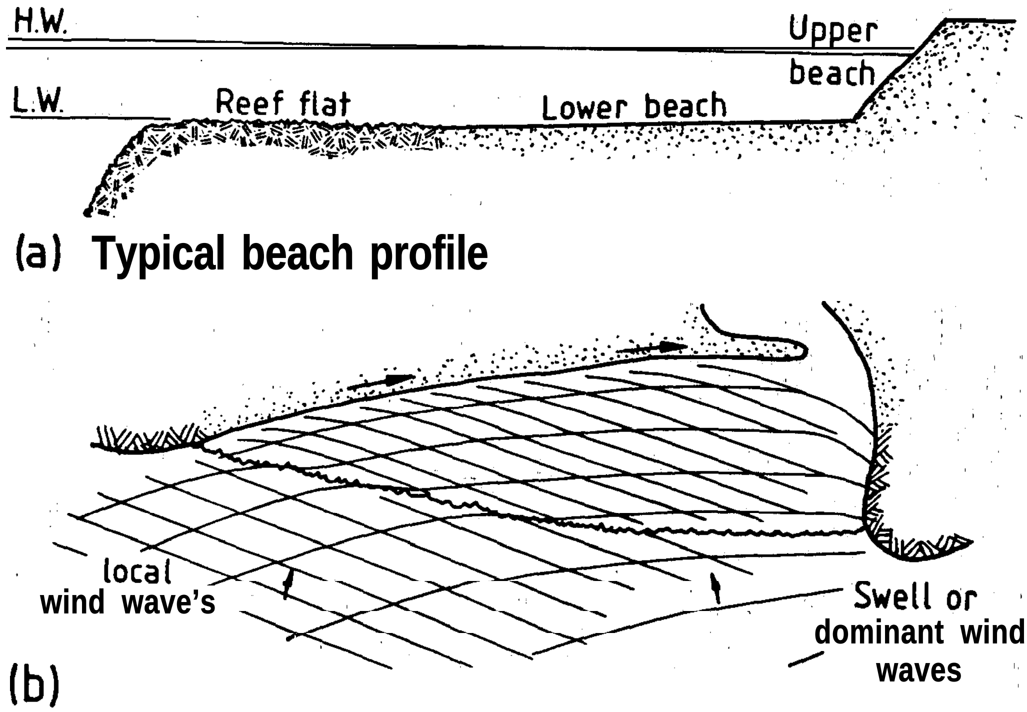

Figure 6. BEACHES ON FRINGING REEFS