CHAPTER 25

Wave Attenuation on an Offshore Coral Reef

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ABSTRACT

The wave climate along the northeastern tropical coastline of Australia is controlled by The Great Barrier Reef (GBR). However, the processes by which the GBR attenuates and transforms waves are little understood. As the first part of an on-going study of the interaction between waves and coral reefs, a field experiment was conducted to study the processes that occur as waves break on an offshore reef and proceed across the reef flat into the lagoon. Eighteen wave, water level, and current measuring instruments were deployed and data for a wide range of tide and wave conditions were collected. Preliminary results for wave attenuation are presented. Results for wave attenuation across the reef show that wave heights on the reef flat and in its lagoon are controlled by the depth of water over the windward reef flat. As the waves travel across the reef flat, the ratio of significant wave height to water depth reduces to a value of 0.40, and the ratio of maximum wave height to water depth reduces to a value of 0.6 to 0.8. In the deeper water in the middle of the reef lagoon both the ratios of significant wave height to the depth over the reef flat and maximum wave height to the depth over the reef flat remain in the above ranges. However, at the mid-lagoon position these results are less general as wave heights inside a lagoon are also dependant on wind speed, direction, and fetch length inside the lagoon.

INTRODUCTION

The Great Barrier Reef (GBR) stretches for approximately 2000 km along the eastern tropical coast of the state of Queensland in northeastern Australia. Much of the GBR is relatively inaccessible as the reefs are usually more than 50 km, and often much farther, offshore. This is particularly the case in the lower two-thirds of GBR which is

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nearer to populated areas. Because of its remoteness and the relatively small population on the tropical coast, visits to the GBR were relatively few until the last few years. However a recent boom in overseas tourists who are eager to enjoy the pleasures of snorkelling and SCUBA diving has initiated improvements in transportation including large wave piercing catamarans that have greatly reduced travel times to the reef.

Even with the fast catamarans, the trip out to the reef can be long (over two hours at some locations) and uncomfortable. Few of the reefs have any land permanently above the water; therefore, tourist operators are eager to provide stable platforms at their reef destinations. Numerous pontoons have been anchored inside the lagoons of individual reefs. Furthermore, a "floating hotel" was located for one year inside the lagoon of one reef. The design and operation of such facilities requires information about waves after they have proceeded from relatively deep water across the reef front and into the reef lagoon. Such information is needed for both normal operational conditions, as well as during tropical cyclones.

Coral reefs have a marked effect on waves as the waves reflect, refract, and break on the almost vertical seaward reef front, and also as the waves travel over the shallow and rough coral surfaces on the shallow reef flats. Despite this obviously important role, very little is known about the physics of wave energy reflection, dissipation, and transmission on coral reefs. There have been few studies in the GBR. A preliminary experiment was conducted by Young (1989) at Yonge Reef, one of the outer barrier ribbon reefs near Lizard Island in the Far Northern Section of the Great Barrier Reef Marine Park. Measurements between the GBR and the mainland coast north of Cairns and outside the GBR near Myrmidon Reef, offshore of Townsville, have been published by Murray and Ford (1983) and Wolanski (1985), respectively. In addition, laboratory experiments by Nelson and Lesleighter (1985) have been used as a basis for engineering design. These sources confirm that the GBR is a significant barrier to wave penetration but none of the studies is extensive enough to provide understanding of the processes involved.

Published studies of waves on coral reefs from outside Australia have concentrated on landbacked or fringing coral reefs. Gerritsen (1981) and Lee and Black (1979) report on the wave-induced processes occurring on a fringing reef in Hawaii. However, this work has limited application for the GBR, not only because a fringing reef was studied, but also because the Hawaiian wave climate is dominated by longer period swell unlike the shorter period sea which dominates much of the GBR. Other studies include those by Roberts (1981) in the Caribbean and by Kono and Tsukayama (1980) for Okinawa.

In order to gather data on the interaction of waves and coral reefs, a field study was conducted in 1988 on an offshore coral reef in the Great Barrier Reef region. An extensive set of wave, water level, and current data was collected on the windward edge of the reef. The purpose of this paper is to present preliminary results on wave attenuation from this investigation.

DESCRIPTION OF THE STUDY REEF

John Brewer Reef, located approximately 70 km northeast of Townsville, Queensland in the Central Section of the Great Barrier Reef Marine Park (Figure 1), was selected as the experimental reef primarily because of the logistical support that was available. John Brewer was the site of the floating hotel which was located in the lagoon for just over a year encompassing the duration of the experiment. In addition, there was a daily catamaran service to John Brewer from Townsville. It would have been difficult if not impossible to conduct the experiment without the availability of transport and a safe and stable haven from rough conditions for both computer equipment and researchers.

The Central Section of the Great Barrier Reef Marine Park is one of the least densely reefed segments of the GBR. John Brewer Reef is on the inner (landward) edge of the reef matrix and is elliptical in shape (6 km by 3 km) (Figure 2), with the major axis approximately normal to the southeast which is the predominate wind direction. The elevation of the seabed surrounding the reef drops rapidly to a depth of approximately 50 m below Lowest Astronomical Tide (LAT). The windward edge of the reef is a continuous reef flat which is 200 to 300 m wide and uniform in elevation at approximately 0.1 m above LAT. This reef flat extends along not only the southeastern edge but wraps around both the southwestern and northeastern ends of the reef extending approximately three-fifths of the perimeter of the reef. The leeward edge of John Brewer is much less continuous, being composed of coral heads or "bommies", which reach just higher than LAT and are separated by sandy patches with depths of 10 to 20 m. Whereas the windward reef edge could be considered to be 100% solid reef, from aerial photographs, the leeward edge is estimated as being approximately 50% solid.

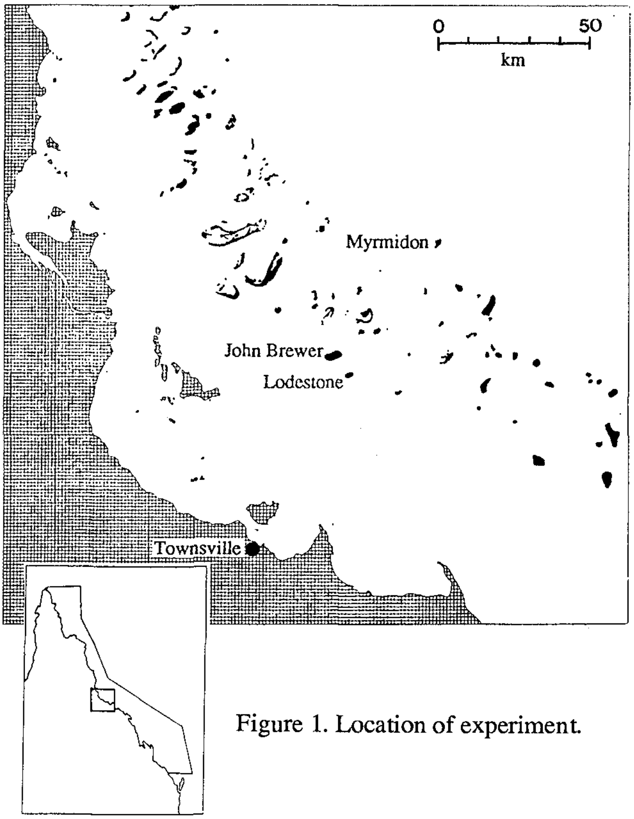

Figure 1. Location of experiment.

The lagoon of John Brewer is mostly sandy bottom and is interspersed with hundreds of medium to large sized bommies most of which remain under water at LAT. The lagoon can be separated into two categories based on depth. The deep lagoon occupies approximately 50% of the area of John Brewer and averages about 10 m in depth. A shallower lagoon provides a transition band of several hundred metres between the windward reef flat and the deep lagoon.

In comparison to reefs in most of the other sections of the GBR, John Brewer is relatively isolated from other reefs. However, being on the inner edge of the reef matrix means that John Brewer seldom receives direct wave energy from seaward of the GBR. The nearest reef in the windward directions (east to southeast) is Lodestone which is approximately 7 km southeast of John Brewer.

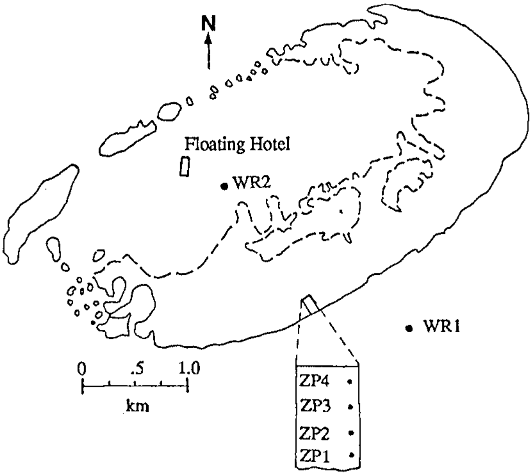

Figure 2. Instrument positions on John Brewer Reef.

A primary criterion in the design of the experiment involved selecting an experimental site that offered a simple geometry so that the physics of the problem could be more easily understood and also so that results from this site could be more easily transferred to other sites. With this in mind, a linear array was envisioned normal to the reef front and parallel to the predominate direction of the wind, which is from the southeasterly direction. It was anticipated that most of the wave attenuation would be caused by wave breaking and bottom friction over the several hundred metres of the relatively shallow reef flat. Therefore, it was decided to concentrate the wave measuring instruments in this zone.

DESCRIPTION OF THE INSTRUMENTS

A combined total of 18 wave, current, tide, and wind measuring instruments were deployed during the experiment. These were made up of two Waverider buoys, four surface piercing wave measuring staffs, six S4 current meters, four tide gauges, one pressure sensing wave gauge, and one anemometer. Since the purpose of this paper is to present wave attenuation data, only the wave measuring instruments will be discussed.

The two Waverider buoys were specially purchased for the experiment. They were imported from Datawell, The Netherlands and were calibrated in Sydney, before being flown to Townsville. Both the buoys were equipped with telemetry and the data signals were captured by a receiver located in the radio room of the Floating Hotel.

The wave measuring staffs used in the field experiment were first proposed by Zwarts (1974). Each staff was six metres long and consisted of two pipes, one inside the other, forming a coaxial cable. Three of the staffs were made of copper pipe, with diameters of 50 mm and 25 mm for the outer and inner pipes, respectively. Slots in the outer pipe allow the movement of water into the space between the outer and inner pipes. The fourth staff was made of aluminium and was of similar design to the copper staffs.

These wave staffs employ a principle commonly used in the telephone industry to detect the location of faults in coaxial cables. The set up of the pipes in a coaxial cable configuration acts as the tuning element of an electronic oscillator. The battery powered electronics located at the head of the pole direct an electromagnetic wave down the pole. This wave reflects off the discontinuity in the dielectric constant at the air-water interface. The length of the unimmersed section of the staff is directly proportional to the period of the oscillation of the electronic signal. The output of the system is a time series of the number of reflections of the electronic signal during a very small time interval.

A battery powered programmable data logger, developed at the Australian Defence Force Academy for the project, controlled the discrete time interval, the length of the time series, and the start of each time series, as well as stored the data. One logger serviced two wave staffs. Approximately 200 time series (100 from each of two staffs) could be stored.

Each of the staffs had to be calibrated so that the counts resulting from the data collection could be translated into water level. Static calibration tests were conducted several times during the design and testing of the loggers in addition to pre- and post-experiment tests. The results were always extraordinarily linear. That is, the recorded points fell on a straight line of water level *vs* reflection count with a high degree of accuracy. Also, for a given material (i.e. copper or aluminium) the slope of the plotted line was a constant. The slope did not change from one copper staff to another or from one test to another of the same staff. Therefore, the raw counts recorded by the logger could be reduced to water level through a highly accurate linear relationship.

Although the static calibration results are used to convert the instrument counts to water level, it is important to consider the errors that might affect the measurement of the more rapid movement of the water up and down the pole that will occur with waves. At the conclusion of the field work at John Brewer Reef, dynamic tests were conducted on one of the copper staffs. The testing set up was similar to the static tests. The staff was placed in a PVC tube and supported vertically, the tube was half filled with water, and the electronics connected to the logger and computer. But instead of lowering and raising the water level, the staff was moved vertically by the use of a cable and pulley system driven by a variable speed electric motor. An eccentric cam fitted to the flywheel of the motor caused the position of the water surface on the pole to follow a sinusoidal pattern when plotted against time. The response of the system was excellent, the difference between the sinusoidal input signal and the wave staff output was much less than 1%, even with conditions equivalent to wave periods of 1 s and with wave steepnesses near breaking.

Although the primary purpose of the wave staffs was to obtain wave data, tide data is available from the wave records by averaging over a time period much longer than the 3 to 7 seconds of the predominate wave periods. The water level information would give insight into the wave induced water level changes as well as the tide levels at which the wave records were taken.

EXPERIMENTAL SETUP

Figure 2 shows the experimental layout. The primary instruments of the experiment were the two Waverider buoys and the four wave staffs. The "outside" Waverider, WR1, was located approximately 500 m seaward of the reef front in a depth of 50 m. The four wave poles were aligned in a linear array normal to the reef front. The seaward most staff, ZP1, was 27 m from the reef front and staffs ZP2, ZP3, and ZP4 were located at intervals of 42 m, 49 m, and 50 m, respectively. The "inside" Waverider, WR2, was located in the middle of John Brewer lagoon, approximately 1.5 km from the reef edge and in a depth of 12 m.

The deployment of the wave staffs was a formidable task. Not only was the experimental site on the windward edge of the reef, but the site was 70 km from the mainland. Each wave staff was supported by an aluminium tower which was held in place by rope stays attached to metal fence posts that were driven into the reef flat by hand. The towers had to support the wave staffs and logger, but also had to allow access to the top for researcher and portable computer for downloading of data. Each tower was deployed separately during a two day trip. This one-at-a-time deployment allowed for alterations to the design, as the towers were designed especially for the project and the original design was untested. The position of ZP1 was in the breaker zone and this made it difficult to erect the tower, as well as keep it standing. This front tower was toppled during the first strong winds after its initial establishment. However, after re-deployment with extra stays and continual maintenance (the constant pounding of the waves tended to bend the anchor posts) the tower remained functional during the duration of the experiment. All four towers were erected and were well tested in operational conditions several weeks before the deployment of the wave staffs.

The outside Waverider was deployed in early March 1988. The rest of the instruments were deployed during the period of 12-15 August 1988. There were some initial difficulties with the wave poles and it was necessary to reprogramme the loggers and re-deploy the poles during 1-2 September 1988. The wave poles were removed on 15 October 1988. The Waverider buoys were left in position at the end of the main experiment and were removed on 11 July 1989.

DATA ANALYSIS AND RESULTS

A time series containing 2048 samples of water level at a discrete time interval of $\Delta t = 0.3906s$ was collected once an hour from both Waverider buoys. For the wave poles, a time series of water level with 4800 samples or 20 minutes at $\Delta t = 0.25s$ was collected each hour during the first five days of the experiment and every two hours for the rest of the experiment.

The data collection from the six primary instruments was a great success. More than 3000 individual time series were gathered from these main instruments. There were 286 times when all 6 instruments were operating and of these, 254 were when waves were approaching from the East to South directions for which the experiment was designed. Data were collected for a wide range of tide and wind conditions. We believe that this data set is the largest and most comprehensive ever collected in this environment.

Preliminary analysis for wave height attenuation has been completed on the large data set from the six primary wave measuring instruments. A frequency domain analysis was conducted by transforming the time series into frequency space using an FFT. Significant wave height was calculated as $H_{m0} = 4.0\sqrt{m_0}$, where m_0 is the zeroth moment of the variance spectral density. A time domain analysis has also been conducted using a zero downcrossing technique, and the maximum wave height, H_{max}, was calculated for each wave record. Each of the time series and spectra were plotted. A twenty second time period surrounding the time of the maximum wave in each time series has also been plotted to aid in the discovery of bad data points.

Figures 3-5 contain plots of the time series of wind speed (Myrmidon Reef, see Figure 1), water level, and significant wave height, at three of the wave measuring stations (WR1, ZP4, and WR2) for 5-6 September 1988. During this period wind speed reached 10.8 m/s (21 knots) during a 2 m tidal range. The influence of the tide is apparent in the plots of H_{m0}, except for the outside Waverider (WR1). At higher water levels, there is a noticeable reduction in H_{m0} from the outside Waverider, WR1, through the inner most pole, ZP4, and into the inner Waverider, WR2. At lower water levels the reduction is more dramatic. This is certainly the expected result since all the mechanisms that will reduce wave height (reflection, refraction, wave breaking, and bottom friction) have a greater effect at lower water levels.

Figures 6-11 contain the plots of H_{m0} *vs* water depth over the reef flat for WR1, ZP1, ZP2, ZP3, ZP4, and WR2, respectively. The plot (Figure 6) for the outside Waverider (WR1) shows no indication of a dependence of wave height on water level. It is not expected that tidal variations in the inter-reefal areas would significantly effect the wave results because these depths average 50 m and the maximum tidal range at John Brewer is less than 4 m. Therefore, any tidal effect on wave height at WR1 would have to result from the effect of other reefs upwind of John Brewer. There would be a lag between tide level and the effect at WR1 caused by the time the wave train took to travel the distance between reefs. However, studying the time series of tide, wind speed and wave height reveals no obvious trends. The lack of stationarity (the wind does not remain constant) complicates a rigorous statistical correlation analysis.

In contrast to Figure 6, Figures 7-11 all show a marked dependence of H_{m0} on tide level. The envelope is well defined and reasonably linear, especially at lower water levels. Using the relationship, $H_{m0} = \gamma d$, where d is the water depth over the reef flat and γ is the slope of the upper envelope of the H_{m0} *vs* water level relationship, γ reduces from 0.7 at the outermost pole (ZP1) to 0.4 at the innermost pole (ZP4). These results are similar to results from laboratory experiments conducted by Horikawa and Kuo (1967) in which waves broke on the seaward edge of a horizontal shelf fronted by a sloping offshore bottom, a topography similar to that of a coral reef. Values of γ from their experiment decreased from 0.80 at the shelf edge (recall that ZP1 was 27 m in from the reef edge) to 0.35 to 0.40 landward along the shelf.

Figures 7 to 9 for ZP1, ZP2, and ZP3 show, that for water depths greater than 1.5 m, the larger waves do not reach the limiting value corresponding to the envelope determined for water depths less than 1.0 to 1.5 m. However at ZP4 (Figure 10) the larger waves at depths greater than 1.5 m do approach the same limiting envelope as determined for smaller depths. This behaviour suggests that width of the surf zone may be extending past the location of ZP4 during more extreme conditions at higher tide

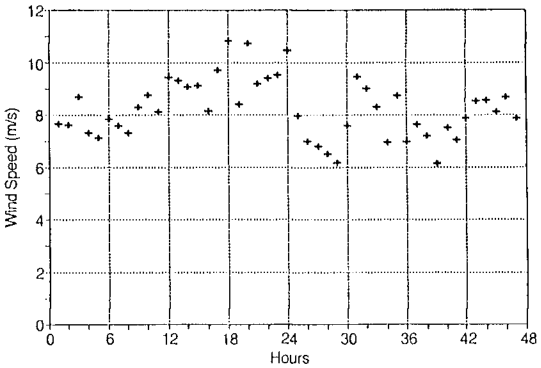

Figure 3. Wind Data, September 5-6 1988.

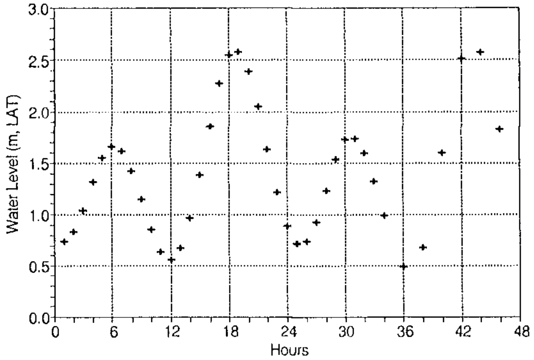

Figure 4. Tide Data, September 5-6 1988.

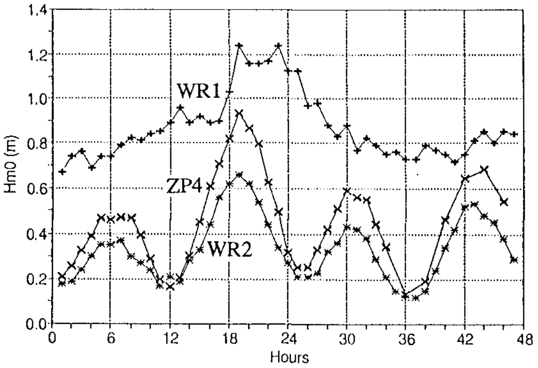

Figure 5. Significant wave heights, September 5-6 1988.

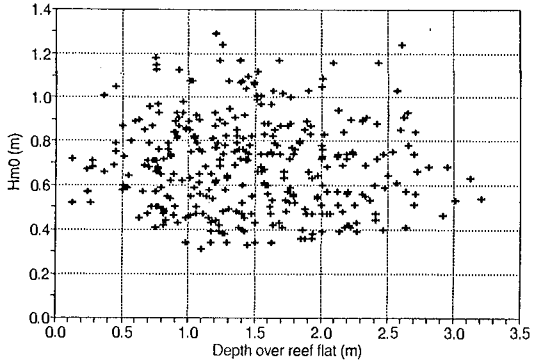

Figure 6. Significant wave height *vs* water depth over reef, WR1

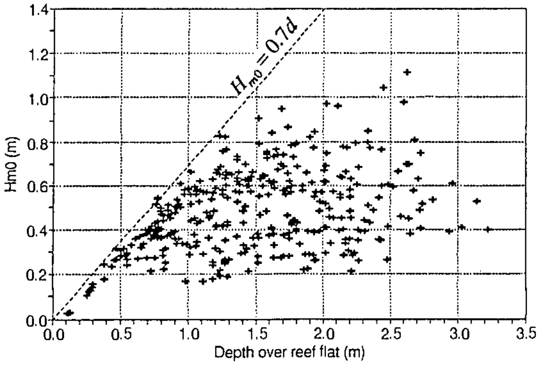

Figure 7. Significant wave height *vs* water depth over reef, ZP1

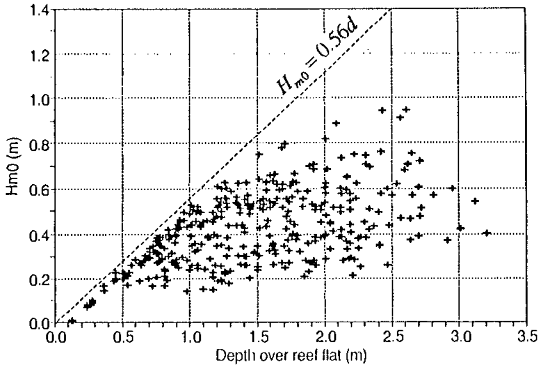

Figure 8. Significant wave height *vs* water depth over reef, ZP2

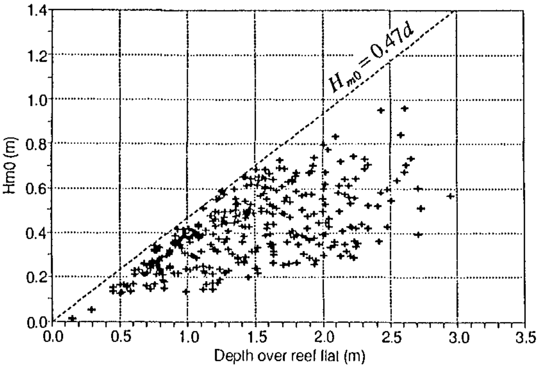

Figure 9. Significant wave height *vs* water depth over reef, ZP3

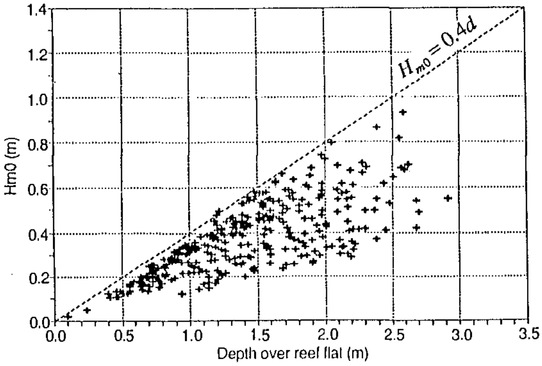

Figure 10. Significant wave height *vs* water depth over reef, ZP4

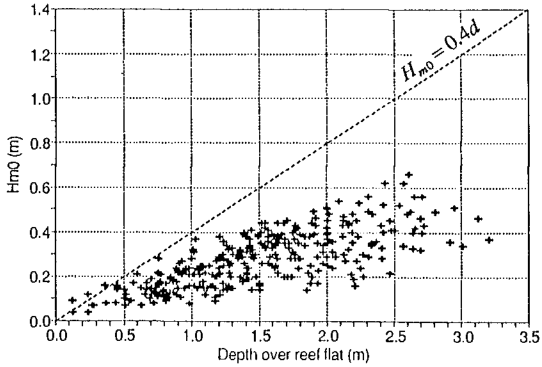

Figure 11. Significant wave height *vs* water depth over reef, WR2

levels. Visual observations indicated that ZP4 was almost always free of wave breaking activity (especially at lower tide levels), but these observations did not include severe conditions at higher tide levels.

The analysis of the wave height data at WR2 is more complicated than at the wave staffs. Wave heights at WR2 were not limited by the depth at that instrument. Recall that WR2 was located in the middle of the reef lagoon in an average depth of 12 m. Wave heights at WR2 generally are smaller than at ZP4. This may be partially explained by the negative shoaling effect as the waves propagated from the shallow water over the reef flat into the deeper water in the lagoon. Also, although outside energy that reached WR2 was limited by the depth of water over the reef front, this outside energy will not necessarily be that which came past the wave staffs. Furthermore, observations while travelling by boat across the lagoon indicated that there could be significant wave growth during periods of high wind speed. Since the distance that locally generated waves travelled across the lagoon to WR2 varied with wind direction, the results shown in Figure 11 should be a function of local wind speed and direction, as well as water depth over the reef front. Although the upper envelope in Figure 11 is not as well defined as those shown in Figures 7-10, the depth of water over the reef flat is clearly an important control on the amount of wave energy reaching WR2. This conclusion is also strongly suggested in Figure 5, where, as previously mentioned, the wave height and water depth over the reef are strongly correlated.

For higher water levels at WR1, there is a trend for the larger waves to fall short of the linear extension of the enveloped defined by the lower water levels. This is similar to the trend noted above for ZP1, ZP2, and ZP3. There is a temptation to suggest that using a linear trend, based on the lower water levels, to predict the larger significant wave heights might result in over-prediction. However, it is expected that the envelope would be more poorly defined at higher water levels, since there are fewer wave heights greater than the depth limiting condition as compared with the lower water levels, and (in the case of WR2) the wind speeds and directions for maximizing the wave height may not have been encountered during the experiment. Fortunately, data were collected outside the main experiment which help define the envelope for WR2 at higher water levels. Cyclone Aivu passed approximately 100 km to the south of John Brewer Reef on the morning of 4 April 1989. At 07:32 the high astronomical tide in Townsville was predicted to be 3.6 m, just 0.1 m short of highest astronomical tide. At 07:00 the largest significant wave heights, $H_{m0} = 2.89m$ and $H_{m0} = 1.65m$ were measured at WR1 and WR2, respectively. (The wave staffs were not deployed.) There were no water level measurements at John Brewer Reef, but using an estimate of 4.0 m (adding cyclone induced water levels to the astronomical tide) for the depth of water over the reef front, $\gamma \approx 1.65/4.0 = 0.41$, which agrees well with the estimate of $\gamma = 0.4$ taken from the lower portion of Figure 11.

Plots of $H_{\max}$ *vs* d for all six wave measuring instruments are shown in Figures 12 to 17. Since the maximum wave height is a single wave as opposed to the significant wave height which characterises the whole of the wave field, the upper envelope of the plots of $H_{\max}$ *vs* d are not as well defined as those of H_{m0} *vs* d (all records with values of the ratio of $H_{\max}$ to H_{m0} greater than 2.0 were checked for bad data points). Still, as expected, the dependence on depth is clear for the four wave poles (Figures 13-16) and WR2 (Figure 17). Again there is no apparent dependence of $H_{\max}$ on depth over the reef flat for WR1 (Figure 12).

The ratio of maximum wave height to water depth, (γ_{max}, reduced from approximately 1.1 at ZP1 to between 0.6 and 0.8 at ZP4. As with significant wave height, the results for WR2 are less linear and not as well defined as for the wave staffs. The maximum wave height recorded at WR2 during cyclone Aivu was $H_{max} = 2.33$ m at an estimated $d \approx 4.0$ m, which gives $\gamma_{max} = 0.58$. This indicates that at higher water levels the results for γ_{max} lie more closely on a linear extension of an estimate of $\gamma_{max} = 0.6$ taken from the lower portion of Figure 17 than the plotted data would indicate. It should be noted that laboratory data for the maximum height of regular waves on horizontal or very flat bottoms, i.e. conditions similar to reef tops give a maximum value of $\gamma = 0.55$ (Nelson, 1985).

The results from WR2 must be used with caution for application to other locations. Although depth over the windward reef flat is clearly an important and perhaps the most important variable for wave heights inside the lagoon, other site specific variables will also play a role. The width of the reef flat will be important, as will the local wind speed, direction, and the length and depth of the fetch inside the lagoon.

FUTURE WORK

The analysis of the wave data has not been completed. For example, the effect of wave breaking on wave frequency is still to be investigated. As a final product, it is hoped to incorporate knowledge gained on the attenuation and transformation of waves on coral reefs into an improved spectral wave model for both inter- and intra-reefal regions. As the first step in this process the partitioning of the energy losses into the components of refraction, breaking, bottom friction, and reflection will be attempted.

Wave induced water levels and currents are important for both engineering and biological requirements. Observations at John Brewer reef indicate that wave induced currents could significantly affect the circulation in the reef lagoon. The current and water level data have not yet been analysed. However, as part of the overall study of wave and reef interaction, laboratory measurements of wave setup and wave generated currents across an idealised two dimensional reef have been completed and are being prepared for publication.

Another component of the overall research is the study of wave induced processes affecting coral cay formation and stability. The construction of a physical model of a planar coral reef with a cay has been completed in the University of Queensland wave basin. Experiments using this physical model to study the wave-induced water levels and currents on a three dimensional planar reef are on-going.

ACKNOWLEDGEMENTS

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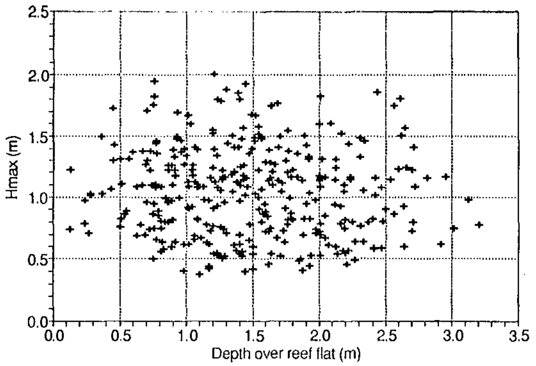

Figure 12 Maximum wave height *vs* water depth over reef, WR1

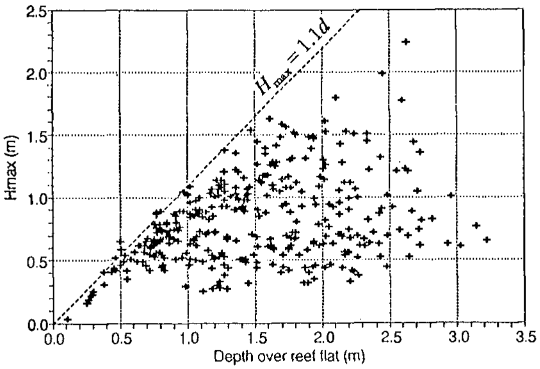

Figure 13. Maximum wave height *vs* water depth over reef, ZP1

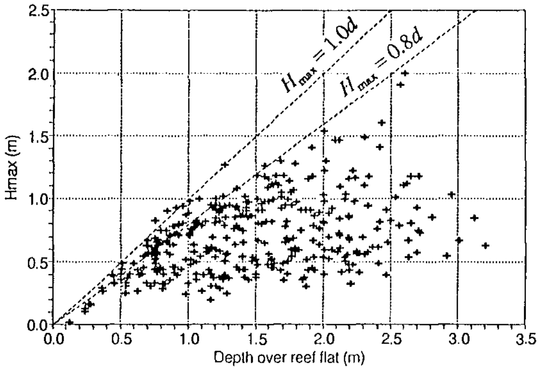

Figure 14. Maximum wave height *vs* water depth over reef, ZP2

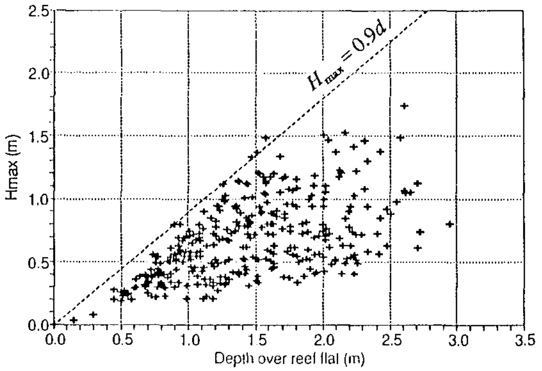

Figure 15. Maximum wave height *vs* water depth over reef, ZP3

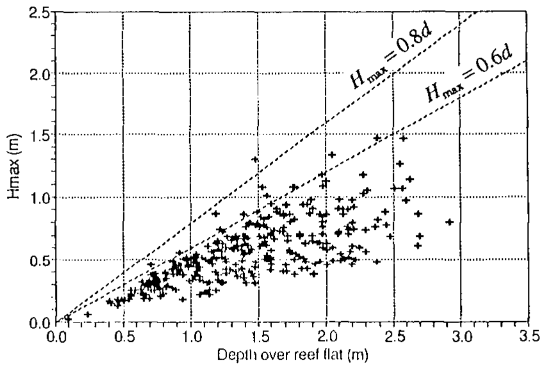

Figure 16. Maximum wave height *vs* water depth over reef, ZP4

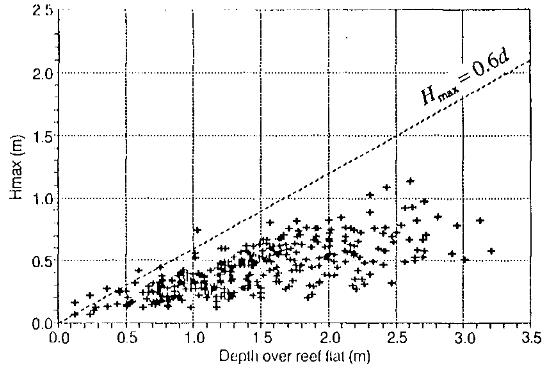

Figure 17. Maximum wave height *vs* water depth over reef, WR2

REFERENCES

Gerritsen, F. 1981. "Wave Attenuation and Setup on a Coastal Reef", Look Lab. Tech Report No. 48, Univ. of Hawaii, 416 pp.

Horikawa, K. and Kuo, C.T. 1967. "A Study of Wave Transformation Inside the Surf Zone", Proc. 10th International Conf. Coastal Eng., ASCE, vol. 1, pp. 217-233.

Kono, T. and Tsukayama, S. 1980. "Wave Transformation on Reef and Some Consideration on its Application to Field", Coastal Eng. in Japan, vol. 23, pp. 45-57.

Lee, T.T. and Black, K.P. 1979. "The Energy Spectra of Surf Waves on a Coral Reef", Proc. 16th International Conf. Coastal Eng., ASCE, vol 1, pp. 588-608.

Murray, R.T. and Ford, L.R. 1983. "Problems in the Analysis of Data for the Assessment of Longshore Sediment Transport: an Example from North Queensland", 6th Aust. Conf. Coastal and Ocean Eng., Inst. Engrs. Aust., pp. 21-26.

Nelson, R.C. 1985. "Wave Heights in Depth Limited Conditions", Trans. Inst. Engrs. Aust., Civil Eng., vol CE 27, pp 210-215.

Nelson, R.C. and Lesleighter, E.J. 1985. "Breaker Height Attenuation over Platform Coral Reefs", 7th Aust. Conf. Coastal and Ocean Eng., Inst. Engrs. Aust., vol. 2, pp. 9-16.

Roberts, H.H. 1981. "Physical Processes and Sediment Flux Through Reef-Lagoon Systems", Proc. 17th International Conf. Coastal Eng., ASCE, vol. 1, pp. 946-962.

Wolanski, E.J. 1985. "Some Properties of Waves at the Queensland Shelf Break", 7th Aust. Conf. Coastal and Ocean Eng., Inst. Eng. Aust., vol. 2, pp. 61-70.

Young, I.R. 1989. "Wave Transformation over Coral Reefs", Journal of Geophysical Research, vol. 94, no. c7, pp. 9779-9789.

Zwarts, C.M.G. 1974. "Transmission Line Wave Height Transducer", Proc. International Symposium on Ocean Wave Measurement and Analysis, New Orleans, ASCE, vol. 1, pp. 605-620.