

# Shore & Beach

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## **Island Repair in the Maldives**

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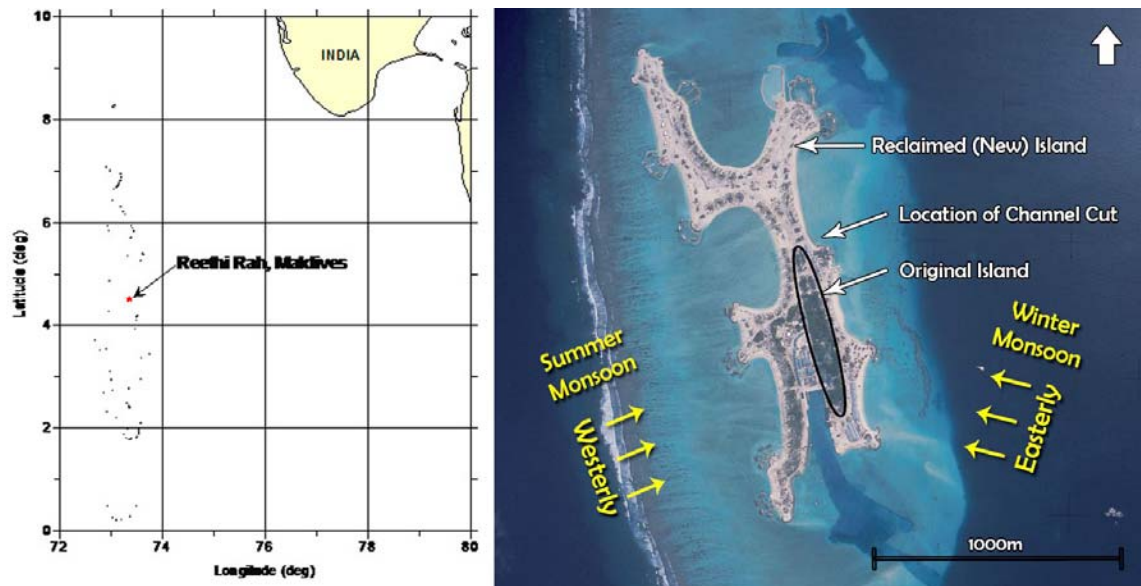
### **ABSTRACT**

After substantial expansion and re-shaping of a resort island in the Maldives by dredging, the island's new shoreline rapidly eroded and nearshore water circulation declined. To address these problems in time for the new resort to open, over 50 different rock structures were designed and constructed to create 19 distinct beaches totaling 4 km in length, and a channel was cut to sever the island and partially restore tidal flow. The authors completed the site studies and designs while living on-island amidst frenetic resort construction during several weeks in the summer of 2004. The works were completed that autumn, and thereafter withstood impact from the December 2004 tsunami. To-date, the project repairs have successfully stabilized the beaches and improved water circulation, per the design predictions.

### **INTRODUCTION**

In early 2004, one of our firm's long-time clients was the first to begin developing a large hotel resort on the new "palm shaped" islands being created in Dubai. On their behalf, I (the first author) was finishing a week of due-diligence in Dubai and preparing to head back to Florida. The client, however, asked me to divert instead to another resort that they were constructing in the Maldives. I had heard of the project, but otherwise knew no details of it, not even exactly where it was.

Upon my eventual arrival at the site, I found a fancifully shaped, 2-kilometer long island along which all of the sand shorelines were rapidly eroding (Figure 1). There were extensive areas of wave overwash and of poor water circulation, the latter being characterized by algae, silt and stagnation in the island's embayments. Most of the infrastructure, foundations and framing for the new resort facilities and its 200+ villas were already in place or under construction. Many of the structures were being undermined by the failing beaches (Figure 2). The client asked if we might "fix" the problem – adding that this unique luxury resort was scheduled to open in only six months.

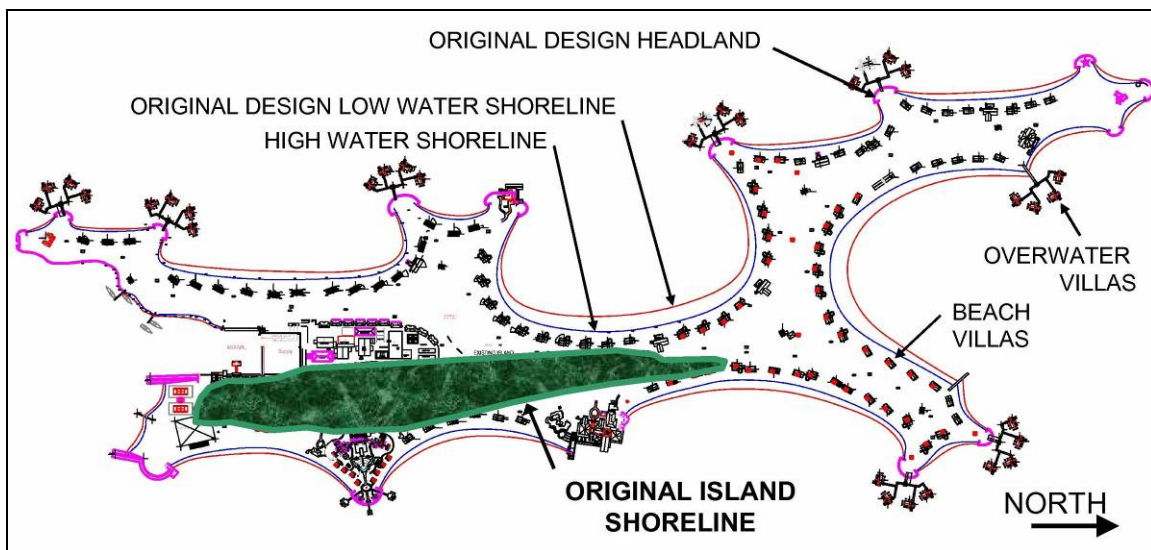


**Figure 1. Location map and aerial view of the island (in construction).**



**Figure 2. Typical shoreline conditions upon initial arrival at site.**

The basic problem was simple. Using locally dredged material, the island had been more than tripled in size and lengthened from about 1000 m to 1900 m. It was shaped in an unnatural geometry that bore no resemblance to the original or local islands, and which created large, poorly-flushing embayments. The layout was from the project Architect's original masterplan (Figure 3). The plan sought to maximize shoreline frontage and minimize set-backs between the assumed shorelines and the villas. It also violated fundamental principles in coastal design and engineering. For example, the indicated width between the design high-tide and low-tide shorelines varied around the island; and this width converged to zero at the beach's rock headlands. There, the design shorelines were drawn evenly with the face of the headlands (instead of being set-back from the headlands as dictated by typical beach geometry). The infrastructure and foundations for the resort facilities and villas were located relative to these imagined shorelines; and as the shorelines retreated to their more physically realistic location, the structures became quickly imperiled. From this initial visit, we concluded that the requisite reparations would add a couple of millions of dollars (US) and months to the schedule; and the work would have to be designed and built immediately, without luxury of formal studies or surveys.



**Figure 3. Original island and architectural master plan for new island.**

## SETTING

The Republic of Maldives is a nation of some 1200 low-lying islands, grouped across 26 atolls, along and north of the equator in the Indian Ocean, about 600 km southwest of India. The project island is located about 25 km north of Malé, the capital. Tides are semi-diurnal with mean range of about 1.4 m. Like the rest of the Maldives, all of which

are below +2.3 m above mean sea level (MSL), the island's original and new elevations are low: about +1.5 to +1.8 m MSL.

The island is bound by shallow reefs on the east and west sides (Figure 1). It is characterized by easterly winds and waves in the northern winter monsoon (November-April) and by very strong westerly winds in the summer monsoon (May-October), with one or two months of flat calms between them. Breaking waves on the reefs routinely exceed 3-4 m height; but waves in the reefs' lee are typically less than about 0.5 m, or sometimes up to 1 m height according to anecdotal accounts.

The reclaimed island's shoreline totaled about 4 km in length. The beach is composed of 0.25-0.35 mm mean grain size carbonate sands. The seabed between the island and reefs is mostly flat at between about -1.5 and -1.8 m MSL, and it consists of coral rubble fractured from the reef and pushed shoreward by the monsoon winds and waves. The natural beach berm elevation is about +1.5 m MSL.

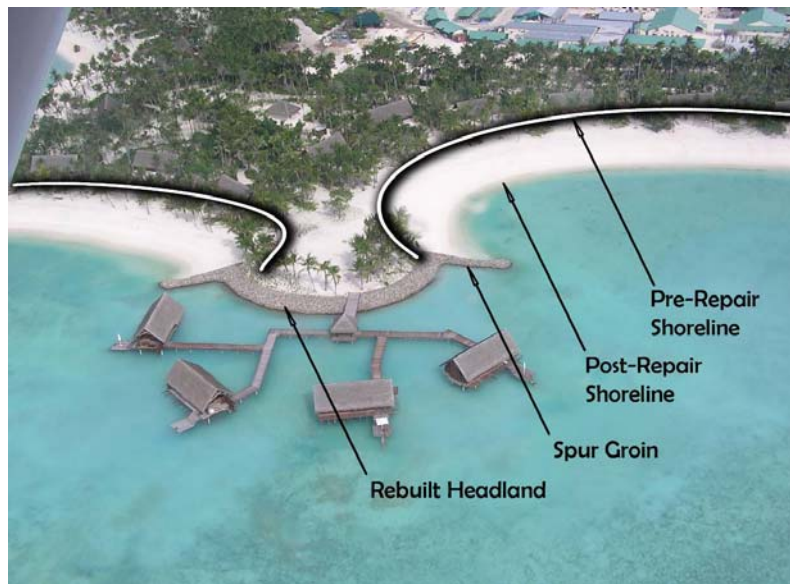
## BEACH REPAIRS

In early June 2004, a few weeks after the original reconnaissance visit, both authors headed to the island. Our approach to the beach reparations entailed five elements. The first of these was to add beach fill everywhere to increase the buffer between the shorelines and the villas, and to provide for fill equilibration (which was not included in the original construction). The other four elements involved modifying the structures. This included (1) adding spur groins at the existing headlands, (2) creating new headland designs for those not yet constructed, (3) constructing T-head groins and pocket beaches where possible, and (4) armoring the shoreline with revetments where beach stabilization was otherwise infeasible. It was imperative that all solutions be both expeditious and aesthetically congruent with the luxury island resort setting that was under construction.

Using standard level, rod and chain pre-shipped from the US, we surveyed the typical existing profile shape via quick transects at every beach and we measured the shoreline position relative to each villa (for which locations were already mapped). Prescriptive beach fill was added to create a minimum 15-m setback (plus 10-m contingency) off of every structure with a conservatively-predicted equilibrium slope of 1:12. A small dune feature was added to reduce overtopping whilst not interfering with villa views.

Between the existing rock-rubble headlands, the placed shoreline had predictably eroded as a vertical scarp, often right up to the villas. At these locations, we added spur groins to the existing headlands to "pull" the shoreline further seaward (Figure 4). The spurs, each about 28-m long and oriented to clear the existing over-water villas, resulted in an unusual structure shape, but one which was ultimately successful in stabilizing the shoreline at its intended location (Figure 5).



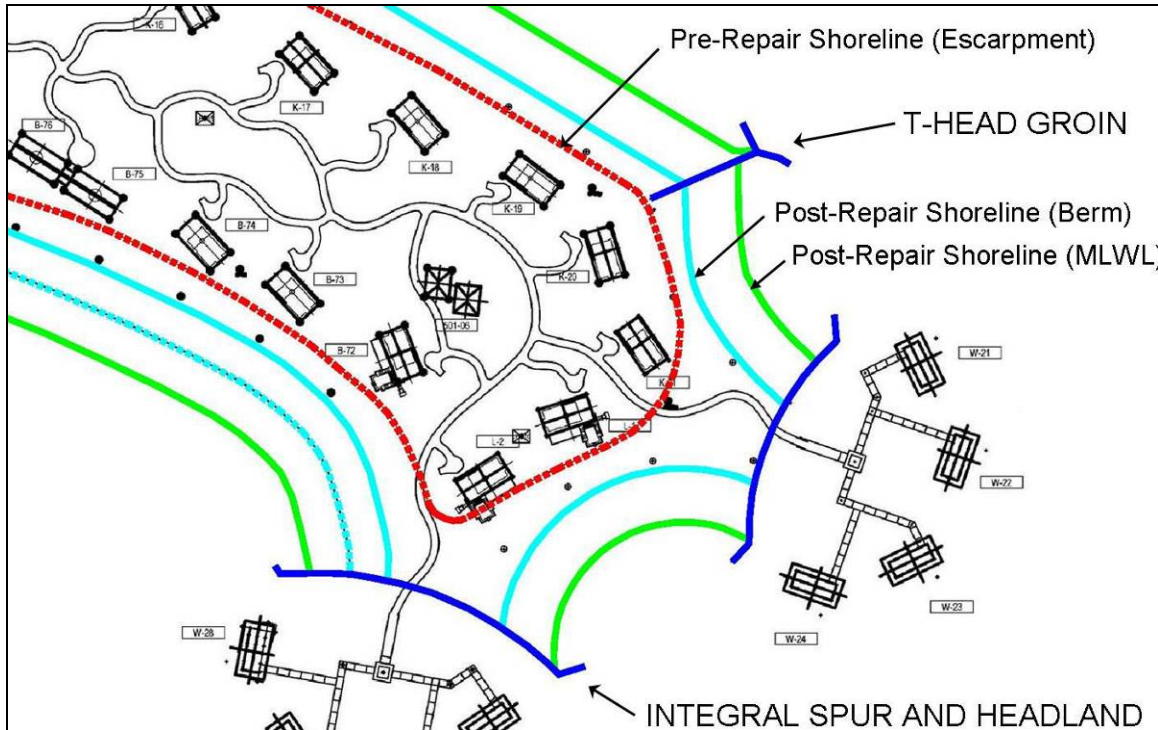


**Figure 4. Spur groins were added to the ends of existing headlands to stabilize the adjacent bay beaches.**



**Figure 5. Beach improvements after addition of spur groin at end of headland (upper: pre-repair; lower: several months post-repair).**

Where the headlands were not yet built, an alternative headland design was introduced that integrated the spur-groins at its ends. The result is a broad concave structure (in lieu of the masterplan's original, short convex structures), often tied to an opposing T-head groin where a convex break in shoreline orientation was required (Figure 6).



**Figure 6. Combined headland-spur groin structures, with T-head groin.**

T-head groins were used to create smaller pocket beaches wherever practical, owing to their generally stable and predictable behavior (Figure 7). The additional stabilization afforded by these structures was particularly critical along the chronically erosive, higher-energy shorelines, typically located within a few hundred meters from the fringing reef. The lay-out design of the T-heads and pocket beach geometries followed a simple empirical predicate developed from prior experience (Bodge 2003). It presumes that the mean low waterline (MLWL) is located a fraction  $\gamma$  of the gap distance between heads, where  $1/3 < \gamma < 2/3$  and in the present case taken as about 0.4. The berm shoreline is located behind the MLWL as a function of the inter-tidal beach slope. The predicted berm shoreline must lie at least several meters seaward of the prescribed (design) berm, including setbacks (Figure 8). If it does not, the gap is narrowed, the groins are lengthened, the setbacks are reduced, or all three, in an iterative design process.

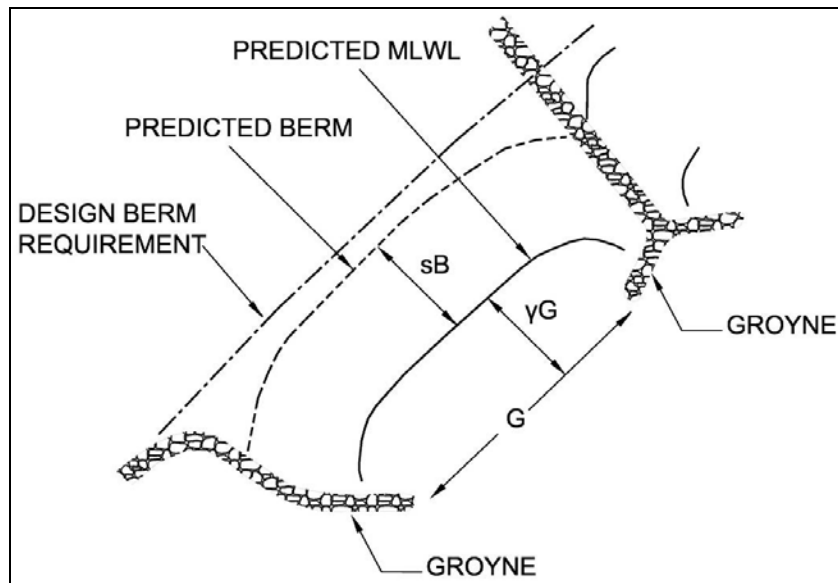


**Figure 7. T-head groins (lower photo) used to stabilize eroding beach near the resort lodge (upper photo).**

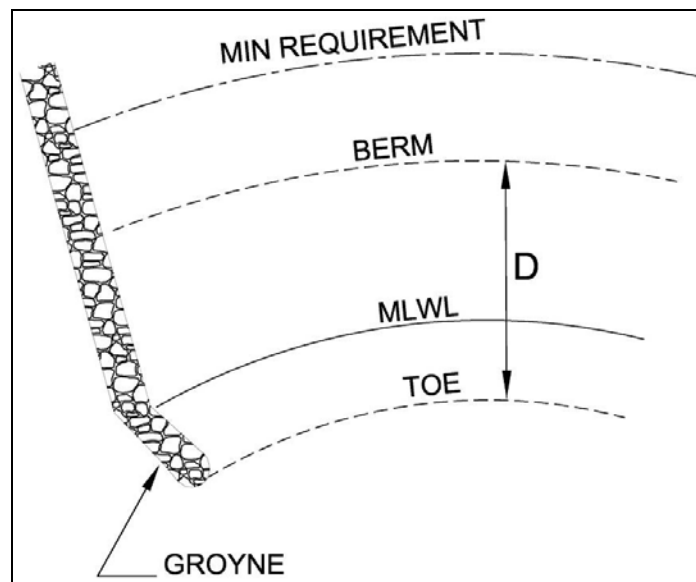
Where a single groin was used, such as at the terminus of a beach strand, another simple “in-house” design predicate was used. The beach elevation at the seaward end (toe) of the groin is presumed to be equal to one-half the tide range below mean low water (or, alternately stated, one tide range below mean sea level). The corresponding location of the berm is the slope-distance  $D$  above and behind this “toe” elevation (Figure 9). At this site, for a tide range of 1.4 m, the beach elevation at the groin’s end is predicted at -1.4 m MSL. The berm elevation, +1.5 m MSL, is located 2.9 m above this level at a typical



slope of 1:12. Thus, the berm location is predicted to be  $D = 2.9 \times 12 = 34.8$  m from the groin's end. If the predicted berm is too far landward, then the groin must be lengthened or other modifications made.



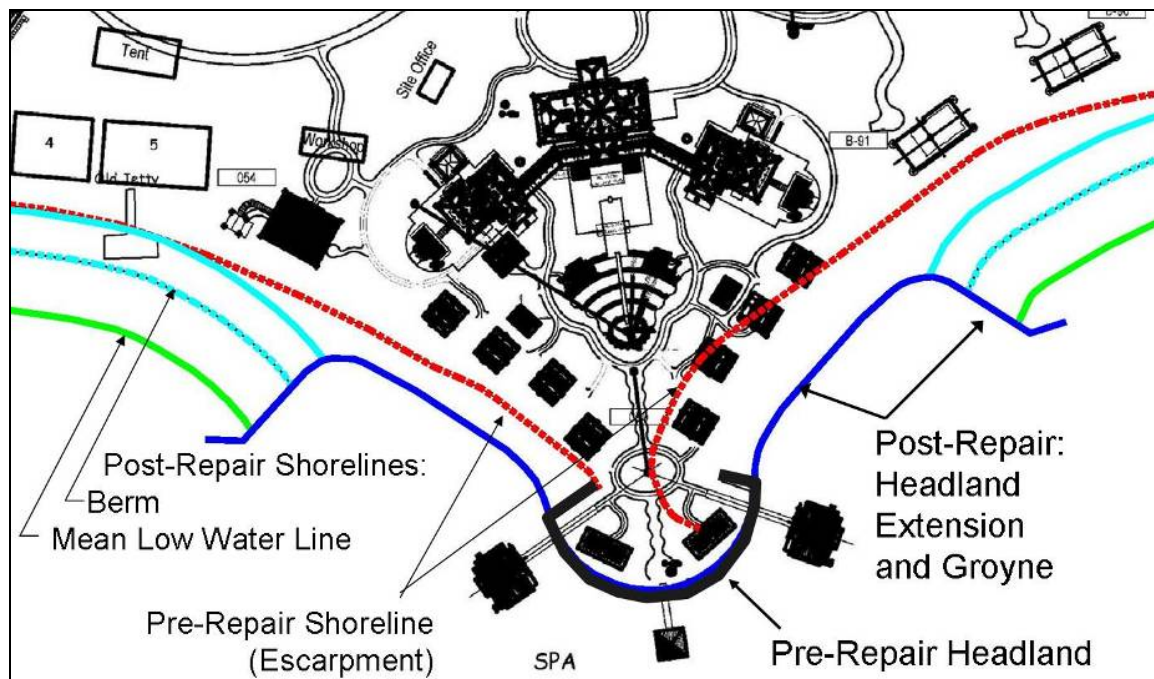
**Figure 8. Beach geometry between two groins (plan view).**



**Figure 9. Beach geometry adjacent to single groin (plan view).**

In locations where a beach was impractical due to insufficient space or set-backs, the headland had to be extended to armor the shore until the location at which a beach could be developed. An example is illustrated in Figure 10 at the resort's spa location. Other examples are illustrated in Bodge and Howard (2006).

The granite stone that was available to build the beach structures was very small (20-35 cm diameter). It was loaded by hand in India and shipped in fabric bags, one of which is shown at the right of Figure 2. While awaiting arrival of larger stone, the 1400-kg bags of small stone were placed to mark the correct footprint of each structure and to construct a core to be armored. This sped construction and helped to ensure proper layout.

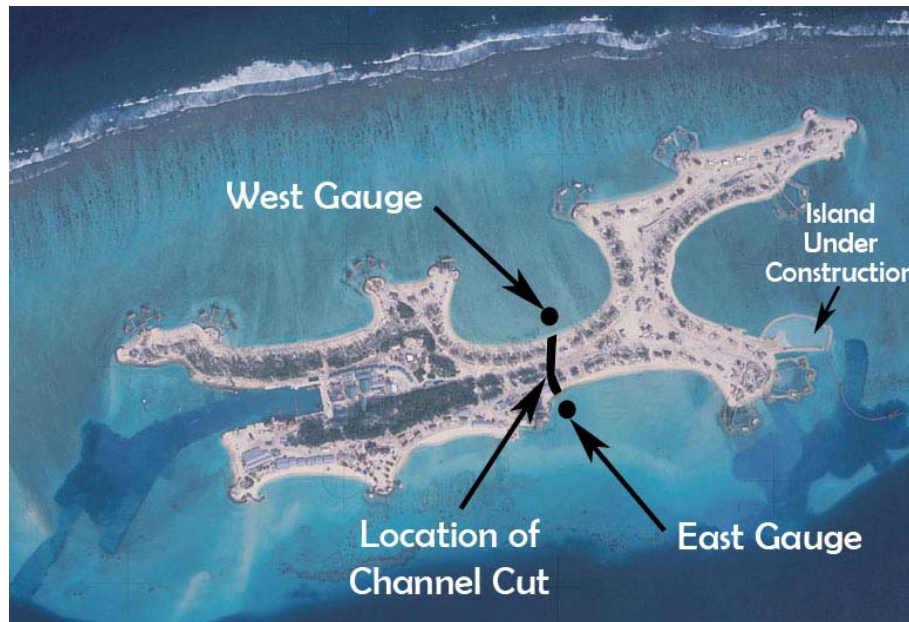


**Figure 10. Alongshore extension of headland and addition of groins to terminate the beach at a promontory where beach creation was infeasible.**

## THE CHANNEL CUT

Another principal objective was to improve water quality, particularly in the largest embayment on the island's western side. Here, algae growth and cloudy water was prevalent in the calms between monsoon seasons. Buried culverts to connect opposite shorelines were ruled out because of the shallow depths, limited flows, and requisite outfall structures. Instead, at the base of the bay, near the northern end of the original island, we found a strip of land between villas that would be just barely wide enough to cut a channel across the island and connect two opposite bays (Figure 11). The open

channel would be 14 m wide and 200 m long, and it would exit along the main lodge as a water feature, with entrance groins along the adjacent beaches. But it would sever the existing utility trunks, require two unanticipated bridges, and impact operations.



**Figure 11. Locations of tide gauges and new channel cut across island.**

We knew that the channel would flow strongly during the east/west winds of the monsoon seasons and quickly flush the bays. But a fundamental question was whether the channel would provide any flow benefit during the dead-calm months between monsoons, when it was most critically needed. We hypothesized that there may be a slight tidal lag between the east and west sides of the island – enough to drive a tidal current when the waters were otherwise still. So, during our field design, we deployed two recording tide gauges on opposite sides of the proposed cut, leveled them together carefully, and deployed a redundant gauge half-time on each side as a back-up check. We also deployed a recording anemometer.

As expected, the water levels on the island's *west* side – from which the summer monsoon blew – were consistently higher than on the *east* side. But the magnitude surprised us: averaging 15 cm difference from west-to-east across the island's neck. This was due not only to the westerly winds, but the deep shape of the bay and set-up from the 4 m high waves breaking on the west reef nearly every day during the summer monsoon. This difference would result in predicted open-channel flow of over ½ meter per second. This flow speed was similar to that which we had measured around the ends of the island by timing the drift of fruit thrown into the sea.



The critical problem was to deconvolve the tide signal from the meteorological influence. Recourse to our anemometer data proved useless. Fourier Transform and tidal harmonic analysis gave ambiguous phase results (Bodge and Howard, 2006). So, instead, we ultimately printed the smoothed time-series data on large sheets and manually identified the apparent lead or lag of the two gauges' water level records. On average, the results suggested a 66-second tidal lag from west to east. In the absence of any wind or waves, this lag would drive a 5 to 10 cm/second current thru the channel, and this would flush the large bay in 20 to 60 hours, depending upon the lunar tide cycle.

The channel was constructed as designed, and subsequent dye-tests proved the predictions correct (Figure 12). During a test on a rising spring tide that autumn, the estimated 66-second tidal lag should have created an easterly-directed 14 cm/s flow. Even with stiff 12 knot easterly winds from the winter monsoon, the channel flowed east – against the wind – at 40 cm/seconds, driven by the tide, as predicted. The typically high velocities appeared to have mostly obviated the potential problem of sedimentation along the channel and at the entrances.



**Figure 12. Channel cut through the island (center left and inset), with spur groin and headland (far right).**

## CONCLUSIONS

In all, 52 rock structures – each essentially unique for every location – were designed to stabilize over 4 km of sand shoreline divided into 19 different beaches, along with the open channel that severed the island in two. The design was mostly accomplished in the field over the course of a few weeks in the company of about 50 other engineer-officers and 2000+ laborers all encamped on this 100-acre equatorial island.

The works were tested hard, and unexpectedly, by the Boxing Day Tsunami of December 2004. Because of the narrow atoll and deepwater to either side, the waves' surge velocities were small, but all of the Maldives islands were completely overtopped and flooded. Surprisingly, all of the structures and beaches – completed just weeks before – survived with minimal damage, despite structural damages elsewhere on the island.

The island, now the One & Only Reethi Rah Resort, opened five months later, in May 2005. Three years (and one tsunami) since the coastal engineering reparations were built, all of the beaches and structures have held per the design intent. In the absence of formal post-construction beach monitoring (for which a program was developed but never wholly implemented), reports and photographs from the island's managers and guests indicate that the beaches, channel, and water quality have met the project's objectives.

## REFERENCES

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