A FIRST PEEK AT 'FIRST PEAK'

Daniel A. Osiecki
and
William R. Dally

Surfbreak Engineering Sciences, Inc.
207 Surf Road
Melbourne Beach, Florida 32951

dosiecki@surfbreakengineering.com
wdally@surfbreakengineering.com

ABSTRACT

During the planning stages to rebuild a fishing deck that tops the north jetty at Sebastian Inlet, Florida, local surfers expressed concern that modifications might affect the world-renown surfbreak known as 'First Peak'. Consequently, a study was commissioned by the State of Florida to 1) identify the key elements of wave-structure interaction that create First Peak, 2) examine the wave, tide, and geomorphic conditions favorable to surfing, and 3) determine if the planned jetty improvements would have an impact on First Peak.

To study First Peak, a 1:35 scale undistorted hydraulic model of the north jetty and adjacent beach was constructed based upon hydrographic survey data. The scaled dimensions of the wave basin were equivalent to 213m (700ft) cross-shore by 299m (980ft) longshore by 7.9m (26ft) in the vertical. A boat-deployed helium balloon was used to record aerial video as a method to validate the reflection-refraction processes in the physical model. The major finding of the model study was that the oblique orientation of the north jetty is the key to creating reflected waves that become trapped to the beach by refraction. It is the interaction of these refracted-reflected waves with the incident waves that makes First Peak consistently surfable.

ADDITIONAL INDEX WORDS

Surfing, surfbreak, physical model, hydraulic model, wave-structure interaction, wave reflection, wave refraction, wave-wave interaction, jetty, oblique breakwater, aerial video.

INTRODUCTION

Sebastian Inlet State Park is one of the most heavily visited parks in the State of Florida. Much of its popularity is attributed to the northern jetty, constructed in 1970-71. The outer two-thirds of this jetty is a concrete pile crib structure topped by a fishing deck and the inner section is a rubble-mound structure topped by a concrete walkway. Popular recreational activities at the jetty include fishing, diving, and surfing. An aerial photograph of the inlet, jetties, and a portion of the surrounding park is shown in Figure 1. Cumulative damage through the years, compounded by extreme wave loads during Hurricanes Floyd and Irene in late 1999, resulted in the closing of the outermost 80 ft of the deck. This closing, and the overall deterioration of the structure, prompted an effort to rebuild the jetty's crib and fishing deck in 2001.

The most cost-effective means of rehabilitating the deck was to simply build a new pile-supported deck above the old one, thereby obviating the significant cost and complication of demolition. This concept met with almost uniformly favorable reaction from the fishing interests, but the local surfers were more guarded in their outlook. Although pleased that the intent to maintain the basic orientation and footprint of the north jetty, the surfers were concerned that new structural elements might adversely affect the world-renowned surfbreak known as 'First Peak', as well as additional surfbreaks, which exist adjacent to the jetty, and are in fact created by the jetty. These breaks are the main attraction to surfers who are a substantial component of Sebastian Inlet State Park's patron base.

The objectives of this engineering study were to a) identify the key elements of wave-structure interaction that create and influence First Peak, and b) assess whether, and in what manner, the proposed deck construction might impact this surfbreak.

Figure 1 – Aerial photograph of Sebastian Inlet taken in 1997.

BACKGROUND

In the most basic terms, First Peak is created by wave reflection induced by the north jetty of Sebastian Inlet. The surfbreak is enhanced by the interaction of the incoming waves and the reflected waves, which a) increases the height of the wave in the vicinity of the point(s) of intersection of the two wave trains, and b) creates a critical breaking region that translates at speeds slow enough for surfers to ride (see e.g. WALKER, 1974 and DALLY, 2001). The first intersection point closest to the north jetty (usually within 20-100 m) is First Peak. However a second break, appropriately called Second Peak, often appears farther to the north, and is associated with the next point of intersection of the incident and reflected wave crests. During some wave conditions even a third and fourth break may appear still farther to the north. It is well-recognized by local surfers that First Peak is ephemeral, its location moves and its 'surfability' changes with variations in wave climate, tide stage, and beach conditions. Beyond knowing that First Peak was somehow due to wave reflection, the distinct details of the wave processes that create and control the surfing breaks adjacent to the north jetty were heretofore unexplored.

According to established wave theory and historical laboratory observations there are three common reflected wave patterns. (1) Secular reflection patterns are created when waves intersect structures at angles greater than about 45 degrees. If viewed from above, the incoming and reflected wave crests form a classic diamond pattern. (2) Mach-stem reflection occurs if waves are in shallow water and are of finite amplitude, and if the intersection angle is between 45 and 20 degrees. Mach-stem reflection creates a hexagonal wave pattern in which a short section of the wave crest or ‘stem’ is roughly perpendicular to the structure. (3) Finally, if the intersection angle is less than 20 degrees, the reflected wave crest disappears, leaving only the incident wave and the stem (see MEI, 1989). In this context, shallow water means that the wave length is long compared to the water depth, and finite amplitude means that the wave height is comparable to the water depth. If the wave period, water depth, and wave height are such that the wave is not a shallow-water, finite amplitude wave, secular reflection prevails.

During this study, both secular and Mach-stem reflection were observed at the north jetty of Sebastian Inlet. In either case, the fact that the water becomes shallower as one moves shoreward along the jetty brings the additional processes of wave shoaling and refraction into play. As a wave travels into progressively shallower water, shoaling increases the wave height until breaking finally occurs. Refraction turns the wave crests naturally aligning them with the bottom contours. Finally, the incident and reflected waves interact in a nonlinear manner, which is an effect that grows stronger as the combined wave approaches breaking. Nonlinear means that the crest pattern and wave heights in the combined sea are not simply due to a linear superposition of the incident and reflected waves. It is the complex interplay of the four wave processes - reflection, refraction, shoaling, and wave-wave interaction - that creates and controls the surfbreak adjacent to the north jetty. Reflection, however, is the key element in stimulating the jetty-induced surfbreaks.

Although waves reflect to some degree from the entire length of the jetty structure, local surfers indicate that the majority of the time it is the rubble-mound segment at the landward end of the jetty that is the most active and important zone of reflection. When breaking at its best, First Peak generally appears slightly offshore of this rubble-mound feature. Also, the very best break occurs when the north fillet is most eroded (usually late in the summer season), with large swell arriving from the east-northeast at mid to low tide with offshore winds. In the course of the field study and physical modeling investigations described below, the nature of the break-enhancing processes and the reasons underlying the best-break anecdotes were identified.

INVESTIGATIVE STUDY

Physical Model Construction

For the purposes of identifying and studying the wave processes that create and control First Peak, a 1:35 scale hydraulic model of the north jetty and the adjacent beach was constructed. Overall dimensions of the basin were 6.1m cross-shore by 8.5m longshore by 0.3m tall, which is the scaled equivalent of 213m cross-shore by 299m longshore, by 7.9m vertically. Nearshore bathymetry was generated using digital terrain modeling software and data from actual surveys of the north beach conducted in the summer of 1998. The bathymetry covered from approximately –7.3m to +2m NGVD (National Geodetic Vertical Datum, 1927) in elevation, as shown in Figure 2, and was oriented such that the offshore side of the model was rotated 20 degrees counter-clockwise from true north.

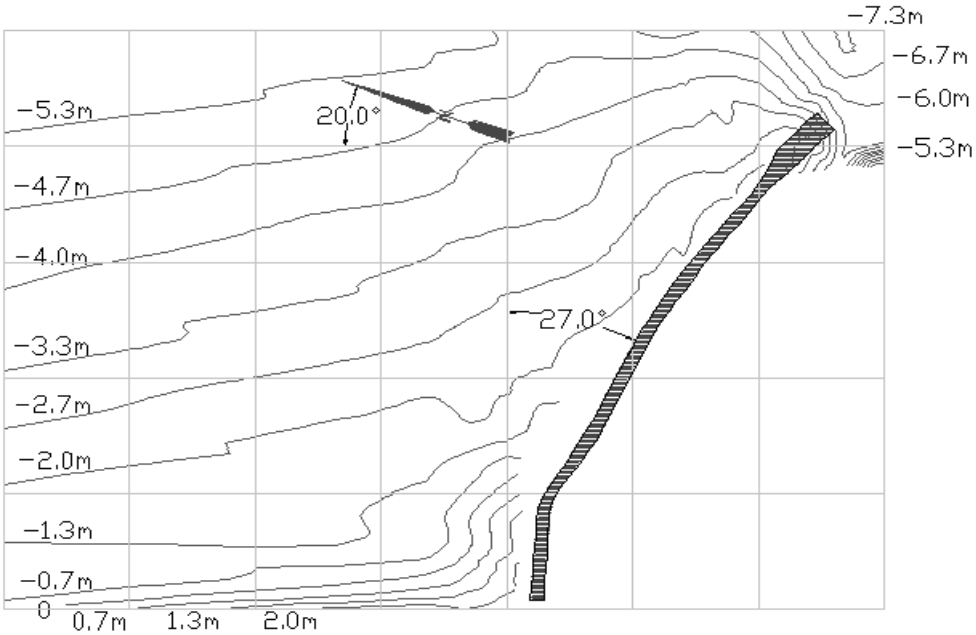

Figure 2 – Digital terrain bathymetry used to construct the First Peak model basin.

Model contours were cut from sheets of 1.9cm thick Styrofoam, placed in the basin, and then smoothed with a layer of concrete stucco. The stucco was then covered with an elastomeric paint to render the basin watertight. The north jetty was fashioned from foam strips, fronted by 1.3cm diameter wooden-dowel pilings (100 in all), and back-filled with landscaping cobbles/gravel to represent the jetty's rubble.

The basin was outfitted with an electromechanical wave generator, comprised of a single-board, flap-type paddle driven by a 3 hp DC motor and controller. The wave paddle was hinged to the side of the basin and was oriented 20 degrees counter-clockwise from north-south. This restricted test conditions to waves approaching only from the east-northeast, encountering the jetty at an angle of approximately 27 degrees. Photographs of the model and wave generator are shown in Figures 3 and 4.

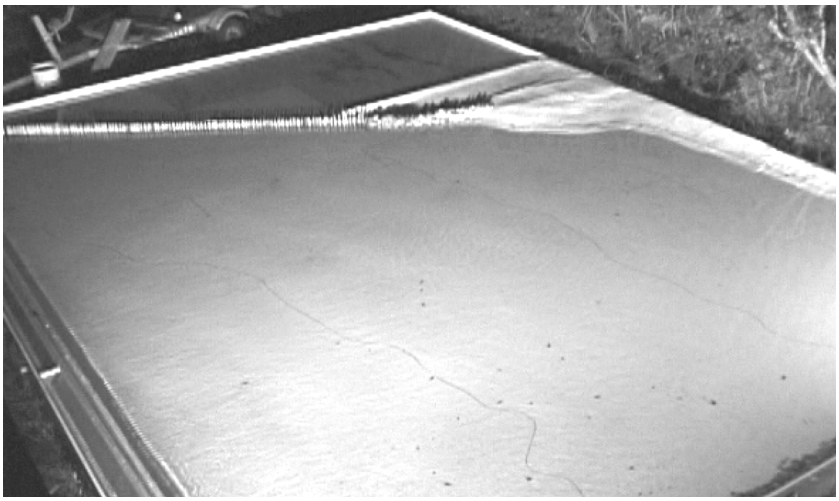

Figure 3 – First Peak physical model basin.

Figure 4 – Wave generator paddle, motor, and controller.

Field Investigation

On August 9, 2001 a 4m-diameter (or 11.3 m^3) helium balloon was used to suspend a digital video camera above the area of First Peak at Sebastian Inlet. The balloon was deployed from a 10m-research vessel, using a special tether and winch system. The vessel was maneuvered and anchored according to current and wind conditions in order to optimize the camera's location. The camera was operated in self-record mode, and the proper field of view was established by trial-and-error. A total of approximately 2 hours of videotaped observations were made. A sequence of frame-grabs from the balloon-borne video are provided in Figure 5.

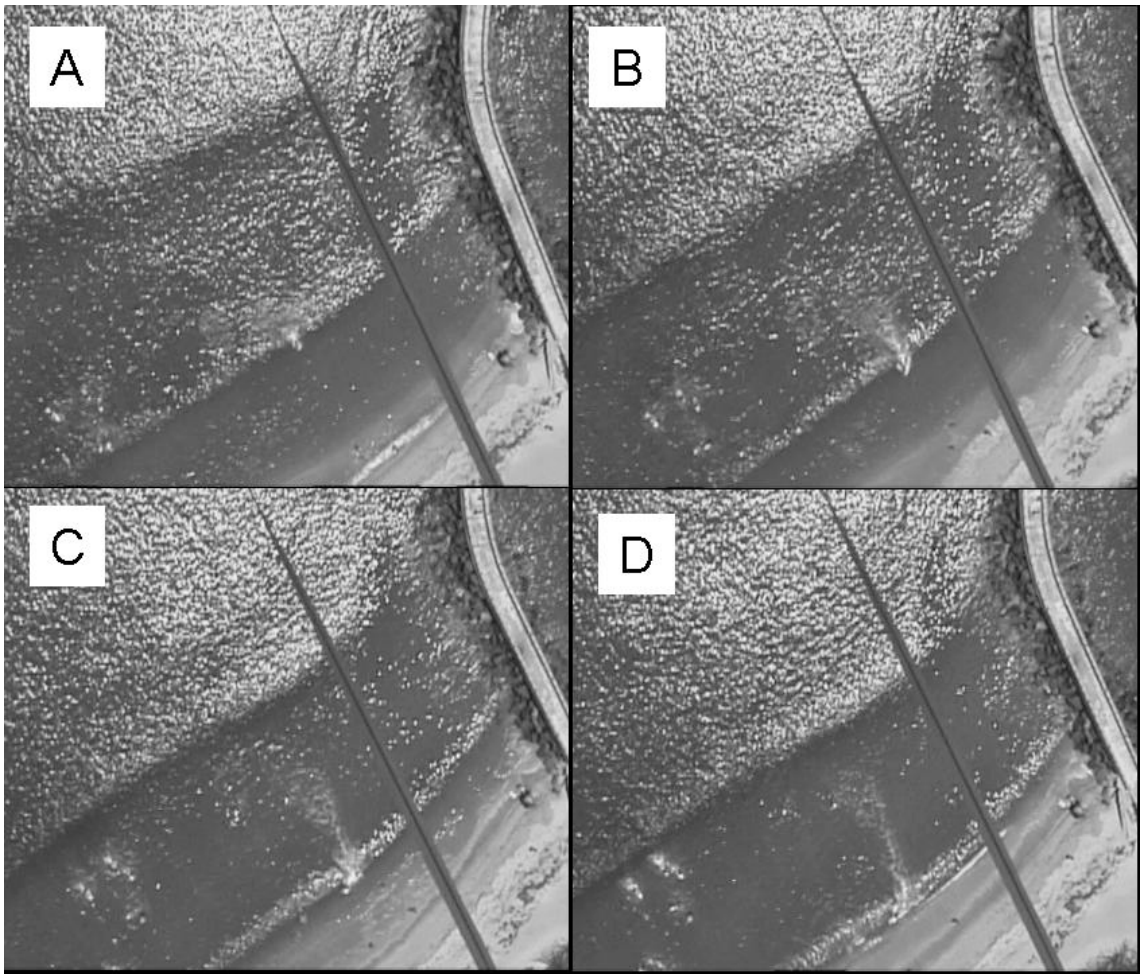

Figure 5 – Surfing photo sequence at Sebastian Inlet.

During this deployment, surfing conditions at First Peak were not considered 'prime', as the height of the largest waves was no more than 0.6m. Consequently, as is evident in the video frames, the break point was situated adjacent to the rubble-mound section and close to shore. Although it was originally hoped that field observations could be conducted several times in September and October during the heart of hurricane season, time constraints imposed by the jetty rehabilitation schedule precluded this.

Nevertheless, the video observations made were viable for use in validating the physical model.

Validation of the Physical Model

Wave conditions videotaped during the latter part of the field investigation were used to validate the physical model. At the time, the observed wave period at Sebastian Inlet was estimated to be 12 seconds. The longest wave period that the model basin wave generator could reproduce was 1.86s which corresponds to a Froude-scaled wave period of 11s in the ocean. Figure 6 shows a frame of video shot from the balloon of the 12s wave, in contrast to a frame taken from the Froude-scaled 11s model wave at approximately the same position and orientation. Note that the modeled wave crest has a similar pattern to the observed wave.

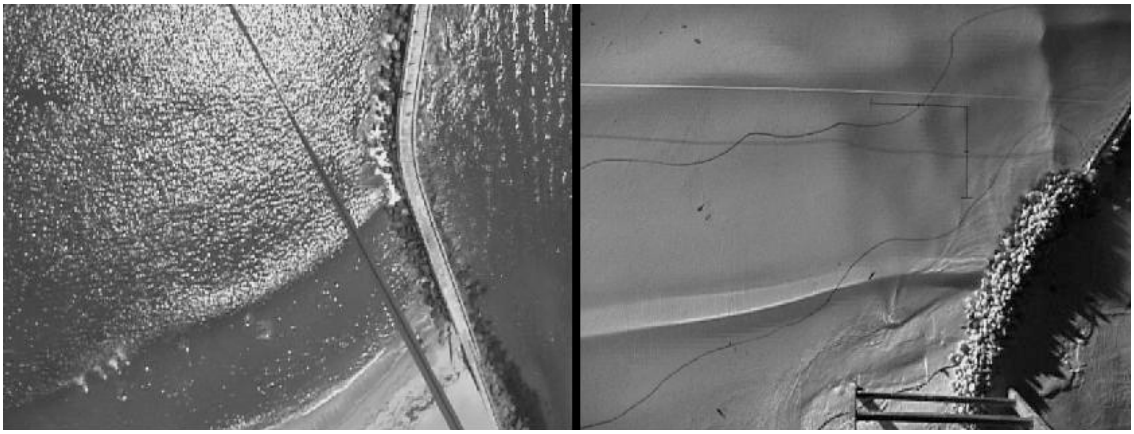

Figure 6 – Aerial view of First Peak at Sebastian Inlet, Florida on August 9, 2001(left) and overhead view of First Peak in the physical model wave basin (right).

In addition to this simple, yet reassuring visual validation, several local surfers familiar with the Sebastian Inlet breaks were invited to examine the physical model and judge its ability to replicate First Peak. They were impressed with the model's ability to represent First, Second, and even Third Peak, under optimum wave conditions.

Froude-scale modeling is typically used in laboratory wave basins to reproduce ocean observations. For the First Peak model a 1:35 scale was used. To scale real world or prototype waves to the model basin, Froude-scaling multipliers are applied to the prototype conditions. For this case, the wave period multiplier is $(1/35)^{1/2}$ and the wave height multiplier is (1/35). Typical storm waves at Sebastian Inlet have 8-9s periods and 1-1.5m heights which produce excellent surfing waves at First Peak. Working within the limits of the wave generator it was decided that an input or prototype wave period of 8.9s would be used to represent the 'optimum' surfing wave in the model. This corresponded to a Froude-scaled wave period of 1.5s. The height of this wave near the offshore end of the jetty was estimated to be 1.6cm by videotaping a ruler placed in the model. Measurement error was estimated to be ± 0.3cm, which translates to ± 10.3cm in the prototype. As the wave reached the tip of the rubble mound segment at the landward end

of the jetty, shoaling and reflection had increased it to 3.5cm in the model (or 1.2m in the prototype). These were the waves that local surfers observed in the model for comparison to their real world knowledge.

Surfbreak Analysis

With the physical model validated in this simple, yet reasonably certain manner, the model was operated under a variety of wave conditions and water depths so that the wave processes that control the various existing surfbreaks could be identified and their behavior examined in detail. A fascinating interplay of reflection, refraction, shoaling, wave-wave interaction, and breaking was discovered. As shown in Figure 7, the favored breaks are created when waves striking the jetty at an oblique angle are partially reflected in a secular fashion, initially creating diamond patterns. However the pattern is not uniform, because the wave reflected from the jetty immediately experiences strong refraction due to the rising sea bed. This causes the wave crest to rotate in a counter-clockwise direction. Consequently, the diamonds made by the intersecting wave trains elongate and 'squash' as one moves to the north, away from the jetty. Both incident and reflected waves shoal as they approach the beach, with the region where their crests overlap creating the favored Peaks as breaking is initiated. First Peak generally has a distinct, well-defined take-off point because of the more oblique intersection angle of the two wave trains. However, at Second and Third peaks where the intersection angle is reduced, initial breaking occurs simultaneously along a section (i.e. a section that 'closes-out'), and so the optimum right or left take-off points at each of these Peaks are spatially separated. At First Peak, due to the close proximity of the jetty, most rides are taken to the surfer's right.

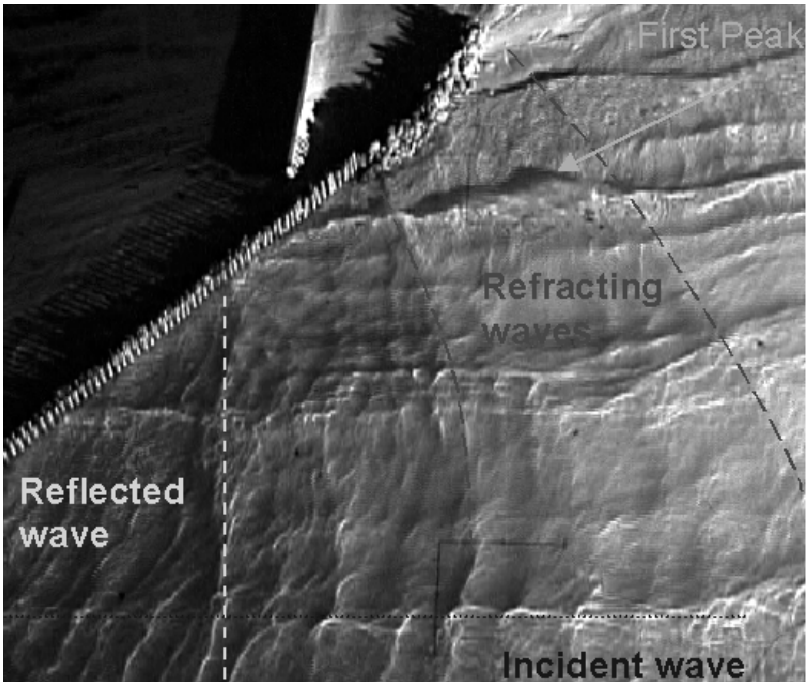

Figure 7 – First Peak wave basin showing incident, reflected, and refracted waves.

Although the angle of incidence of the waves in the physical model was fixed at approximately 27° from the alignment of the jetty, the diamond patterns associated with secular reflection were most often created. Under conditions of low water levels and long wave periods however, hexagonal stem-reflection patterns could be observed. Here it is also noted that even on an open coast where no jetty structures are present, wave-wave interaction of two shallow-water, finite amplitude wave trains arriving from different directions (e.g. from different storms) will naturally, as a consequence of their nonlinearity, create hexagonal patterns instead of diamonds.

Finally, it was also discovered in the model that at higher tide stages, wave transmission over the jetty crib rubble increases, with an associated reduction in reflection. This leaves only the rubble segment as an active reflector. In consequence, the quality of the break at Second and Third Peaks deteriorated, or sometimes vanished completely.

Based upon the work with the physical model, much of the anecdotal knowledge of the local surfers was validated. The quality of the break at First Peak at any given time depends upon many factors which affect the wave phenomenon discussed above. Listed roughly in order of importance, these are: 1) wave height, 2) tide stage, 3) wave direction, 4) wave period, 5) wind properties, and 6) state of the north fillet. Specifically:

Wave Height: Larger waves improve surfing conditions at First Peak (and in general) for two reasons: a) they move the point of incipient breaking seaward, thereby allowing longer rides, and b) they generate faster rides - the maximum speed a surfer can sustain is roughly proportional to the square-root of the wave height (DALLY, 2001). In shallow water, larger waves are also more nonlinear, which stimulates Mach-stem and hexagonal reflection conditions at the jetty.

Tide Stage: Because the jetty's crib structure is filled with rubble only up to approximately mean sea level, the strength of wave reflection from the north jetty varies with the elevation of the tide. Specifically, at high tide more wave energy passes over the rubble, and the reflection that generates good surfbreak is reduced (hence the importance of the impermeable, non-overtopped rubble-mound segment at the jetty's shoreward end). At low tide, more wave energy is reflected and surfing conditions can improve. In addition, at high tide the break point is moved towards the shore because the beach profile has a concave-up shape, thereby compressing the surf zone and making rides shorter.

Wave Direction: Because the pattern and amount of wave reflection depends strongly on the angle at which waves strike the structure, the quality of the break at First Peak also varies with incident wave direction. Waves approaching from the east-southeast pass almost tangential to the outer jetty, and consequently little reflection is created and First Peak is essentially inactive. In the other extreme, when waves approach from the north-northeast, although there is strong reflection, the reflection angle is too oblique for refraction to trap the reflected wave to the beach. However when waves

approach from the east-northeast, they encounter the structure in the grazing-angle range. Under this condition, favorable secular reflection, and even Mach-stem reflection, can be created.

Wave Period: As discussed above, Mach-stem reflection is a nonlinear, shallow-water wave phenomenon, which means that it occurs when a) the wave length is long relative to the water depth, and b) the wave height is comparable to the water depth. Longer period waves have longer lengths, thereby favoring the Mach-stem effect, and so the First Peak break improves under swell conditions, as opposed to stormy, short-period sea conditions. In addition, long-period waves that reflect from the north jetty experience more refraction before breaking starts, thereby influencing Second and Third Peaks.

Wind Properties: As is generally the case on open coasts, surfing conditions at First Peak improve if a gentle wind is blowing in the offshore direction. Such a wind delays the onset of breaking, allowing the waves to reach greater heights and subsequently plunge as opposed to spill. This delay in breaking also allows the waves to become more nonlinear, thereby enhancing the nonlinear wave-wave interaction phenomena.

State of the North Fillet: When the north fillet is fully saturated with sand, usually at the end of the winter months, the beach profile adjacent to the north jetty is steepened significantly. This steepening 1) compresses the surf zone, and 2) enhances wave reflection from the beach face, both of which are detrimental to the First Peak break. In addition, when the north fillet is full, less of the rubble-mound segment of the north jetty is exposed. With less reflecting surface available, surfing conditions deteriorate. However, in the summer months the north fillet erodes, the beach profile flattens, and more of the rubble-mound segment is exposed. Unfortunately, wave energy levels drop in the summer and waves tend to approach from the southeast, both detrimental to surfing. In fact, those who have been surfing First Peak since the early 1970s indicate that surfing conditions actually were better immediately after the original crib extension was completed, i.e. before the shoreline had a chance to prograde in response to the lengthening of the jetty.

IMPACT OF PROPOSED FISHING DECK REHABILITATION

With the wave processes and other factors that create and control the surfbreaks adjacent to Sebastian Inlet's north jetty identified and examined, an assessment of potential impacts by the proposed fishing deck rehabilitation could be rationally deduced. In essence, if the new fishing deck would not 1) alter the gross reflection properties of the jetty structure, nor 2) affect the size and shape of the north fillet, then changes to the surfbreaks should not be expected.

Additional Row of Pilings

In regard to the reconstruction of the fishing deck, of primary concern is whether or not the additional row of pilings that will be added along the north side of the jetty will affect the reflection properties of the jetty. Before conducting this study, it was unknown if this additional row of pilings would either a) degrade the surfbreak by acting as a source of wave energy dissipation due to flow separation, which would be bad for the desired reflection effect, or b) actually enhance the break by presenting additional frontal area that might strengthen the reflection.

To investigate this issue, the jetty in the physical model was altered to depict the rehabilitation scheme for the fishing deck. This was accomplished by adding a second set of pilings (dowels), with spacings and placements scaled from that specified in the construction drawings. This situation is shown in Figure 8.

Figure 8 – Physical model of north jetty deck improvement with second row of pilings.

With this structural modification in place, the resulting breaking wave patterns were studied in the model under a variety of wave conditions, including those established as characteristic of the existing conditions (i.e. period = 8.9s, offshore height = 0.5m). The scaled prototype wave height measured in the model near the rubble mound segment was now equivalent to 1.1m with a margin of error of ± 10cm, which was essentially unchanged from the previous existing condition. Close examination of overhead video revealed no discernible change in breaking patterns in either First or Second Peak.

Deck Extension

Of secondary concern to surfing at First Peak was whether or not a proposed deck extension would block or otherwise adversely affect the break. The extension proposed in the construction drawings was approximately 12m long, was comprised of five rows of pilings including batter piles, and curved toward the east. To represent this, two rows of pilings were added to the jetty in the model to represent the northern side of the extension (see Figure 9). Tests were then conducted that could be compared to the results of the tests without the extension.

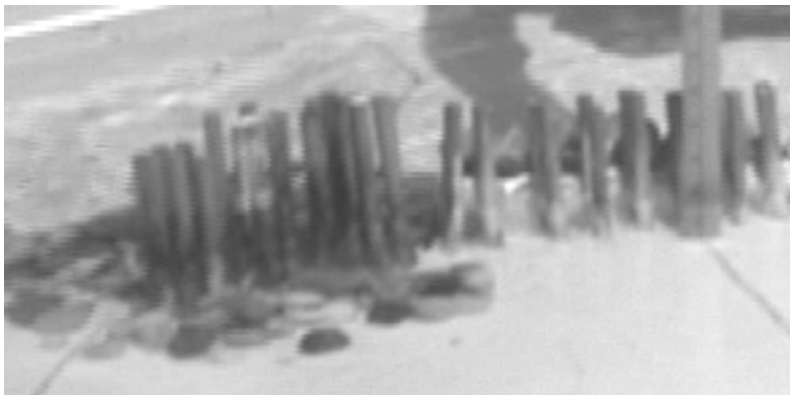

Figure 9 – First Peak physical model of north jetty deck extension with double pilings.

For the single wave direction allowed in the model, no impact of the First or Second Peak breaks could be detected. With the extension in place, the wave height measured in the model at the end of the rubble segment was 3.5cm (or 1.2m in the scaled prototype), i.e. identical to the results with the existing jetty configuration. This would appear to be because any wave shadow zone that might be created by this extension for the east-northeast direction is not sufficiently large enough to affect the breaks in question. However, in examining the construction drawings and the physical model, local surfers did express concern over the potential for adverse impacts on the break with waves arriving from the south. Under these conditions, the extension would be expected to cast a shadow that would reduce the wave height in the area close to the end of the jetty, which reportedly was a take-off point that broke 2-3 times per year.

Construction Along the Rubble-Mound Section

During the course of this investigation, local surfers often reiterated their observation that as the north fillet gains sand, i.e. typically during the winter, surfing conditions at First Peak deteriorate notably; but, as the fillet erodes in the summer, good surfing returns. They repeatedly emphasized the desire that the fishing deck reconstruction not cause any additional impoundment of sand adjacent to the north jetty. Raising the crest elevation of the rubble-mound segment of the jetty, or otherwise rendering it more sand-tight, would result in additional growth of the north fillet and ultimately lead to a deterioration in surfing conditions. Fortunately, early in the design process so that the north fillet would not grow to the detriment of the downdrift beaches it was recommended that no such modifications be included in the design. Also, any such modification would restrict one of the major sediment pathways to the inlet's sand trap, which is a low, leaky section in the jetty deck that tops the rubble-mound segment. This low section periodically allows storms to push fillet-sand over the jetty and into the inlet, after which tidal currents carry it to the trap. Consequently, it was recommended that along this segment, the new deck be raised well-above the existing one, so that sand could continue to pass underneath. The findings of this study indicate that this is also a good idea from the standpoint of surfing.

CONCLUSIONS

The First Peak break, as well as additional breaks farther to the north, are the result of a complex sequence of wave reflection, refraction, shoaling, wave-wave interaction, and breaking processes. This conclusion is supported by theory, balloon-borne video observations, and physical model experiments.

The quality of surfing conditions at First Peak is sensitive to wave conditions (height, direction, and period), tide stage, the condition of the north fillet, and wind conditions. Generally surfing is best when large swell arrives from the east-northeast, at mid-to-low tide, with light offshore winds, and with the north fillet in its eroded, summer phase.

Any jetty modifications that would notably change any of the parameters that govern the reflection phenomenon (e.g. structure orientation, or reflection / transmission / dissipation coefficients) would be expected to directly affect the neighboring breaks. Specifically, any modifications that would reduce the strength of the reflection from the jetty would be expected to cause surfing conditions to deteriorate.

Based upon physical model tests, the additional row of pilings proposed for the north side of the jetty should not cause a notable change in wave reflection from the jetty, and consequently in surfing conditions at First or Second Peaks.

Based upon the physical model tests, the jetty extension should not have an adverse impact on the First or Second Peak breaks during times when waves arrive from the east-northeast quadrant. However, it is a concern of some local surfers that under a southeast swell, a break that sometimes appears towards the end of the jetty will be adversely impacted by the extension. Detailed investigation of this relatively limited issue was beyond the scope of this investigation, given the scale and configuration of the physical model as built, and the limited time allowed for field observations.

POST SCRIPT: FIRST PEAK LIVES ON

The Sebastian Inlet north jetty improvements were completed in July of 2003. No adverse impacts to the Surfbreak have since been reported.

ACKNOWLEDGEMENTS

This investigation was a stimulating look at a world-famous Surfbreak, and a rewarding experience in engineering diplomacy. The locals were truly appreciative of the efforts undertaken to preserve the unique experience of surfing First Peak. The authors are equally appreciative of their contributions to this study and we gratefully acknowledge them along with the support of the State of Florida, and the Sebastian Inlet Tax District staff and commissioners.

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FIGURE CAPTIONS

Figure 1 – Aerial photograph of Sebastian Inlet taken in 1997.

Figure 2 – Digital terrain bathymetry used to construct the First Peak model basin.

Figure 3 – First Peak physical model basin.

Figure 4 – Wave generator paddle, motor, and controller.

Figure 5 – Surfing photo sequence at Sebastian Inlet.

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