INVESTIGATION OF EVENTS SURROUNDING THE CAPSIZE OF THE DRILLSHIP SEACREST

VOLUME 1 OF 2

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EXECUTIVE SUMMARY

At the request of Unocal Thailand's legal department, Failure Analysis Associates®, Inc. (FaAA) performed an investigation and analysis of events related to the loss of the drillship Seacrest. The scope of the investigation encompassed the analysis of: the physical condition and design of the ship; the weather and the affect on the dynamic response of the ship; the search and rescue effort; and safety training and operating procedures. This report covers the results of this investigation.

On November 3, 1989, the drillship Seacrest capsized in Unocal's Platong Gas Field during Typhoon Gay. The Seacrest had a crew of 97 at the time of the incident and six survived the event. The cause of the capsize is attributed to the severe weather conditions encountered by the ship during the storm.

A detailed stability review was performed as part of the investigation. The ship was designed, built, and operated in accordance with American Bureau of Shipping (ABS) Standards. In 1988, the ship was modified to include a top drive unit. The stability effect of this modification was analyzed, and it was found that stability improved due to conversion of the No. 3 center tank to permanent ballast as part of the top drive modification.

At the time of the capsize, the ship was operating within accepted stability standards. However, the investigation revealed errors in the wind overturning moment calculations performed by the shipbuilder and approved by ABS. Erroneous instructions in the operator's manual would allow the ship to be operated with the height of the vertical center of gravity above accepted limits, resulting in reduced stability margin. While this could have been a serious issue in this situation, it was not, since the ship was operating at less than the maximum allowable vertical position of the center of gravity prior to the event.

Typhoon Gay was the first typhoon in the past forty years to form in the Gulf of Thailand. Other typhoons which have traversed the Gulf have all formed outside the Gulf and then entered the Gulf, providing substantially more warning of their intensity and direction. Based on weather modelling, the hindcast analysis indicates that the storm rapidly intensified in the vicinity of the Platong field during the morning of November 3, 1989. The storm reached typhoon strength as it approached Seacrest. No weather forecast accurately predicted either the actual path or the intensity of the storm. The forecast paths for Gay would have taken the storm about 40 nautical miles south of the Seacrest path.

Typhoon Gay is known to have passed directly over the Platong Living Quarters and then over the Seacrest. Both reported the calm during the eye of the storm. The Seacrest is known to have capsized after the eye passed over the ship and the weather abruptly turned severe again. At that time, the Seacrest was swinging on one bow anchor; the other seven anchor cables had either broken or were released. The ship oscillated broadside to the predominant wind, and, during a series of high waves, coupled with gusty typhoon-strength wind, suddenly capsized to port.

Recovery and inspection of anchor cables showed that anchor cable #1 was released and had run completely off the anchor winch drum. This was the only anchor winch with the brake in the off position. Anchor cables #2, #3, #4, #5, #6, and #8 failed in overload. Anchor cable #7, a port bow anchor, remained intact throughout the storm, even though it dragged. Side scan sonar showed the drift path of Seacrest and located the capsize site. Anchor #7 created a noticeable furrow in the sea bottom as the ship drifted first to the southwest of its original position, then veered northwest, and eventually capsized approximately 2.1 nautical miles from the well site.

It is now known that at the time of the capsize most of the crew were gathered on the main deck aft, near the abandon ship stations. The ship appeared to be satisfactorily handling the seas and wind until several larger waves approached the ship and contributed to the capsize. It is believed that most of the crew were thrown into the sea at that time.

Communication records indicate that the last communication with Seacrest was at 1326. The ship is believed to have capsized within the next half hour. Communication records indicated that attempts to call Seacrest were made as early as 1458. By 1530 the Marine Controller directed the Gray Guard to proceed to the Seacrest well site; shortly thereafter, at 1643 hours, the Gray Guard confirmed that the Seacrest was not present on radar. At this time, as weather conditions began to abate, search and rescue operations commenced.

Search and rescue efforts were performed by Unocal and the Thai Navy. Unocal utilized helicopters, boats, and divers. The wreck, floating inverted approximately four nautical miles from the well site, was found by helicopter on November 4, 1989, at 0745 hours.

Divers were sent to the wreck to locate any crew who might have been trapped within the inverted hull, while supply boats and helicopters continued searching the surrounding sea for any crew who might have drifted away from the wreck. Divers found no survivors in the capsized ship. By November 5,1989, Unocal's supply boats and helicopters had searched an area of approximately a 30-mile radius from the Seacrest without finding any survivors. On November 5 and 6, Thai fishing boats and the Thai Navy found six survivors in two groups approximately 62 and 69 miles northwest of the Seacrest. At that time, Unocal redirected search to that region.

An analysis of the survivor drift trajectories was performed through analytical modelling of the wave, wind, and current forces. The analysis was based on hindcast wind, wave, and current data. Results showed that initial drift velocities for survivors in the water were high immediately after the capsize and for the next 24 hours. Within 24 hours the survivors were predicted to have drifted beyond the 30 nautical mile radius initially searched.

Hindsight application of guidelines in the United States' National Search and Rescue

Manual failed to accurately predict the actual survivor drift trajectories. Guidelines included in the manual are not applicable to rapidly changing weather such as those present in the vicinity of the eye of a typhoon. Several hindsight studies applying techniques included in this manual failed to predict either the correct drift velocities or direction. Based on this manual, the survivors should have been found within the region searched by Unocal.

Unocal's emergency safety procedures for severe weather were reviewed. The documented threshold for emergency is wind speed in excess of 75 knots, which is typhoon-strength wind. This criteria is too high. By the time the wind reaches this speed, it is impossible for supply boats to handle anchors, and evacuation becomes difficult. An emergency control center was established in Bangkok at 1000 on November 3, 1989, at which time the wind speed in the field was about 50 knots. This is below the stated severe weather criteria, but still above the wind speed for safe anchor handling and evacuation.

The Seacrest wreckage was eventually towed approximately 10 nautical miles north to an approved military dumping ground. Petroleum products were removed from the ship's tanks and the ship was subsequently scuttled.

In summary, the conclusions of this investigation are that the drillship Seacrest was in satisfactory physical condition and was operating within design limits with regard to weight and stability. Emergency and safety training procedures were in place and drills occurred periodically. The capsize is attributed to the unforeseen elevation of tropical disturbance Gay to typhoon strength in the vicinity of the Seacrest. The combination of severe weather and waves overturned the ship unexpectedly. Forecast information did not indicate the force and location of this storm, thus failing to provide sufficient time to initiate emergency procedures and evacuation of the ship. Search and rescue activities were initiated by Unocal within hours of the capsize and continued for 10 days after the storm. The great loss of life can be attributed to the severity of the storm and rapid drift of the crew away from the capsized vessel.

TABLE OF CONTENTS
VOLUMES 1 AND 2

VOLUME 1

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

VOLUME 2

TABLE OF CONTENTS (Continued)

1.0 INTRODUCTION

Failure Analysis Associates®, Inc., at the request of the legal department of Unocal Thailand, Ltd., investigated and analyzed events related to the loss of the drillship Seacrest. The project involved many aspects, such as: analyzing the weather; reviewing ship stability; determining conditions aboard the ship on the day of the incident; establishing the sequence of events aboard the ship; determining the cause of the capsize; documenting and analyzing search and rescue; and, reviewing of operations procedures and training.

In order to perform all of the tasks, Failure Analysis Associates sent a team of engineers to Unocal's offices in Bangkok, Thailand, to collect and organize data pertinent to the investigation. Analysis of the project occurred at Failure Analysis Associates office in Menlo Park, California. Subsequent visits to Thailand by various team members were made in order to review the project status with Unocal and to obtain additional data on site. FaAA engineers also participated in recovery of anchor cables and inspection of the capsize site by remote video camera.

This report provides a comprehensive summary of the investigation and its findings and is divided topically. At the request of Unocal, charts used in previous briefings have been included. Unless noted otherwise, all times are presented in local Bangkok time. (The conversion is Greenwich Mean Time plus seven hours equals local time.)

2.0 HISTORY OF THE SEACREST

2.1 Ownership, Fabrication, and Classification

The Seacrest was a drillship owned by Seacrest Drilling Company and operated by Great Eastern Drilling and Engineering Company. The principle dimensions of this ship were length-over-all, 362 feet; beam, 70 feet; and depth, 24 feet. Figures 2.1 and 2.2 are photographs of the ship.

The ship was built in 1977 by Far East Levingston Shipbuilding Ltd., Singapore. The vessel was designed in accordance with American Bureau of Shipping Rules (ABS) and had an ABS classification A-1 Drilling Unit. The ship had Panamanian registry.

2.2 Service History

The ship had been operating in the Gulf of Thailand since 1981, for the purpose of drilling gas wells for Unocal. At the time of the incident, the Seacrest had been anchored at the Platong Gas Field position 9.7°N 101.4°E and had been at that site since the last rig move on October 23, 1989.

When drilling, the ship was moored over the well site by eight anchors distributed around the ship, as shown in Figure 2.3. Each anchor weighs 30,000 pounds and was connected to the ship by wire rope cables 2 inches in diameter and 7,000 feet in total length. All of the anchor cables on Seacrest were replaced with new cables during the summer of 1989, shortly before the storm. The ship heading as indicated on the last rig move report was 90°, east.

2.3 Modifications

While Seacrest Drilling Company owned the ship, several modifications were made. A major modification on Seacrest was the top drive, which took place between September and October of 1988 in Sataheb. The purpose of the top drive modification was to reduce drilling time. Before this modification, the drill string had been handled and rotated with the Kelly. The system placed on Seacrest is manufactured by VARCO and was used in place of the rotary table, Kelly, and Kelly bushing. It rotated the drill pipe directly from the derrick and traveled down a pair of rails as the bit advanced down the hole. It also performed all the normal hoistings.

The VARCO Top Drive Drilling System consisted of a DC drilling drive motor assembly that connected directly to the drill string. The motor was mounted to the rig's swivel. The swivel attached to the hook or traveling block and supported the string weight during hoisting operations. A "pipe handler," consisting of a torque wrench and an elevator, assisted pipe-handling operations during connections and round trips. The elevator links and elevator were supported on a shoulder located on the extended swivel stem. An overall view of the system is depicted in Figure 2.4, and the pipe handler assembly is shown in Figure 2.5.

The addition of the top drive coincided with the removal of a Byron Jackson Dynaplex hook (model 5500) associated with the previous Kelly system. The derrick was extended by ten feet and reinforced at several places. The structural enhancements of the derrick were determined by the contractor (Brown Services), based on the results of structural analyses. The previous dolly tracks and associated bracing were removed and replaced by new guide tracks. The rotary table remained on Seacrest.

The total weight of the top drive unit was 18.15 LT, based on VARCO's quotation DSO-7707 Rev. B (dated August 11, 1988) to Great Eastern. Subtraction of the removed Byron Jackson hook weight yields a net added weight of 13.66 LT. The unit also contained other items which were taken into account, including the service loop termination kit on the derrick, a drillers' console and panel, hydraulic power supply on the rig floor, a raised backup system ten feet above the rig floor, and elevator links stored on the bulkhead between the divers' compound and the port aft pipe rack.

The changes on the derrick associated with the top drive modification were evaluated based on the contractor's drawings (Brown Services) and the original manufacturer's drawings (Pyramid Derrick and Equipment Corporation). Dimensions of structural members of the derrick are considered proprietary by the manufacturer. The dimensions needed for weight evaluation were obtained from the finite element model constructed by Brown Services from dimensions obtained by direct measurements. The total weight and position of the center-of-gravity changes associated with the top drive modification are presented in Figure 2.6.

The top drive modification induced less than a 0.5 percent change in the lightship weight. The vertical shift of the center of gravity of the ship was not significant. The center of gravity was raised by one percent of its initial vertical position. Those changes did not significantly affect the static stability of the ship. Nevertheless, Great Eastern judged it necessary to counterbalance the slight reduction of stability due to the top drive modification by some other means. In December 1988, the No. 3 center tank was converted from mentor oil into a permanent ballast tank utilizing 296 LT of drill water. No. 3 port and starboard tanks were converted from void to mentor oil tanks. This conversion resulted in a significant improvement in stability affecting a drastic reduction of the height of center of gravity above base line, and of free surface effects due to a wide center tank. The overall stability of the ship was actually improved after the combined top drive modification and tank conversion.

Some other minor modifications to the Seacrest were done by members of the crew. The pilot house was extended aft by 10 feet and to the side in order to create two more state rooms on the bridge. This modification was accompanied by a 15-foot extension of the Schlumberger deck aft of Frame 27 1/2. These modifications are depicted graphically in Figure 2.7. Operational requirements necessitated the addition of a tent between Frames 45 and 48 at the divers' compound on the port side of the ship. In addition, a sack housing the Gearhart equipment was placed on the weather deck just port of the forward starboard crane pedestal. The combined changes due to these minor modifications are shown in Figure 2.8.

In conclusion, modifications made to Seacrest were not significant. The total weight change due to those modifications were not great enough to dictate a new inclining experiment. More importantly, the stability of the ship was essentially improved after the modifications.

2.4 Safety Features

Life saving equipment aboard the Seacrest consisted of a complement of lifeboats, life rafts, life jackets, life ring buoys, and an emergency position indicating radio beacon (EPIRB). The numbers of each type of safety equipment aboard the ship are shown in Figure 2.9. Seacrest's safety equipment inventory before the capsize was documented most recently July 11, 1988, in the ship's Mobile Offshore Drilling Unit (MODU) Safety Certificate. Additional safety equipment outfitting details can be found in the ship's drawing, Far-East Drawing 3B148-G18a. Specific descriptions of life saving equipment will follow crew accommodation details.

Panama issued the safety certificate in accordance with recommendations of the International Maritime Organization (IMO) Code for the Construction and Equipment of MODU's. The code requires lifeboats and life rafts each capable of accommodating 100% of the crew, life jackets for 105% of the crew, and eight life ring buoys. The Seacrest exceeded IMO MODU Code recommendations for life saving equipment needed for a crew of 97. The ship was equipped with lifeboats for 103% of the crew. The Seacrest carried life jackets for 118% of the crew and twice the required life ring buoys.

While Seacrest was not required to meet U.S. Coast Guard standards for life saving equipment, the ship did fulfill most of them. U.S. Coast Guard standards match the IMO MODU standards for the number of required life rafts, lifeboats, life ring buoys, and EPIRB's. The U.S. Coast Guard's life jacket requirement for 125% of the crew exceeds the IMO MODU 105% requirement. The Seacrest had life jackets for 118% of the crew.

Another guideline for safety equipment is promulgated by IMO through the Safety of Life at Sea (SOLAS) Convention recommendations. Although MODU's registered in the U.S., it must comply with SOLAS recommendations, the U.S. Guard will accept either the SOLAS Safety Equipment Certificate or the IMO MODU Safety Certificate. The Seacrest complied with SOLAS recommendations for numbers of life rafts, life jackets, and life ring buoys. However, SOLAS guidelines include recommendations for lifeboat accommodations for 200% of the crew and two EPIRB's. The Seacrest would have required twice the lifeboat capacity and an additional EPIRB to comply with SOLAS guidelines.

Figures 2.9 through 2.13 summarize and compare amounts of safety equipment aboard the Seacrest with IMO MODU Code, SOLAS, and U.S. Coast Guard recommendations.

Seacrest's lifeboats, Builder's #M254 and #M255, were manufactured by Watercraft Shoreham Ltd. They were of the laminated, glass fiber, enclosed, motor propelled type. The boats' dimensions were length, 8.0 meters, breadth, 2.7 meters; and depth, 1.1 meters. Each boat weighed 3574 kilograms with fixed equipment. The engines were Petter water cooled diesels. The lifting hooks were tested to 10.75 tons. Estimated davit load was 7324 kilograms. The boats were surveyed by a Lloyd's Register of Shipping surveyor on 12 March, 1975 [1].

Seacrest carried 6 inflatable life rafts. They were built by three different manufacturers and complied with SOLAS regulations. The life rafts were inspected annually by SOLAS approved surveyors. Housed in hard plastic shells, the rafts were designed to float free of a sinking vessel and self-inflate. The rafts contained SOLAS emergency packs and survival provisions. These included food rations, water, a first aid kit, a sea anchor, flares, a leak repair kit, bilge pump and paddles. See Table 2.1 [2,3].

Seacrest life jackets, classified as type 1 personal flotation devices, were manufactured by Atlantic-Pacific. This type of life jacket is a typical example of those approved by the U.S. Coast Guard in CFR §6.002 for use on all vessels. They were constructed on compliance with SOLAS and U.S. Coast Guard requirements. The flotation material in the jackets was kapok, a buoyant, fibrous material derived from the Indonesian silk-cotton tree. The jackets were designed to render the unconscious wearer face-up in the water [4].

Seacrest's life ring buoys, model #C30, were manufactured by Cal Jan Inc. The buoys were approved by the U.S. Coast Guard in CFR §160.50. They were 30 inch buoys with an inside diameter of 24 inches [4].

Seacrest's EPIRB, model #RLB-14, was manufactured by ACE Electronics Inc. The EPIRB was a battery-operated, self-buoyant beacon transmitter. The device was housed in a high impact, waterproof plastic case. It was so designed to float free of its storage bracket in the event of a sinking vessel. The magnesium batteries had a storage life of 6 years. The EPIRB transmitted on the emergency frequencies of 121.5 Mhz and 243.0 Mhz [4].

2.5 Safety Training

Safety training meetings and safety drills were regularly performed onboard the Seacrest. Unocal Thailand's published safety policies are contained within a document entitled "Safety Policy and Procedures Manual." This document was periodically updated, and the last date of revision before the incident is January 1987. The policy includes requirements for both "Safety Meetings" and "Drills."

Safety meetings are specified to be held "regularly." The policy manual's requirements for safety meetings state: "Contact supervisors will conduct regularly scheduled safety meetings with their employees. Subject matter of these meetings will include accidents, potential accidents, and conditions that could cause an accident and will be presented to the Unocal supervisor in the form of a written report. Each person attending the meeting must sign the report. Attendance at safety meetings held on Company time is mandatory unless specifically excused by your supervisor. Safety meetings held outside working hours are for your benefit. You are encouraged to attend."

The policy manual's requirements for drills state: "Emergency drills such as fire, man overboard, abandon procedures and blowout, under the direction of the Field Superintendent shall be executed at least monthly by all crews. Both on-duty and off-duty personnel will participate. Drills shall be held on an unscheduled basis and a written record kept in the files on the facility and a copy sent to the Fire and Safety Supervisor."

Aboard Seacrest, safety meetings were held on a weekly basis. Safety meetings, called "Good Operations Meetings," were held for ship crew and service personnel. Standard forms were used to document attendance and topics discussed. Copies of the forms for the last two meetings on October 22 and 29, 1989, are included as Appendix A. A variety of topics were discussed among the several groups attending safety meetings. The topics would vary depending on the specific jobs of the attendees.

Separate safety meetings, called "IDAC Safety Meetings," were held for drilling rig crews. The meetings were held weekly, with the last documented meeting on October 29, 1989. Separate forms were used for driller's meetings. The forms come from the International Association of Drilling Contractors (IADC) in a set of 52. Each form is unique and includes safety reminders on different drilling-related topics. Each form is filled out with a description of topics covered and is signed by attendees. An example is provided as Figure 2.14.

Drills were also performed on a weekly basis aboard Seacrest. Two types of drills were scheduled, each on alternate weeks. Drill A was either a fire/explosion, helicopter accident, or medical emergency. On alternate weeks Drill B, an evacuation drill, was performed. The last evacuation drill was performed on October 29, 1989. Drill report forms for the last two drills are included as Appendix B.

Safety policy requirements are applicable to Unocal employees and contractors. In Section 7.2 of Marine Procedures, the following is stated:

Unocal requires each marine contractor to strictly comply with Unocal Safety Regulations as part of the terms and conditions of the contract. The contractor is responsible for conducting all marine operations in accordance with the contractors established procedures as well. However, where the contractor's procedure and Unocal's are not explicit, then the publications listed below should be consulted and a procedure agreed upon.

B. Marine Publications

1. U.S.C.G. - Rules for Cargo and Miscellaneous Vessels.
2. U.S.C.G. - Manual for Lifeboatman and Able Seamen.
3. Merchant Marine Officers Handbook, by E.A.. Turpin.

4. Marine Cargo Operations, by C. Saverbier.
5. Knight's Modern Seamanship.

Figure 2.15 provides a summary of safety meetings.

2.6 References

[1] Certification Documents of Lifeboats (FaAA Record #10018)

[2] Inflatable Life Rafts Specs Services (FaAA Record #10016)

[3] Inspection Certificates for 6 Life Rafts (FaAA Record #10017)

[4] Life Preservers and Emergency Position Indicating Radio Beacon (EPIRB) (FaAA Record #10011)

3.0 ACTIVITIES OF THE SEACREST

3.1 Before the Storm

The Seacrest was drilling in the Platong Gas Field at an intended depth of 10,214 feet (measured from the rotary table) on November 2, 1989. The superintendent's morning report sent to Bangkok by 0600 indicated the drilling crew would continue laying out the 7-inch casing. On November 3, 1989, the 5-inch drill pipe had reached a depth of 3,707 feet. The superintendent's report also stated that winds and seas increased at approximately 0100 on the day of the capsize. The increasing severity of the weather forced the drilling crew to hang the drill pipe on the lower rams. It can be determined from the morning report that drilling activities ceased around midnight. By 0300 the drill pipe was hanging on the lower rams [1].

3.2 Preparation for Heavy Weather

Guidelines for preparation of the Seacrest for adverse weather were contained in the ship's (A) Operations Manual on Emergency and Evacuation, Section B; and (B) Operations Manual, Section 3.5. The recommended actions in these manuals include:

1. Minimize the amount of slack tanks
2. Curtail drilling operations
3. Secure movable equipment
4. Lay down the drill pipe and pull the riser
5. Close all water-tight and weather-tight doors and hatches
6. Close specific ventilation openings

3.2.1 Minimize the Amount of Slack Tanks

This measure is aimed at the elimination of free surface effects due to the shift of liquid weight. It is not known if and how the captain had followed this directive. The effect on stability is described in Chapter 9.

3.2.2 Curtail Drilling Operations

According to the morning report, drilling stopped at around midnight on November 2, and hanging off was completed during the early morning of November 3, 1989.

3.2.3 Secure Movable Equipment

All the movable equipment (mostly tubulars) have to be secured and moved to as low a level as possible. During radio communications between the ship and the Control Center, there was no mention of removal of drill pipes from the derrick set-back area to the drill floor. During the communications, it was mentioned that the casing on the forward port pipe rack shifted. Therefore, it can be assumed that the casing had not been secured adequately by the crew, since the roll acceleration and force were not high at this position. Nevertheless, shifting of the casing did not have significant impact on the accident, as discussed in Chapter 9.

3.2.4 Lay Down the Drill Pipe and Pull the Riser

The total estimated time to complete these tasks, based on 10,000 feet of drill pipe, was 14 to 18 hours. According to the morning report, the drill pipe was hung down on the lower rams and the riser was unlatched at 0530 hours.

3.2.5 Close All Water-Tight and Weather-Tight Doors and Hatches

The manual specifically lists which water-tight and weather-tight doors, and hatches exposed to the open sea have to be secured. The Unocal diver's recollections from his underwater inspection is that doors 3, 5, and 6 were closed, and door 4 was about 9 inches open. The location of doors is shown in Figure 3.1. These particular doors were hydraulically operated and were on the main deck level. The diver found other doors open, but their condition (doors and hatches off their hinges and/or badly twisted) suggests that they were damaged during the incident. It is not known whether these doors and hatches were closed during the incident.

3.2.6 Close Specific Ventilation Openings

The manual also dictates that some specifically listed ventilation openings be closed. During the radio communications, Seacrest reported that water entered the mud room. Obviously, the path of water was through the louvered vent openings on the port and starboard side. There was also water in the emergency generator room that entered through the aft vent openings. From this information it is deduced that the crew had not taken the measures recommended in the Operations Manual to close the vent openings.

3.3 Communications with Seacrest

During normal and routine operation, Seacrest had several means of communicating, including: telephone and FAX via a microwave link; High Frequency Single Side Band Radio (HF SSB Radio); Marine VHF Base Station Radio, approximately 15 mile range; Marine VHF Handheld Radio, battery powered with a range of about 5 miles; and Ground to Air VHF Radio for ship to helicopter communication. The microwave link was interrupted at about 0500 on November 3, 1989 when Seacrest was moved, after "hanging off" the well, in anticipation of heavy weather. Both HF SSB Radio and Marine VHF Base radio communication was interrupted from about 0955 until 1040 on November 3, 1989 due to a loss of electrical power. During this time period, nearby support vessels, using radar, confirmed that Seacrest was still in its working location. Contact was established and maintained through Platong LQ using the battery powered Marine VHF radio until electrical power was restored and HF SSB Radio could be utilized. No ground to air communication took place, since flight was hampered by poor weather conditions [2].

At midnight (0000 November 3, 1989), Seacrest was moored at its working location, northwest of Platong LQ. Two support vessels, the Gray Guard and Gray Vanguard, were standing by. The Gray Guard was moored at Platong LQ Buoy and the Gray Vanguard was standing by a buoy near Seacrest [3, 4].

By 0300, Seacrest had "hung off" of the well and by 0530 the riser was disconnected [5].

At about 0700 the Marine Controller contacted the "company man" on the Seacrest with regard to sending the Gray Guard to assist the drifting Robray T-4 [6]. At 0713 the Gray Guard departed for Satun field to assist [3].

The Marine Controller talked with the "company man" aboard Seacrest at about 0800 with regard to sending the Gray Vanguard to the Robray T-4. The "company man" agreed on the basis that the Seacrest was self propelled as opposed to the engineless Robray T-4 [6]. At 0830 the Gray Vanguard let go of the buoy near Seacrest and departed to assist the Robray T-4. Shortly after the Gary Vanguard headed for Songkhla after sustaining storm damage. The master recorded in the deck log, "...steering compartment water pouring in pump's running all on full power. Head for Songkhla head against sea swell" [4].

At about 0945 the Marine Controller was contacted by the "company man" aboard Seacrest. He stated that, "...anchor cables #3, #6, #7 and #8 were broken and that the SC [Seacrest] was hanging on anchors #1 and #2...Anchors #4 and #5 were without tension...the vessel had a approx. 4-5 degree list, which they had compensated" [6]. At 0954 communication was lost with Seacrest [6, 7].

At 1000 "lookouts" were posted on Platong in case Seacrest personnel were in the water [7]. Shortly after, at 1042, the Gray Sword confirmed that the Seacrest was still on radar [8]. Also at 1012 Platong LQ reported contact with Seacrest (using Handheld Marine VHF Base radio) [7, 8]. The Marine VHF Base radio and HF SSB radio on Seacrest were interrupted due to a loss of electrical power [2].

At 1016 Seacrest reported, "...lost single side band. Anchors number 3, 6, 7, and 8 gone." Bangkok recommended, that , "...Seacrest release all but one anchor and steam into the wind. Harold Lite [Light] said that Seacrest is on one anchor" [7].

At 1035 the position of the storm was broadcasted as, "Center of storm at 9.6°N 101.0°E." Harold Light relayed this message to Seacrest [7].

Platong LQ contacted Seacrest by HF SSB radio at 1040 [9].

At 1041 Seacrest informed Harold Light of the situation, "...stable. Vessel is headed into the wind. Water is in the standby generator room. Power in radio room. Seacrest has had 85 knot winds for 1 hour" [7].

The Marine Controller contacted the company man aboard Seacrest at 1100. The company man reported that the HF SSB radio was operational; anchor cable #2 was gone and Seacrest was "hanging on" anchor #1; anchor cables #4 and #5 were slack; both thrusters were operating at maximum in order to ease the tension on anchor cable #1 [6, 7].

At 1120 Platong LQ relayed a message from Bangkok to Seacrest. Bangkok suggested that if anchor cable #1 breaks then Seacrest should release cables #4 and #5. (Seacrest agreed) [7].

At 1123 a recommendation was made to Seacrest to check the fuel system and change filters if possible. This was due to a problem another vessel experienced with water in fuel [7].

Seacrest contacted Marine Control at 1217 and reported that they lost anchor #1 and the tension was now on #7, the thrusters were on full power; they were listing (due to shifting casing) and had seawater in the mud room; there was no wind and the seas were out of the east; and the Schlumberger house shifted and the Gearhart shack was crushed [7].

At 1250 Seacrest contacted the Robray T-4 but the conversation was not documented [7].

The last known contact with Seacrest occurred at 1326. The Seacrest contacted the Marine Controller and stated that "winds back up. Checking life rafts. Listing to Port 5 Deg. Winds from Starboard. Drill pipe coming free from (Derrick?) 3 life rafts left. Lifeboat partly damaged. Studebaker (GE) says there are 8 life rafts on board" [7].

3.3.1 Evidence Recovered From Seacrest

Divers recovered two wet "log books" and the ship's clock from the bridge of the Seacrest. FaAA provided instructions to preserve the wet books by freezing them while they were still wet. The books were then hand carried by an FaAA employee to California, where they were delivered, still frozen, to Document Reprocessors, specialists in restoration of wet books.

After the books were dry, they were examined by FaAA. One book was the Chief Officer's log book, but it was not the current logbook. The time frame covered by the log book is approximately May 16, 1986 (the first several pages were illegible), through November 24, 1986. The second book is a pocket sized (4-inch by 6.5-inch) memorandum notebook. The notebook did not contain any information regarding the storm; rather, it contained personal random notes from safety meetings and work assignments spanning the time frame from October 24, 1988 until approximately August 11, 1989.

FaAA inspected and documented the condition of the ship's clock. The ship's clock, shown in Figure 3.2, was battery operated. The hands of the clock stopped at 1350. It is believed that this clock ceased operating when it was immersed in seawater. The battery connections were not insulated and would short circuit if immersed in seawater. Therefore, it is reasonable to assume that the Seacrest capsized shortly before 1350 hours. This timing for the capsize is also consistent with survivor estimates, which place the capsize at around 1330 to 1400.

3.4 Initial Position and Path During Storm

The Seacrest had been drilling a well in the Platong Gas Field at position 9.7°N 101.4°E, and had been at that site since the last rig move on October 23, 1989.

Normally, the heading of the ship is in the direction of the prevailing wind. Its heading as shown on the last rig move report was 90°E. When drilling, the ship was moored over the well site by eight anchors distributed around the ship, as shown in Figure 3.3.

In order to establish the path of the drillship from the well site to the capsize location, as well as the location of events along the way, several surveys and inspections were performed: side scan sonar, anchor and anchor cable recovery, and ROV (remote operated vehicle) video inspection of the capsize site. FaAA participated in all surveys and inspections, and results of each are presented below.

3.4.1 Side Scan Sonar

After the capsize, the sea bottom in the vicinity of the well site was surveyed by side scan sonar. The purpose of the survey was to locate the anchors and position of debris. Large furrows where anchors had dragged could easily be seen. Anchors #1, #2, and #7 showed evidence of dragging. The other anchors were still in their original positions. The drag path for each anchor is shown in Figures 3.4 and 3.5. The drag path of anchor #7 was followed by side scan sonar out of the well site. The path led into, and through, an area heavily littered with debris (the capsize site) and then into a second debris site (top section of the derrick).

Anchor #7 created a furrow in the sea bottom that traced the path towards the PTT pipeline. Upon reaching the pipeline, the anchor dragged parallel with the pipeline for 1,250 feet and then jumped/traversed south of the pipeline on a westerly heading. It then veered northwest again, crossing the pipeline and ending at the derrick debris, where the anchor came to rest lodged in the derrick top.

3.4.2 Anchor and Cable Recovery

Each anchor weighed 30,000 pounds, and was connected to the ship by wire rope cables 2 inches in diameter and 7,000 feet long. All of the anchor cables on Seacrest were replaced with new cables during the summer of 1989, shortly before the storm. The cable manufacturer tested a sample of each cable and provided certification of strength. The nominal tensile strength of Seacrest cables was 356,400 pounds. However, when tested to failure by the manufacturer, the actual strengths ranged from 365,430 to 366,130 pounds.

The last available rig move report indicated that, when the Seacrest was moored at the well site, the anchor cables were paid out to lengths of approximately 2,250 feet. A load test is performed to ensure that anchors are firmly set in the bottom. Typically, cable tensions and anchor holding power are tested to approximately 120,000 to 150,000 pounds. Cable tensions are then reduced to normal operating levels of about 75,000 pounds.

The capsized Seacrest was located four nautical miles northwest of the drill site. Only anchor and cable #7 remained attached to the ship. Anchor cable #4 had approximately 75 feet of cable hanging below the anchor fairlead. Anchor cable #5 had an unknown length hanging from the ship. At the time of recovery, it was at least long enough to reach the bottom, having disappeared in the mud. The remaining cables all failed near their fairleads.

A detailed plan of anchor recovery and physical evidence documentation was developed. The purpose of the cable recovery was to record the position of the cables as they lay on the sea bottom; to inspect the cables for defects, damage, and mode of failure; and to measure their lengths. FaAA engineers directed the activity.

Position measurement was accomplished by a microfix system installed aboard the recovery boat with an accuracy of approximately one meter. Translational and rotational offsets were taken into account, with a coordinate reference of the centerline of the stern roller of the recovery boat. The inspection and measurement procedure is shown in Figures 3.6 to 3.11. First, the anchor buoy was brought to the stern of the ship and was recovered (see Figure 3.6). Not all buoys were present (buoy 3 was missing). In those cases the anchor cable or pendant was grappled (see Figure 3.7). After the buoy was detached from the anchor pendant, the pendant was pulled taut, and the anchor reference location was recorded (see Figure 3.8). Next, the anchor was raised aboard and the cable was disconnected (see Figure 3.9) Several location data points were recorded during this procedure. The cable was then brought aboard and rolled onto the ship's winch drum (see Figure 3.10). During the retrieval process, the cable was sprayed clean, inspected, and measured, and a new location data point was recorded (see Figure 3.11). This process continued until the end of each cable was brought aboard. The last 50 feet of each cable were cut from the rest, labelled, and preserved.

The parted end of anchor cable #6 is shown in Figures 3.12 and 3.13. Its appearance is typical of the other parted cables, and is also typical of an overload failure. No significant damage was noted along the lengths of anchor cables, except #4, which showed mechanical abrasion due to rubbing against the anchor pendant for anchor #3 (see Figure 3.14). This damage probably resulted in anchor pendant #3 failing and its buoy drifting free. The abrasion on anchor cable #4 did not cause the failure, since it broke another 1,635 feet along the cable.

The raw measurement data for anchor cable positions are plotted in Figure 3.15. When the recovery boat had retrieved nearly all the cable, insufficient cable weight remained on the bottom to restrain drift; thus, the distance between adjacent positional measurements became greater than the absolute length of cable for the same two data points. This only occurred at the end of the cable recovery, typically within the last 500 feet. Accordingly, the positional data was corrected for the last cable lengths. These corrected data are shown in Figure 3.4. The solid lines represent reliable data. The dashed ends of the cables are corrected to the correct cables length and are an approximation of their likely position. Specific cable location is shown by an arc, showing the furthest extent the cable could reach,

The path of the Seacrest moving southwest from the well site is consistent with data from both the side scan sonar and the anchor recovery. The data also indicate that all cables except #7 had parted or had been released well before the ship had reached the capsize site.

Divers inspected and video recorded the condition of each anchor winch. An analysis of the videos was inconclusive in determining the length of cables remaining on the winches, except for anchor #1. Its drum was empty. The winch for anchor #1 was also the only one with the winch brake in the off position. The length of cable installed for each winch, the measured length of the retrieved cables (cable paid out), and the condition of winch brakes for each cable are summarized in Figure 3.16.

3.5 Location of Capsize

The capsize location was discovered by side scan sonar mapping of the bottom. As it dragged, anchor #7 created an identifiable furrow in the sea bottom. At coordinate 107°49.60N and 75°52.22W, the side scan images showed a unique response, uncharacteristic of the surroundings. In this region the survey also showed origination of a second furrow slightly north of the first. The second furrow ran parallel with anchor #7's furrow for 5,500 feet. At the end, both furrows terminate in a second region with bottom clutter. ROV inspection of both sites confirmed that the first region is the capsize site, and the second region is the top portion of the derrick.

When the Seacrest capsized, loose equipment on the deck came adrift and sank to the sea bottom. The location of various debris was plotted as part of the ROV inspection. The location and identity of many items were established. These items are shown in Figure 3.17.

3.6 Heading at Time of Capsize

The heading of the ship when it rolled over can be established based on the location of items on Seacrest's deck when it capsized. In general, there is a northeast to southwest distribution of debris, corresponding to items located from the bow to the stern of the ship. This is particularly true for "boxy" heavy objects, which would tend to descend straight to the bottom. The radioactive source and the gas quads are two such items. The former is located at the bow of the ship. The latter are near the stern, just forward of the accommodations.

The debris layout at the capsize site is shown in Figure 3.17. Using the radioactive source as a reference for the bow direction, Figure 3.18 shows, superimposed on the debris layout, the angle of the ship heading of 30 to 50°EN during capsize. The figures also show the debris in relation to the anchor #7 furrow and the origin of the second furrow created by the derrick when the ship capsized. Since the water depth was less than the height of the ship, the derrick reached the bottom when the ship capsized. As the wind continued to push the ship, the derrick dragged along, creating another furrow.

3.7 References

[1] Superintendents Morning Report, 11/03/89

[2] Seacrest Communication Before/During Typhoon Gay, 11/03/89-11/03/89 (FaAA Record #4001)

[3] [Gray Guard] Deck Log, 11/01/89-11/12/89 (FaAA Record #3018]

[4] [Gray Vanguard] Chief Officer's Log Book, 11/01/89-11/13/89 (FaAA Record #3015)

[Where is #5?]

[6] Marine Controller Report [Report from Eddie Kiak, 11/02/89-11/06/89 (FaAA Record #4030)

[7] Single Side Band Radio Log, 11/03/89-11/05/89 (FaAA Record #4002)

[8] [Gray Sword] Deck Log, 11/01/89-11/13/89 (FaAA Record #3017]

[9] Platong LQ Radio Log, 10/31/89-11/11/89 (FaAA Record #4028)

4.0 HISTORICAL WEATHER

The past weather in the Gulf of Thailand was reviewed. A list was prepared of all tropical depressions (wind up to 35 knots), tropical storms (wind greater than 35 knots), and typhoons (wind over 65 knots) that have occurred in the Gulf of Thailand since 1950. Figure 4.1 is a list of all of the occurrences, their intensities, and when they occurred. Between 1950 and 1989, there were 37 tropical depressions, 10 tropical storms, and only 3 typhoons, including Typhoon Gay.

Storm tracks for each decade are plotted in Figures 4.2 through 4.6. Each typhoon track is highlighted with a bold line. One typhoon has occurred in each of the last three decades. The two previous typhoons, Harriet in 1962 and Sally in 1972, originated outside of the Gulf of Thailand and then entered the Gulf. Typhoon Gay, the first typhoon in the Gulf of Thailand in 18 years, was the only one in at least 40 years to have formed within the Gulf of Thailand. For the time Unocal has been operating in the Gulf, Typhoon Gay was the storm of greatest intensity.

Typhoon Gay had an intensity equal to a 100-year storm in the vicinity of Seacrest. Expected significant wave heights for return periods of 10, 25, 35, 50, and 100 years are shown in Figure 4.7. Significant wave height is the average height of the highest one third of the waves. These estimates were based on the five storms of greatest intensity occurring at this location in the past 35 years. Storms used in the prediction are shown in Figure 4.8. Typhoon Gay generated estimated significant wave heights at the Seacrest location of 19 feet. This is comparable with expected wave heights from a storm with a return period of 100 years. The calculation of expected significant wave heights for the Seacrest location during Typhoon Gay is described in Section 8 of this report.

5.0 STORM PROCEDURES DURING PAST TYPHOONS

In the Seacrest investigation, questions have arisen about the preparedness of Unocal vessels during storm alerts. During typhoons Sally and Percy the vessels reflect appropriate action plans for typhoon alerts when sufficient notice is available of impending severe weather.

Typhoon Sally entered the Gulf of Thailand in early December 1972 and passed over Unocal WODECO VI. The rig suffered some damage, although operators had taken several steps to minimize the damage before the storm. Most of the crew were evacuated.

Typhoon Percy formed in the South China Sea and started moving toward the Gulf of Thailand on November 21, 1983. Unocal vessels in the Gulf braced themselves for the event and evacuation plans were initiated. However, Percy changed direction and did not enter the Gulf of Thailand.

5.1 Events During Typhoon Sally

In December 1972 Unocal's WODECO VI was operating in the Gulf of Thailand at 9.54°N 101.05°E. Drilling reports indicate that the drilling of a 8 1/2-inch hole was in progress through December 1. Rough seas were reported but work continued.

Typhoon Sally originated at 6°N 126°E on November 28, 1972 and became a tropical storm by December 1. Its course is plotted in Figure 5.1. By 0600 December 1 the storm was at 6.8°N 109.1°E, with 60 knot winds. By 1800 it reached 6.8°N 106.7°E with winds of 75 knots. Sally was forecasted to enter the Gulf of Thailand. The 24 hour forecast at 1800 was 8.4°N 102.0°E with 65 knot winds, while the 48 hour forecast was 10.6°N 98.7°E with 40 knot winds.

On December 2 drilling continued with reported 15°-18° roll of the vessel and rough seas. Sally turned into a typhoon. The typhoon's position was 7.1°N 105.7°E with 80 knot winds at 0000 that day. The warning issued for 0000 gave a position of 7.1°N 105.6°E with wind of 65 knots; the 24 hour forecast was 9.0°N 101°E with 65 knot winds; and the 48 hour forecast indicated the typhoon leaving the proximity of WODECO VI. The vessel started battening down for the approaching typhoon by laying down drill pipe. The 1800 warning showed a position of 8.4°N 104.0°E and wind speeds of 65 knots; the 24 hour forecast at 1800 predicted the storm to move to 10.2°N 101.3°E with 65 knot winds.

WODECO VI reported to be riding out Typhoon Sally on December 3. Sally's course was towards WODECO VI. WODECO VI pulled up to 10 stands, hung pipe on "donut" and let the bit 60 feet off bottom. Forty-seven men were evacuated, while forty-nine remained. The riser was released at 0400. Stern lines were slackened, enabling the rig to swing into the wind. The foreman's report shows a 24 hour wait while the storm passed. Winds reported were 50-85 mph with 12 to 14 foot seas. Anchors #7 and #8 were slipping. Sally was at 8.0°N 103.0°E with a wind speed of 70 knots at 0000. The 24 hour forecast was 9.7°N 100.4°E and wind speed of 75 knots. By 1800 December 3, the storm reached 9.2°N 101.5°E with a wind speed of 60 knots. The corresponding 24 hour forecast indicated that the storm would move away from the region.

On December 4 at 0000, the storm was at 9.6°N 101.1°E with a wind speed of 60 knots. The 24 hour forecast predicted further northwest movement out of the region. WODECO VI was reported to be riding out the typhoon with no radio communication. The vessel had a 13 - 20° roll. Reported winds were 80 mph, and seas were 20-25 feet. Drilling reports showed that risers and hydro lines were released at 0400. Anchor #2 broke at 0600; anchors #7 and #8 were slipping. The typhoon passed right over the WODECO VI location traveling northwest. The center of Typhoon Sally was 10 miles northwest of the rig at 0100. At 1800, the typhoon was located at 10.0°N 99.5°E with 45 knot winds.

Typhoon Sally reached 10.0°N 99.2°E at 0000 on December 5. Damage caused by the typhoon was surveyed on WODECO VI. Forty-two men were taken to Eastern Service at 1030. Seven remained on board. The drilling report shows that all but five men were taken off at 0600. Anchor #6 was let go at 2300 hours. Anchor #5 was let go at 0100. Anchor #4 was broken. The vessel swung on anchors #7 and #8 even though they were dragging. The drill reports showed the winds to be 120-150 mph with 30 foot seas. WODECO rode out the storm held by anchors #7 and #8.

The drill reports for December 6 show that the storm broke at 0100 with 40-45 mph winds and 20-25 foot seas. A post-storm damage survey showed no damage to the hull and no water in the holds. WODECO VI started recovery operations. Anchor #5 was installed, and two anchors were recovered. "Choke" and "kill lines" were retrieved. WODECO VI resumed operation on December 26, 1972.

5.2 Events During Typhoon Percy

Typhoon Percy also originated outside the Gulf of Thailand. It began as a tropical disturbance on November 18, 1983, at 10°N 111°E. The course and intensity of Typhoon Percy is plotted in Figure 5.2. Percy became a tropical storm on November 19. The first warning was issued at 0600. At the time of the alert, Percy was reported to be centered at 8°N 112°E, 600 miles east of Unocal's rigs. At this time the typhoon was 600 miles from the vessels in the Gulf of Thailand. The weather forecast predicted a track toward the Gulf.

By 0660 November 20 Percy became a typhoon at 7.5°N 111.5°E, with a wind speed of 65 knots. By 1800 on November 20 the typhoon was at 7.4°N 111.3°E with a wind speed of 65 knots. The 24 hour forecast positioned the storm at 8.3°N 109.2°E with a wind speed of 80 knots; the 48 hour forecast predicted the storm to be moving to 9.4°N 107.6°E, with a wind speed of 70 knots, and the 72 hour forecast predicted a location of 10.7°N 106°E with a wind speed of 30 knots.

By the next day Percy had decreased in intensity, although it stayed in the same area moving at 2 knots. On November 21 at 1200 it was at 7.5°N 112°E with a wind speed of 55 knots. Forecasts still predicted that the storm would come towards the Gulf of Thailand, but the approach speed had decreased. The 24 hour forecast was 7.3°N 111°E with a wind speed of 50 knots, the 48 hour forecast was 8.6°N 108.7°E, with a wind speed of 40 knots, and the 72 hour forecast was 9.3°N 106.2°E, with a wind speed of 30 knots.

Information from drilling reports indicates that between 1300 and 1400 on November 21 all rigs located in the Gulf of Thailand at about 9°N 101°E were notified about Typhoon Percy and were warned to take precautions. Percy was moving at 2 knots WNW. Unocal expected it to enter the Gulf of Thailand during the afternoon of November 23. The worst conditions were expected on November 24.

Reaction time varied, depending on the operation being conducted by the rigs at the time, but all rigs began to take precautions when they could. The alert time for this storm was about 40 hours.

Seacrest was operating in the Gulf during this period. Seacrest cut short a drill stem test it was performing to layout test tools and 3 1/2-inch drill pipe and pulled the top BOP package. The drill ship secured for the storm by mooring in an east-west heading. No anchors were pulled. Two drilling tenders were towed to safer locations, 5 nautical miles and 30 1/2 nautical miles away from the platforms. The other three tenders pulled away from the platforms, disconnecting all service lines and equipment. Anchor handlers were kept at each rig.

Morning reports on November 22, 1989 from Seacrest, Eastern Queen, Eastern Princess, Robray, Robray T-6, and Robray T-7 indicate that they stopped drilling, secured equipment, and waited on weather during the alert period.

From the six rigs, a total of 125 excess personnel were evacuated to shore by either boat or helicopter. Helicopters evacuated 113 people. The estimated total number of evacuated personnel from rigs and platforms was about 400. Eleven boats were used, including catamarans, utility, crew, and anchor handling boats.

Construction barge WB-8 was towed toward a safer location. "Knut Constructor" was secured for the storm. A K2-pipe laying barge continued working in Satun field. It was operating with its own anchor handling boats.

By 0000 November 22, Percy was at 7.7°N 112.7°E, with a wind speed of 45 knots. Percy then started moving farther away from the Gulf of Thailand. By 0600 the storm was located at 7.2°N 113°E.

Although Percy had been downgraded to a tropical storm approximately 14 hours after the alert, the evacuation of personnel continued. Tenders movement continued but was curtailed as three still remained at the platforms.

Percy continued its course away from the Gulf and headed for the Philippines with decreasing intensity. It dissipated by 1800 November 24 at 12.4°N 122.4°E.

6.0 WEATHER FORECASTS

6.1 Weather Known to Unocal

Weather forecasts for the Gulf of Thailand are available from several sources. The primary source of weather forecasts for the Gulf of Thailand is the Meteorological Department, Ministry of Communications, Thailand. Weather data are issued daily at noon in a document entitled "Synoptic Situation and Daily Weather Forecast." Included in the daily weather report is a synoptic situation, a weather map, and a daily forecast. While the document is issued at noon, reported weather data are for 0700, five hours earlier. Weather is forecasted 30 hours beyond the time of issue.

Summaries of daily synoptic situations and forecasts for the period October 31 through November 6, 1989 are shown in Figure 6.1. The storm track reported by the same source for the same period, is shown in Figure 6.2.

At 0700 on November 2, 1989 the weather map showed the position of the tropical depression to be 8.0°N 102.0°E. The forecasted direction of travel was slowly WNW. The weather map also shows the first isobar at a barometric pressure of 1008 millibars. Similar information was conveyed in the synoptic situation, which stated:

> Tropical Depression in the lower part of the Gulf of Thailand is centered at latitude 8.0 degrees north, longitude 102.0 degrees east or about 220 kilometers east/southeast of Amphoe Muang, Nakhon Si Thammarat province and moving almost stationary with intensifying. Thus causes almost widespread rain with heavy to very heavy falls in Southern Thailand from Chumphon southward to Narathiwat province with rough sea are expected in the Gulf of Thailand for 1-2 days.

At this time, the center of the tropical depression was 107 nautical miles to the south of the Seacrest, and the forecasted northwest direction of travel would have taken the worst of the storm far south of the Seacrest location.

However, during the night of November 2 and into the morning of November 3, the tropical depression rapidly intensified; and the direction of travel veered north towards Platong and the Seacrest. During the morning of November 3 communications between Unocal headquarters and field units revealed that the weather was significantly worse than forecasted, and indicated that the path of the tropical depression had come north towards Platong. These communications prompted Unocal headquarters to implement emergency procedures and to create a local Emergency Control Center (ECC) at 1000 hours.

At noon on November 3, 1989, the 0700 weather map indicated that the position of the tropical depression was 9.4°N 101.4°E (approximately 18 nautical miles from Seacrest), with a forecasted direction of travel to the northwest at 3 knots. The weather map also indicated maximum winds of 45 knots and the first isobar at a barometric pressure of 1006 millibars.

Actual conditions in the field as reported to the ECC were much more severe than forecasted conditions. For example, Seacrest had already reported winds of 85 knots for one hour as of 1041. In addition, the lowest barometric pressure recorded by field units was from the supply boat ASIE 4, which reported a pressure of 975 millibars in the eye of the storm.

Between 1130 and 1200, the eye of the storm passed over Platong Living Quarters. This location was three nautical miles from the Seacrest. At 1217, the eye of the storm passed over the Seacrest. The storm then continued to travel to the northwest, gaining in intensity, making landfall on the morning of November 4, 1989.

6.2 Other Sources of Weather Forecasts

In addition to the Thai Meteorological Department reports, weather forecasts are also made by commercial and governmental organizations. A survey of forecasts and weather data available, but unknown to Unocal Thailand, was performed. This section includes a summary of forecasts from various weather sources. In large part, these forecasts were found to be consistent with the Thai Meteorological Department forecasts. None of the surveyed services accurately predicted the rapid intensification of the storm that occurred during the night of November 2, 1989, and the change in track during that night which brought the storm towards the Seacrest.

6.2.1 Oceanroutes Forecasts

Oceanroutes is a commercial weather service. Unocal did not subscribe to Oceanroutes, unlike a contractor on the DB-15. Accordingly, data provided by Oceanroutes to the DB-15 may have been made known to the Marine Controller on Satun LQ by radio. The published forecast included storm positional data, intensity of storm wind and waves, and forecasted positions for the next several days. Figure 6.3 is a summary of date, position, and storm intensity from Oceanroutes forecasts. As late as 1800 on November 2, 1989, the storm was called a tropical disturbance, with winds of 25 knots, forecasted winds of 30 knots gusting to 40 knots, and maximum height of combined seas and swell of 14 feet. The position of the storm was 107 nautical miles SSE of Seacrest. Direction of travel was WNW. This forecasted storm path would miss the Seacrest.

Oceanroutes forecasts for storm intensity and position are summarized in Figure 6.4. The location of the storm center and the direction of forecasted travel based on Oceanroutes data are indicated in Figure 6.2. As can be seen, the storm veered northward during the night of November 2, 1989, coming towards Seacrest. In Figure 6.4 the storm path forecast at 1800 on November 2, 1989, indicated that the storm was heading south and west of Seacrest towards landfall. Instead, as of 1800 on November 3, 1989, Oceanroutes showed the storm just past the Seacrest and increasing in intensity.

Oceanroutes data are consistent with data from the Thai Meteorological Department regarding storm position, intensity, and forecast. Oceanroutes upgraded the storm intensity to typhoon strength as of 0900 November 4, 1989, 20 hours after the storm passed Seacrest.

6.2.2 Japanese Weather Association Forecasts

The Japanese Weather Association has access to satellite coverage for the Gulf of Thailand. They issue weather reports and forecasts based on satellite data. FaAA reviewed their data for the period of November 1, 1989 through November 4, 1989. The published data are summarized in Figure 6.5 and plotted in Figure 6.6. Again, there is consistency with Thai Meteorological Department weather data. As of 1900 on November 2, 1989, the storm was rated a tropical storm and was centered 81 nautical miles SSE of Seacrest, with a forecasted direction of travel of WNW and wind speeds of 40 knots.

The Japanese Weather Association upgraded the storm rating to typhoon at 0100 on November 4, 1989, 12 hours after the storm passed the Seacrest.

6.2.3 Joint Typhoon Warning Center Forecasts

The Joint Typhoon Warning Center (JTWC) monitors storm positions and intensity using satellite data. Their published data are summarized in Figure 6.7. The storm track is plotted in Figure 6.8. Again, as of 1700 November 2, 1989, there was reasonable agreement with Thai Meteorological Department data regarding storm position and intensity.

The Joint Typhoon Warning Center also provides up to 72 hour forecasts. These are summarized in Figure 6.9 and plotted in Figure 6.10. As of 1900 on November 2, 1989, the JTWC forecast for the next 24 hours predicted that the winds would increase to 45 knots with 55 knot gusts. Predicted wind speeds were slightly greater than those predicted by other sources, but the forecast trajectory was similar to the others. Twelve hour increments for predicted storm paths are indicated for November 2 and 3, 1989 weather reports. As of 1900 on November 2, 1989 the predicted path was about 45 nautical miles south of Seacrest.

The Joint Typhoon Warning Center upgraded the storm to typhoon as of 0100 on November 4, 1989, the same time as the Japanese Weather Association, 12 hours after the storm past the Seacrest.

6.2.4 Thai Meteorological Department Broadcast

A separate weather warning was issued by the Thai Meteorological Department for public broadcast on television and radio. The warnings were issued in Thai, not in English. Figure 6.11 summarizes statements and weather conditions included in the warnings. The warnings upgraded Gay to typhoon as of 1600 November 3, 1989.

These warnings did not come directly to Unocal, but they were in general agreement with others issued by the Thai Meteorological Department.

6.3 System of Upgrades and Definitions for Typhoon Events

During the Seacrest investigation it was found that weather reporting agencies gave out varying information about the Typhoon Gay. This section illustrates the criteria and systems of storm upgrades employed by different weather services.

6.3.1 Background

Unocal had weather report services available from Thai meteorological synoptic situation maps and Oceanroutes forecasts. Other sources which reported this storm were Thai meteorological warnings, Japan Weather Association, Joint Typhoon Warning Center at Guam, and other commercial agencies.

6.3.2 Criterion of Upgrades

All the weather services used maximum sustained wind speed (1 minute mean) as the criterion for reporting on the intensity of the storm.

6.3.3 System of Upgrades

Japan weather service followed the WMO system. Thai Meteorological warnings used the Japan style upgrades. This was inconsistent with daily weather reported on Thai synoptic map, which followed the USA system. Others followed the USA style of idiomatic expressions for storm conditions.

System of Idiomatic Expression

Criteria Wind Speed Knots	WMO System	USA System	Japan System
<1-33	Tropical Depression	Tropical Depression	Tropical Depression
34-47	Tropical Storm	Tropical Storm	Typhoon
48-64	Severe Tropical Strom	Tropical Storm	Typhoon
64-180	Typhoon	Typhoon	Typhoon

Weather Service	System
Thai Met Synoptic Situation	USA
Oceanroutes	USA
Thai Meteorological Warnings	Japan
Japan Weather Association	WMO
Joint Typhoon Warning Center, Guam	USA

6.3.4 Definitions

Relevant meteorological definitions for USA system are as follows:

1.Maximum Sustained Wind - Maximum surface wind speed averaged over a one-minute period of time.

2.Tropical Cyclone - A non-frontal low pressure system of synoptic scale developing over tropical or subtropical waters and having a definite organized circulation.

3.Tropical Disturbance - A discrete system of apparently organized convection -- generally 100 to 300 nm (185 to 556 km) in diameter--originating in the tropics or subtropics, having a non-frontal migratory character, and having maintained its identity for 24 hours or more.

4.Tropical Depression - A tropical cyclone in which the maximum sustained surface wind (one-minute mean) is 33 kt (17m/sec) or less.

5.Tropical Storm - A tropical cyclone with maximum sustained surface winds (one-minute mean) in the range of 34 to 63 kt (17 to 32 m/sec) inclusive.

6.Typhoon - A tropical cyclone in which the maximum sustained surface wind (one-minute mean) is 64 kt (33 m/sec) or greater.

6.4 References

[1]Annual Tropical Cycle Report, 1983

[2]Weather Warnings from the Joint Typhoon Warning Center, Guam, (FaAA Record #1030)

7.0 WEATHER RECORDED

7.1 Storm Conditions Offshore

The following is a chronology of events which took place in Unocal's gas fields November 3, 1989. Only those events that involved Unocal and Typhoon Gay are included.

<u>0000 until 1600</u>

At midnight November 2, Typhoon Gay was approximately 70 nautical miles southeast of Seacrest and beginning to enter Unocal's southern gas field. Wind near the center was 50 knots, gusting to 75 knots. Winds at Seacrest were 25 knots, gusting to 38 knots. Weather conditions in the fields continued to intensify throughout the entire morning. During this period all offshore platforms and vessels were being affected by the storm.

At midnight the two drilling tenders, Robray T-4 and T-7, and the pipe laying barge DB15 were working in Satun Field. DB15 was accompanied by Jaramac 45 and 26. Seacrest was north of Satun field in Platong field and was accompanied by Gray Guard and Gray Vanguard. The remaining support vessels were moored in their respective fields. These positions are plotted in Figure 7.1.

At midnight Avondale, moored at Erawan Wellhead F, noted winds of 25-30 knots and swells of 14-16 feet [1]. Avonlake's deck log indicated, "Vessel tied up at Satun East Buoy...observing weather...Vessel pitching and rolling violently sea very rough...Visibility 0-1. Wind at hurricane force [2]."

At 0054 Erawan LQ recorded a wind velocity of 50 mph from the northwest and swells of 16 feet (5 meters) [3].

At 0130 Gray Foil's mooring rope parted from the Erawan LQ Buoy. Cargo began shifting, and attempts at securing the "heavy pipe" failed. The vessel began steering the "most convenient course" until weather moderated [4].

At 0419 wind velocity at Erawan LQ was 50 mph and gusting to 55 mph [3].

The DB-15's anchor cable parted at 0423 as the weather intensified [5].

During the early morning hours both Gray Guard and Gray Vanguard were with Seacrest at its working location in Platong Field. At 0430 Gray Guard "let go" of its mooring and began "steaming" under its own power, moving at a low speed due to the high swells [6]. At 0500 the Gray Vanguard recorded, "Vessel rolling heavily - engine on stdby [standby] beginning to lash pipes again...all lashings broke [7]."

Telephone and Telex communication with Seacrest was interrupted at approximately 0500 due to the change in the orientation of the drillship. The orientation changed as

Seacrest "hung off" the well in preparation for the storm. Afterward, communication with Seacrest was via HF SSB Radio, Marine VHF Radio, and Marine VHF hand-held radio [8].

Erawan LQ logged winds of 50 mph, gusting to 55 mph, at 0510 and 0530. At 0523 Robray T-7 reported that anchor cables were broken [3]. The Marine Controller was contacted at 0540 by the drilling foreman on Robray T-7 and informed that the tender had drifted from the drilling position at Satun Wellhead "J" (SWJ), 11 people had been left on the platform (later confirmed to be 12 people), and the service line connecting the tender with the platform had broken [9]. Shortly thereafter Westertor was contacted by the Marine Controller and instructed to assist Robray T-7 using towing equipment. Westertor was unable to assist because of weather [9].

Avonlake's deck log recorded at 0600, "Mooring line parted. Started main engine and started steaming...in the area of Satun LQ...wake up all crew and don life jackets all watertight-doors and man holes tightly closed...[2]." At 0600 the DB-15 was 2,460 feet from Robray T-7 (at Satun Wellhead "B") [5].

The Marine Controller broadcasted at 0640, "...the prevailing tropical depression was upgraded to tropical storm 'Gay' [9]."

At 0645 Robray T-7 informed Bangkok that, "left 7 on Satun J Platform (later confirmed 12); 88 on board tender; anchors 5-6 unknown; anchors 3-4 broke; anchors 7-8 ?; anchors 1-2 o.k." [10].

The Marine Controller was contacted by the drilling foreman on Robray T-4 at 0700. The foreman informed him that they had disconnected from the platform, leaving 8 people behind; anchor cables were broken; a crane had fallen off its pedestal and damaged the deck; and the tender was dangerously close to the platform, Satun Wellhead "B." The Marine Controller was then contacted by the "company man" on DB-15 and informed that the anchors were dragging and the barge was moving towards Robray T-4 [9].

The Marine Controller dispatched Gray Guard from Seacrest's location at 0700 to Satun Field to assist Robray T-4 [9]. Gray Guard departed at 0713 [6].

The company man on Robray T-7 reported at 0718 that all anchors, with the exception of #7 and #8, were broken and the tender was "dangerously" close to Satun Wellhead "J" platform [9].

By 0730 Westertor had jettisoned deck cargo overboard but was having problems with the towing winch and was in the process of trying to repair it [9].

Seacrest was contacted by the Marine Controller at about 0730 and informed the Marine Controller, "...they pulled away from the well but all anchors were holding [9]." Gray Vanguard was near Seacrest at this time, and had problems with preventing casing (large diameter pipe) from moving [9].

At 0735 Asie IV's deck log recorded that, "Center main engine stripped, sea water entered in air box. Only port and starboard engines are running [11]."

Robray T-4 then reported to Bangkok that, "Anchors 3-4-5 broke at 0750 hrs [10]."

At 0800 the Marine Controller contacted the company man on Seacrest to discuss the situation. The company man agreed to send Gray Vanguard to assist Robray T-4, since Seacrest was self propelled and Robray T-4 was not [9]. Gray Vanguard "let go" of the mooring buoy at 0830, took on water due to storm damage, and proceeded to Songkhla [7].

At 0830 Erawan LQ recorded winds of 50-60 mph, gusting to 65 mph, with heavy rain [3]. Jaramac 47, at McDermott Jurong Yard, Singapore, received an order to prepare for a trip to Thailand at 0900 to assist DB-15 [12].

Erawan LQ recorded winds of 60-70 mph at 0900 [3]. At the same time, Satun LQ recorded wind speeds of 80 mph and zero visibility. The Marine Controller broadcasted to all stations that conditions were at typhoon level intensity [9].

At 0920 Avonbeg recorded that the mooring rope had failed and it was in the process of remooring [13].

The Avondale recorded a weather forecast from Bangkok at 0930. Weather forecast was: tropical storm to gale storm intensity; west direction, 40-60 knots; and, centered at 9°36N 101°00E, heading north at 5 kilometers per hour [1].

At 0940 the Marine Controller contacted Pacific Scimitar, which had departed Songkhla at 0905, and asked that they proceed to the field at maximum speed [10, 9].

The "company man" on Seacrest contacted the Marine Controller at 0945 and informed him that anchor cables #3, #6, #7, and #8 were broken, and Seacrest was hanging on #1 and #2; anchor cables #4 and #5 were without tension; and the vessel was listing 4°, but this had been subsequently compensated [9].

At 0947 Rodney Nicolas, with Robray Drilling Company, contacted Bangkok and confirmed that the "Favco" crane on Robray T-4 had fallen overboard. He also stated that the crane on Robray T-7 had suffered "extensive" boom damage [10].

The Emergency Control Center was established in the tenth-floor conference room in Bangkok at approximately 1000 in an effort to assist offshore staff during the storm [14]. By 1030 four telephone lines were provided for communication purposes [15].

Communications with Seacrest were lost at approximately 0950 [16, 9, 3, 10]. At 1012 Gray Sword was contacted by the Marine Controller and was asked to check for Seacrest on the radar. At 1015 Gray Sword confirmed that Seacrest was still in position and had contacted Platong Central Processing Platform using VHF radio [17].

The Marine Controller informed Bangkok at 1023 that both Robray T-4 and Robray T-7 were on two anchors each [10].

Gray Guard lost power from its port engine at 1030 because of water contaminated fuel [6].

At 1040 Seacrest regained communications via Single Side Band Radio [16, 3]. During the loss of communications, the Offshore Installation Manager on Platong LQ relayed information to maintain communication between Bangkok, the Marine Controller, and Seacrest. The loss of communication was due to the presence of water in the generator room, causing a loss of electrical power [10].

Platong LQ had winds of 85 knots. The Fuel Storage Unit, south of Platong, had winds of 50 knots. As the storm proceeded north, weather conditions began to lessen in the southern fields [18].

Platong LQ lost power and communications at 1050 [18, 3]. Power was regained at 1104 [3].

The construction superintendent contacted DB-15 by relay at 1053. He learned that the Jaramac 26, 2 1/2 miles from DB-15, was taking on water and had only one engine operable. Jaramac 45 was 5 miles south of DB-15 tracking the drifting pipe lay "stinger" [10, 19]. At 1055 Jaramac 45 was instructed to abandon the "stinger" and proceed to DB-15. The "stinger" was abandoned at 9°13.3N 101°13.3E [19].

At 1100 both Gray Vanguard and Gray Foil were en route to Songkhla with storm damage [9].

Seacrest reported at 1114 that anchor cable #2 was gone, anchor cables #4 and #5 were slack, only cable #1 was holding, and the engines were operating at full thrust [10, 3].

At 1129 DB-15 was drifting toward Robray T-4. Robray T-7 reported that anchors #7 and #8 were holding [10, 3]. At approximately 1130 DB-15's anchor cables #3 and #4 parted [5]. DB-15's anchors #7 and #8 were reported lost at 1138, and anchor #5 was reported as "slipping but holding steady [10]."

Gray Guard lost power from both main engines at 1200 and was reported to be drifting with the wind in Satun Field [6].

Seacrest contacted the Marine Controller at 1217 and reported that anchor #1 was lost, the tension was on anchor #7, and there was full power from the thrusters; Seacrest was listing 3° to starboard, and at present there was no wind [10].

At 1320 Westertor was dispatched from Robray T-7 and directed to Robray T-4 [10, 9].

The last documented communication with Seacrest occurred at 1326 and was with the Marine Controller [10]. The company man aboard Seacrest reported that anchor cable #1 was broken but anchor cable #7 was not broken, contrary to earlier reports. The company man also said that there was a 5° list to port, which was being compensated for by using drilling mud. Winds were reported, "back up," implying that Seacrest had passed through the eye of the storm [10, 9]. After this 1326 message, vessels and offshore facilities tried to regain contact with Seacrest and use radar to confirm its position. All attempts failed.

At 1335 Jaramac 26 reported a loss of power due to a rope that was wrapped around the propeller. Jaramac 45, also in the vicinity of DB-15, had an inoperable wheelhouse due to storm damage [10].

At 1410 Satun LQ recorded winds of 50-55 mph [18]. Shortly afterward, at 1436, Robray T-4 reported that it was drifting ENE [10]. At 1430 Bangkok broadcasted the reported position of Typhoon Gay as 10°N 101°E, a position northwest of the gas fields [3, 9]. Avondale's deck log recorded that at 1430 that the wind was "slightly decreasing [1]."

Robray T-4 reported "all anchors gone" at 1435 and that it was drifting ENE due to a WSW wind. Robray T-4 had cleared the platforms and was east of the gas fields. At 1445 Westertor, which was 9 nautical miles from Robray T-4, was in pursuit of the drifting drilling tender [10, 3, 18].

At 1500 Drill Barge 15's #8 anchor cable parted [5]. Shortly afterward, Platong LQ reported winds of 80-85 knots and visibility of 1/2 mile [10]. Weather was becoming moderate in the southern fields. At 1550 Erawan LQ, approximately 37 nautical miles south of Platong LQ, reported light rain, visibility of 3-4 nautical miles, and 30 knot winds from the southeast (230°) [3].

7.2 References

[1] Avondale Deck Log, 11/01/89-11/13/89 (FaAA Record #3023)

[2] Avonlake Deck Log, 11/01/89-11/13/89 (FaAA Record #3025)

[3] Erawan LQ [Radio Log], 10/29/89-11/06/89 (FaAA Record #4029)

[4] [Gray Foil] Deck Log, 11/01/89-11/13/89 (FaAA Record #3016)

[5] Major Events DB-15, 11/01/89-11/03/89 (FaAA Record #5002)

[6] [Gray Guard] Deck Log, 11/01/89-11/13/89 (FaAA Record #3018)

[7] [Gray Vanguard] Chief Officer's Log Book, 11/01/89-11/13/89 (FaAA Record #3015)

[8] Seacrest Communication Before/During Typhoon Gay, 11/03/89 (FaAA Record #4001)

[9] Marine Controller Report [Report from Eddie Kiak], 11/02/89-11/06/89 (FaAA Record #4030)

[10] Single Side Band Radio Log, 11/03/89-11/05/89 (FaAA Record #4002)

[11] Asie 4 Deck Log, 11/01/89-11/13/89 (FaAA Record #3019)

[12] [Jaramac 45] Daily Boat Log, 11/01/89-11/15/89, (FaAA Record #3014)

[13] Avonbeg Deck Log, 11/01/89-11/13/89 (FaAA Record #3022)

[14] Emergency Control Center Report (FaAA Record #7001)

[15] Communication Links During/After Typhoon Gay, 11/03/89-11/09/89 (FaAA Record # 4005)

[16] Platong LQ Radio Log, 10/31/89-11/11/89 (FaAA Record #4028)

[17] [Gray Sword] Deck Log, 11/01/89-11/13/89 (FaAA Record #3017)

[18] Rich Keller's Personal Log Book, 10/31/89-11/30/89 (FaAA Record #7003)

[19] [Jaramac 45] Daily Boat Log, 11/01/89-11/16/89 (FaAA Record #3009)

8.0 WEATHER HINDCAST

The purpose of this study is to provide as accurate a description as possible of wind, wave, and current fields in the central Gulf of Thailand during Typhoon Gay. The principal aim is to specify conditions experienced by the drilling vessel Seacrest, which capsized soon after the eye passed it. However, the complete space-time evolution of wind, wave, and current fields is required to study other aspects of the disaster besides the capsizing itself; such as forces on the vessel before and after capsizing, drift of debris and floating bodies, and relative conditions experienced at other platforms and vessels in the Gulf of Thailand.

There are no instrumental measurements of environmental conditions at Seacrest, just a few eyewitness accounts of peak wind speeds and of eye passage. Time histories of winds were measured at several platforms south of Seacrest. Ship's weather reports are available from several supply boats. Except for a few rough visual estimates of wave height, there are no firm estimates of wave conditions anywhere in the drilling or production areas of central Gulf of Thailand, and no current measurements of any kind. Therefore, the task of providing an environmental description requires the application of the hindcast method.

Fortunately, the science of hindcasting tropical cyclone generated surface wind, wave, and current fields has been highly refined within the past decade or so. Beginning with the pioneering Ocean Data Gathering Program [1] it was shown that quite accurate hindcasts can be provided by numerical models that are driven basically by storm parameters. These parameters typically are available for historical tropical cyclones that have occurred in well-monitored basins, such as most tropical and subtropical parts of the North Atlantic and Pacific basins. The requisite storm parameters include detailed eye location, central pressure, radius of maximum wind or eye diameter, the ambient flow in which the storm is embedded. The above are given in a minimum of 6 hour intervals.

Specification of storm parameters is best made after all meteorological data pertaining to a storm event have been assembled. Data acquired by reconnaissance aircraft are particularly useful. Such data are available for nearly all tropical cyclones that have occurred in the North Atlantic basins (including Gulf of Mexico, Caribbean Sea, U.S. East Coast) since about 1945 and nearly all North Pacific storms that occurred between 1945-1986, when the U.S. Air Force terminated aircraft surveillance. Unfortunately, this leaves Gay devoid of this type of data. All other possible data were assembled from several meteorological centers and combined with the limited in-situ measurements.

Once the storm parameters are determined, the hindcast involves adaptation and execution of three numerical models. The first model accepts as input the storm tract and intensity parameters noted above and calculates wind fields at intervals of 15-minutes on two grid systems. One grid is used in the spectral wave model whose execution is the second part of the hindcast. The other grid is used in the storm surge/current model, whose execution is the third part of the process. In the next sections each of these processes, as specifically adapted to this problem, is described.

More extensive mathematical treatments are reserved to cited references. This is followed by a summary of data sources; a description of the development of the storm tract and intensity history; and a summary of hindcast results, both at Seacrest and throughout the Gulf of Thailand.

8.1 Hindcast Methodology

8.1.1 Wind Field Specification

Two methods are available to specify wind fields in tropical cyclones. In the first approach, a numerical model of the boundary layer flow in a moving vortex is adapted to specify the time and space varying wind associated with a propagating cyclone. Some account of the ambient flow in the far field surrounding the cyclone is incorporated in this approach through the specification of the ambient pressure field, but the assumption that the background flow is prescribed in terms of a constant, equivalent, geostrophic pressure gradient limits this scheme to relatively simple superpositions of tropical cyclones and surrounding systems; for example, the case of a tropical cyclone traveling around the periphery of the sub-tropical anticyclone is handled well by this approach.

Frequent and intensive aircraft reconnaissance of mainly North Atlantic hurricanes has revealed quite complicated wind field patterns in some storms which are not readily handled by the numerical model. For example, some storms exhibit two distinct maxima in the radial variation of boundary layer wind, one often very close to the eye of the storm (10-15 nautical miles), and the second perhaps 50-100 miles away from the center. Other storms exhibit a single maximum near the center, exhibiting a much slower decrease in wind speed, with radial distance outside of the radius of maximum wind. For such storms, a second approach, utilizing kinematic analysis of over-water wind observations (aircraft observations are extrapolated down to the 20-meter reference level), is used to develop a description of the wind field about the translating cyclone. This description is then used to provide a time-varying wind field by propagating the complicated wind field distribution with the moving storm center. On the available evidence, the wind field in Typhoon Gay was not anomalous, but a very small, compact storm with a single radial wind maximum located very close to the center and with the storm embedded in a simple background flow. The numerical model, therefore, should work well.

Developed as part of the Ocean Data Gathering Program, the model provides a description of the surface winds in the boundary layer of a tropical cyclone from the simple model parameters available in historical storms. The model is an application of a theoretical model of the horizontal air flow in the boundary layer of a moving vortex. The model solves, by numerical integration, the vertically averaged equations of motion that govern a boundary layer subject to horizontal and vertical shear stresses. The equations are resolved in a Cartesian coordinate system whose origin translates at constant velocity (v_f) with the storm center of the pressure field associated with the cyclone. Variations in storm intensity and motion are represented by a series of quasi-steady state solutions.

The non-linear system of equations is solved numerically on a fine-mesh nested grid system (inner nest grid spacing is prescribed). Transformation of the steady solution to earth fixed coordinates provides the vertically integrated wind field.

Initially, the Ocean Data Gathering Program wind model included an empirical scaling of the 20 meter wind speed from the vertically integrated wind. Recently, the scaling has been improved by replacing the surface drag treatment [2] with a similarity boundary layer parameterization.

The model pressure field is described as the sum of an axially symmetric part (p) and a large scale pressure field (p) of constant gradient. The symmetric part is described in terms of an exponential pressure profile

$p = p_o + Dp \exp(-r_a/r)$,(8.1)

where p_o is central pressure, Dp is storm pressure anomaly, and r_a is a scaling radius nearly equivalent to the radius of maximum wind and r is the distance from the center of the storm. The model, therefore, can be initialized from parameters that are usually available from historical meteorological records: p_o, r_a, v_f, and the ambient pressure field p. The entire wind field history is computed from knowledge of the variation of those parameters along the storm track.

For each hindcast so-called "snapshots" are specified to describe the surface wind distribution on the nested grid as often as is necessary to describe different stages of intensity; typically, only a few snapshots are required to describe most storms.

The interpolation of winds to the hindcast wave and current model grids from the snapshot wind fields, which are generated on a moving nested grid, proceeds in three stages. First, intermediate coordinates of the storm center are linearly interpolated from a track table. Second, at each time level required by the hindcast model (in this case 30 minutes or 15 minutes), the model wind components are linearly interpolated in time between adjacent snapshots. Third, for each grid point for each time level, given the latitude and longitude of the eye and the latitude and longitude of the point, the smallest nest is found (within which the grid point lies and the wind components are interpolated bi-linearly to the grid point from the four surrounding nest positions).

The model was validated originally against winds measured in several Ocean Data Gathering Program storms. It has since been applied to nearly every recent hurricane to affect the United States offshore area. Comparisons with over-water measurements from buoys and offshore facilities support an accuracy specification of +/- 20° in direction and +/- 2 meters/second in wind speed (1 hour average at 20 meter elevation). Most comparisons have been published [3, 4, 5, 6, 7, 8].

The cyclone wind model has also been applied to the study of tropical cyclones in foreign basins. The model has been used by the U.S. National Aeronautics and Space Administration (NASA) and by the National Oceanic and Atmospheric Administration

(NOAA) to evaluate marine winds sensed remotely from SKYLAB and SEASAT in several Pacific Ocean typhoons. More recently, in proprietary industry-sponsored studies, the model has been applied to model tropical cyclones offshore Borneo; in the Gulf of Thailand; in the Arafura Sea; offshore northwest Australia; and in several studies for offshore China, including waters around Hainan Island and Pearl River Basin.

As presently formulated, the wind model is free of arbitrary calibration constants which might link the model to a particular storm type. The variations in structure between tropical storm types manifest themselves basically in the characteristics of the pressure field of the vortex itself and of the surrounding region. The assignable parameters of the planetary boundary layer (PBL) formulation, namely planetary boundary layer depth and stability, and of the sea surface roughness formulation, can probably safely be taken from studies performed in the Gulf of Mexico, since tropical cyclones world-wide share a common set of thermodynamic constraints.

8.2 The Wave Hindcast Model

The wave hindcast model adapted for this study is a so-called fully-discrete spectral wave model. That is, the wave spectrum is resolved in discrete frequency-direction bins, a grid of points is laid out to represent the basin of interest. A solution is obtained based upon integration of the spectral energy balance equation. This process successively simulates, at each model grid point, and for each time step, the physical processes of wave growth and dissipation (through the source terms of the energy balance and wave propagation).

Three classes of spectral models are generally recognized. First-generation models, such as the ODGP model [1], are part of the family of fully-discrete spectral models originally proposed by Pierson, Tick, and Baer (1966) [9]. This type of model is characterized by a source-term formulation which does not include an explicit representation of conservative transfers of energy between spectral components, believed to be associated with resonant non-linear wave-wave interactions. Second-generation models were introduced to include at least a parametric representation of a wave-wave interaction source term; while third generation models, only recently introduced, attempt to model the wave-wave interaction source term rigorously.

The formulation of the ODGP model has been described in detail in past studies, most recently in MacLaren [10]. The skill of the model has also being documented in numerous studies, including Reece and Cardone [11], and more recently by Cardone and Greenwood [12], wherein the characteristics of the model are compared to those of recent second- and third- generation models.

While a number of second-generation models and the so-called third-generation WAM model [13] have been demonstrated in some applications to achieve hindcast skill comparable to the ODGP first-generation model, no clear superiority of these later formulations has been established. However, a second-generation model developed at Oceanweather for an international wave model comparison program [14], and known as the SAIL model [15], has been calibrated against the same data base used for the ODGP model. It performs about as well as ODGP. The third-generation WAM model was not considered since it requires an order-of-magnitude-greater computer time to run compared to first- or second-generation models.

Basically, the ODGP wave model was adapted in the Seacrest analyses on two very high resolution grid systems. Both grids covered the same domain, as shown in Figures 8.1 and 8.2; but one variant had a grid spacing of 10 nautical miles and the second a spacing of 5 nautical miles. Since the time step on the 10 nautical mile grid is 30 minutes and that of the five mile grid is 15 minutes, the finer grid requires about factor of eight (2x2x2) more computer time. Nevertheless, hindcasts were run first on the 10 mile grid and then repeated with the same wind field, sampled at higher grid spacing, on the five nautical mile grid to ensure that the simulation of the wave field in this very small storm was not unduly affected by the choice of grid spacing. Comparison of wind speed predictions for both models show good agreement, shown in Figure 8.3.

In the ODGP model, the spectrum is resolved at each grid point in terms of 15 frequency bands (the binning is given in Figure 8.4) and 24 directional bands, evenly spaced at 15° intervals. The model solution is formed by simulating successively each time step; the process of wave propagation across the grid (the so-called propagation step); and the spectral growth/dissipation step, which solves for a new spectrum at each grid point in response to source terms associated with energy growth due to the wind, and for energy dissipation due to wave breaking or shallow-water processes. Only deep-water propagation and dissipative processes were included in this study since, at the water depth of Seacrest and the surrounding area, shallow-water effects should be negligible for the wave frequencies excited by a small cyclone such as Gay.

8.3. Storm Surge/Current Model

In several recent studies, a state-of-the-art current/surge model has been applied in problems of this type, including one application in the South China Sea. The particular model adapted was developed at Texas A&M under the direction of Professor R.O. Reid and is described in detail by Bunpapong, Reid, and Whitaker [16]. The model differs from most previous surge models since it was designed for basin-wide simulations (such as Bunapong's initial treatment of the problem of hurricane forcing on a grid covering the entire Gulf of Mexico), rather than models restricted to limited stretches of the continental shelf.

The theoretical formulation of the model is based upon the vertically integrated momentum and conservation equations for quasi-hydrostatic, large-scale disturbances in a basin of variable depth. The model is formulated to handle up to two layers but was used in the single-layer mode in this study.

The normal mode equations are solved by finite-difference on a time-marching model, employing an alternating, direction-implicit differencing scheme. The model is quasi-linear, and tides are not included. Variable bathymetry, variable coriolis parameter, and variable atmospheric pressure are modeled, however. The inverted barometric effect is, therefore, implicit in the model and is automatically included in the modeled water-level anomalies. Surface-pressure anomalies are also used to stipulate barotropic height anomalies on the open boundaries of the model. A no-flow condition is taken at all solid boundaries.

The surge model is forced by specification of time histories of surface pressure and wind stress at the top boundary and by bottom friction at the bottom boundary.

The surge model incorporates a quadratic bottom-stress law with a constant friction coefficient. Bunpapong, Reid, and Whitaker (1985) [16] used a coefficient of 2.5×10^{-3} in their Gulf of Mexico hurricane simulations. For the South China Sea study referred to above, this was reduced to 1.0×10^{-3}, which is at the lower end of the range of friction factors commonly adopted in models of this type. The latter value was retained for this study.

The model was adapted to the Gulf of Thailand on a grid covering the same domain as that of the wave model. However, since the wave model uses an array of points laid out on a direct Mercator gird, and the surge/current model grid is a true latitude/longitude grid (spacing of 5 minutes), as shown in Figure 8.5, the surge model grid points and wave model grid points are not collated. However, since the resolutions are comparable, it is easy to match grid points in order to produce a single archive of hindcast results referenced to the wave model grid point location. (The location of a surge model output point is somewhat ambiguous since the grid is staggered such that the x-component of current, the y-component of current, and the water levels are specified at a different location within a grid box.) Parts of the south and east boundary are treated as open with non-reflecting boundary conditions. The model time step is 15 minutes. Wind stresses and sea-level pressures are provided to the current/surge model at 30 minute intervals and then interpolated linearly to 15 minutes.

8.4 Data Sources

The most difficult part of this study was the specification of the meteorological properties of Typhoon Gay. A number of government centers, including the Joint Typhoon Warning Center (JTWC), Guam, the Japan Meteorological Agency (JMA), the Royal Observatory Hong Kong (ROHK), and the Thailand Meteorology Department (TMD), monitored Gay in real time and issued track forecasts and storm warnings. Forecasts were also issued by some private forecast companies, including at least Oceanroutes (OR) and Japan Weather Association (JWA). However, all of these centers work from the same basic data sources, which in the case of Gay consisted mainly of satellite imagery from the Japanese geostationary satellite and polar orbiting satellites of the U.S. National Oceanic and Atmospheric Administration (NOAA) and the Defense Meteorological Satellite Program (DMSP). Gay formed and moved through an area in which there are few conventional reporting stations; few ship reports; no radar surveillance, except near where Gay crossed the coast of Thailand; and no aircraft surveillance.

Some of the above noted centers routinely carry out a post-analysis of their real-time data and issue a revised "best track" and storm intensity profile, though most of these were not available in time to be used in this study. Figure 8.8 is apparently a summary of the real-time analysis portion of the track and intensity history of Gay provided by JWA. Figure 8.7 is an expanded view showing more clearly the track relative to Unocal's fields and Seacrest. Figure 8.6 gives the real-time storm positions and intensity estimates from JTWC. Intensity is estimated from the satellite imagery using the Dvorak system, which enables an estimate of so-called "current T number" and associated maximum wind speed and central pressure.

The in-situ data from Unocal's platforms, barges, and work boats provided an opportunity for significant refinement of the track and intensity profile of Gay. Black summarized pressure records obtained from platforms and vessels in the Satun and Erawan fields and presented a barograph trace from the Satun Living Quarters platform [17]. These records suggest that the center of Gay passed closer to the Satun field than the Erawan field, and that the storm intensified as it moved north. Since the eye die not pass over any of these stations, the barograph data could not be used to estimate storm central pressure precisely. However, FaAA's intensive analysis of support vessel locations and observations from the many support vessels in the area later established that the ship Asie IV recorded a pressure of 975 millibar in the eye of Gay at a location approximately 10 miles southeast of Seacrest. This observation was later confirmed by FaAA in an interview with the vessel master. A comparison of pressure readings from all available sites in the central Gulf of Thailand during a period of tranquil weather suggests that the ASIE IV barometer was accurate to within about +/- 1 millibar of the true sea-level pressure [17].

Wind observations from platform/barge locations and support vessels were reviewed. Many individual observations were available, but the most extensive and reliable data seemed to be the time histories from Erawan Floating Storage Unit (FSU), whose anemometer recorded speed only, and Derrick Barge 15 (DB15) in the Satun field, whose anemometer recorded wind speed and direction. Wind speed and direction traces were digitized and used to refine track and intensity estimates for the hindcast. Although Black also summarizes "spot" observations of peak wind speeds or gusts from other locations, these estimates are not generally of the same quality as FSU and DB-15 data [17].

Very little environmental data was received from Seacrest by radio before it capsized. The morning report stated winds were 50 mph. At 1217 November 3 there is a report of calm winds, presumable in the eye. This followed a report of 35-40 knot winds at 1152, and a report of peak winds of 85 knots for one hour preceding 1041. Winds were reported to be "back up" at 1326. This was the final message from Seacrest.

8.5 Storm Parameters

Our approach to the specification of input parameters for the wind model was to develop a "trial" set of storm inputs, generate a complete "trial" wind field on the 10 nautical mile grid, compare the measured and modeled time histories of winds at FSU and DB15, and then iterate this process several times until satisfactory agreement was achieved. In fact, the process was iterated eight times before satisfactory agreement was obtained, though many of the iterations involved only slight changes in track. Our starting track was a compromise between the Thai Meteorological Department and Oceanroute "revised" tracks provided by Unocal, but with more precise placement of the eye near Seacrest to provide a wind history consistent with the reported sequence of events there, particularly the timing of eye passage.

The principal change to the trial inputs was to shift the period of maximum deepening forward in time from the preliminary estimates (e.g., JTWC or JWA) so that the period of most rapid deepening occurs in the 12 hour period before Gay arrived over Seacrest. This change was supported also by the pressure reported by Asie IV. Little further deepening was indicated as Gay moved west of Seacrest's location and made landfall. The trial inputs assumed a radius of maximum wind of 10 nautical miles, which is fairly typical of small tropical cyclones at low latitudes, but the radius was reduced to 8 nautical mile for the final run. The steering flow was specified from surface weather maps (we referred to the NOAA tropical strip 12 hour surface charts) and was not iterated significantly.

Figure 8.9 gives the final input data for the specification of wind fields on the 10 nautical mile grid, which requires winds at 30 minute intervals. An explanation of the table is included. A 72 hour period is modeled, providing winds between 0600 GMT November 1, 1989, and 0600 GMT November 4, 1989. This includes ample time for spin-up of the wave and surge/current models and takes the eye to landfall. For the wave hindcast run on the 5 nautical mile grid, and to specify winds for the surge model, the run was extended to 1800 GMT November 5, 1989. Figure 8.10 gives the input data used for that wind run.

At the start of the period simulated Gay was just a weak tropical depression with central pressure 1002 millibars, which deepened slowly over the next 36 hours to 990 millibars. However, in the following 11 hours which ended with the eye over Seacrest, the central pressure was lowered rapidly to 975 millibars, followed by a period of gradual further deepening to 970 millibars at landfall. In the extended run the system weakened to 976 millibars while crossing the Malay Peninsula and then deepened strongly in the Bay of Bengal to 941 millibars, though this aspect of the history has little direct influence on the wind field in the Gulf of Thailand.

Figure 8.11 shows the adopted storm track over most of the period modeled. This track is very similar to the revised Thai Meteorological Department track which shows that the center passed east of DB15, (consistent with the observed trend of wind direction observed there), then passed directly over Seacrest and turned abruptly westward.

8.6 Modeled Wind Field

A general picture of the modeled wind field is shown in the series of 6 hour "wind barb" plots given in Appendix C. The grid point winds are plotted in conventional metrological plot code with each wind representing the wind as would be averaged over a 30 minute interval at an elevation of 20 meters. Peak 1 minute average wind speeds would be approximately 20% greater than the 30 minute average wind speeds. Peak gusts could be as much as 50% greater than the 30 minute average wind speed. Note that the area of calm winds in the eye of Gay covers so small a spatial area that rarely does a grid point reflect this area at 6 hour intervals. At 30 minute intervals the calm area is often captured.

Figure 8.12 is a comparison of the modeled and measured winds at DB15. Much of the iteration was prompted by the difficulty in modeling the decay side of the DB15 history, which was more rapid than initially modeled. The agreement is considered quite satisfactory given that the measured winds are fairly crude estimates above speeds of about 25 m/sec [18], and that winds at DB15 probably represent somewhat shorter averaging intervals than 30 minutes.

Figure 8.13 is a comparison of measured and modeled wind speeds at Erawan FSU. There are no wind directions at FSU; but, since the winds were read off a strip chart, they are probably better averaged than the winds at DB15. At this site winds were raised to a 20 meter height using our standard profile model.

Figure 8.14 is a plot of the modeled wind at the grid point (912) located at our nominal Seacrest location corresponding to the 10 mile grid. The track table purposely places this grid point , and therefore Seacrest, in the north part of the eyewall of Gay at about 0330-0430 GMT (1030-1100 local), with a maximum wind speed of 31.85 m/sec (about 60 knots), and in the eye at 0500-0530 GMT (1200-1230 local), in agreement with the report of calm winds from Seacrest at 1217 local. The modeled wind maximum at Seacrest in the south part of the eyewall is a little lower than in the northern part of the eyewall. Our modeled winds support one minute wind speeds of about 75 knots and peak gusts of about 90 knots at Seacrest, perhaps supporting the reported peak winds of 85 knots at Seacrest just before eye passage.

The wind field generated on the 5 nautical mile wave model grid system provides both greater temporal and operator spatial resolution. However, since the 10 nautical mile grid is in effect a subset of the 5 nautical mile grid, the wind barb plots of Appendix A also display the 5 nautical mile winds, but only at alternate rows and columns of points. The alternate series of winds specified at the Seacrest location by the two wind runs are compared in Figure 8.15. Note that the maximum wind speed in the north eyewall is now somewhat greater at 32.96 m/sec instead of at 31.85 m/sec, and the lull in the eye is better resolved. The maximum wind speed in the south part of the eyewall in unchanged.

8.7 Wave Hindcast Results

As noted above, the wave hindcast program was run for two grid spacings, 10 miles and

5 miles. Differences were found to be quite small, suggesting that either grid adequately resolves the wave field even near the center of this very compact typhoon. Appendix D displays the results of the 10 mile grid run at 6 hour intervals as vectors of length proportional to the significant wave height, and orientation in the vector mean wave direction. The first 36 hours or so of the wave run was a period during which the wave field was adjusting to the forcing wind field from the assumed flat calm-sea starting condition. At the end of this spin-up period, or at about 1800 GMT November 2, significant wave height had grown to about 3 meters at grid point 912 (Seacrest). After this time significant wave height built rapidly to a maximum of 5.45 meters at 0500 GMT, November 3, dropped slightly to 4.l78 meters to reflect eye passage at Seacrest, increased again to 5.1 m in the south part of the eyewall, then slowly lowered as the storm moved away. A detailed table of results at Seacrest is given in Figure 8.18 for the 5-mile grid run.

Figure 8.16 gives a field plot of only the maximum significant wave height and associated vector mean wave direction attained at each grid point in the 10 mile grid run, with peak significant wave height contours at intervals of 1 meters overlaid. This plot shows that peak significant wave height of about 6 meters was hindcast in the northwestern part of the offshore development area, and was nearly 7 meters near where the storm crossed the coast. In the absence of instrumentally obtained wave measurements anywhere in this storm, we make no attempt to validate these results. There were a number of visual estimates of wave height reported from platforms and support vessels, but these span a considerable range. It should be noted that our hindcast of peak significant wave height of 5.5-6 meters would support the occurrence of maximum individual waves perhaps as high as 11 meters (36 feet) at any given site near the path of the center.

The field of significant wave height found from the results of the wave run on the 5 mile grid is shown in Figure 8.17, which hardly differs from Figure 8.15. A more detailed look at the pattern of significant wave height/vector mean wave direction is provided in Appendix E. This Appendix gives field plots at 3 hour intervals over the period 0000 GMT November 3 to the end of the extended run at 1800 GMT November 5 on a part of the 5 mile grid. The time history of selected wind and wave variables at the Seacrest grid point (grid point 3404) at 15-minute intervals over a 24 hour period centered on eye passage is given in Figure 8.18. The maximum significant wave height at Seacrest is now 5.39 meters, with an associated peak spectral period (TP) of 9.12 seconds. The vector mean wave direction changes rapidly from southwesterly to northwesterly at Seacrest with the passage of the storm center. The full directional spectrum (not shown) exhibits a typical complicated and broadly distributed pattern. Plots showing the directional wave spectrum before the capsize are presented in Chapter 10.

8.8 Surge/Current Hindcast Results

The applied hydrodynamic model assumed that the water column became well mixed under storm forcing (probably valid for Gay in water depths of 100 meters or less). The model returned vertically averaged current factors only. The vertical profile of current and near-surface currents were not specified. In very shallow water, depths of 30 meters or less, measurements of hurricane-generated currents in the Gulf of Mexico suggest that there is very little shear in storm conditions, and that the vertically averaged current may be taken to represent the current at any depth except within a very thin layer near the surface and bottom. However, at the water depth of Seacrest, surface currents are probably greater than the vertically averaged current speed, though the model provides the timescale and spatial distribution of the current field excited by Gay. In addition, the surface currents will be enhanced by wave drift (which may be calculated from the wave hindcast results) and tidal and mean background flows.

Field plots of the current speed and direction, and magnitude of the surge (with respect to mean sea level) covering the whole of the domain of the surge/current model are given at 12 hour intervals in Appendix F. Current vectors are plotted only if either the current speed exceeds 10 cm/sec or the surge height exceeds 10 centimeters. For clarity every other row and column of the model grid array are depicted. Field plots showing the surge and currents at each grid point, but for a limited domain, are given at 3 hour intervals in Appendix G. For these plots vectors are shown only if either the current need is at least 15 cm/sec or the surge height is 15 centimeters.

The time history of surge height and the east and north components of the current at hourly intervals at the Seacrest grid point are given in Figure 8.19. The maximum vertically averaged current occurs in the northeasterly flow just before eye passage. It is about 26 centimeters/second from the NE, where the maximum surge height of 44 centimeters is specified. After eye passage, the current speeds lower quickly. Though not shown here, we have examined the solution in detail at grid points just north of where the center of Gay entered the Malay Peninsula. We have found that the model produced peak currents of slightly more than 100 centimeters/second (about 2 knots) and peak surge height of about 1 meter. These seem quite reasonable for this type of storm and for the slope of the continental shelf where this storm came ashore.

8.9 Storm Upgrades in the Hindcast Wind Data for Typhoon Gay

Surface wind hindcasts were found by Oceanweather, Inc. for the Typhoon Gay in Gulf of Thailand. This section compares findings the storm upgrades from the hindcast data and compare it with the actual warnings issued by weather services.

<u>8.9.1 Background</u>

Weather services report tropical cyclones by a system of upgrades depending upon the maximum sustained surface wind (1 min. mean). Hindcasts for wind were calculated by using a numerical model which makes use of parameters from historical storms and from weather service reports on the cyclone. Windfield model gives data on a 10 mile grid of 30 minute intervals and on a 5 mile grid at 15 minute intervals. These winds are average of the interval and modeled at 20 m. height.

8.9.2 Method

Using the criteria employed by weather services for upgrading a storm the upgrade time can be found from hindcasts. Recognizing that 1 minute peak wind is about 22% higher than 15 minute and 30 minute wind average, a revised set of upgrade times can be found.

Another factor into consideration can be the ratio of winds at 20 m. height and the winds reported by aircraft reconnaissance. This factor is approximately 0.8. Since the weather services did not have any air support this comparison was not done.

Upgrade criteria and the corresponding times obtained from the hindcast are shown in Figure 8.20. Scaling in this way the maximum wind intensity is also found. This has been tabulated along with the upgrade times reported by various weather services.

8.9.3 Conclusion

Compared to weather services reports, the hindcast simulated upgrades arrive much sooner. There is about 13-21 hour difference in Typhoon upgrade. Correction factor does not bring the simulated times any closer to the reported ones.

It is recognized that the factors of scaling are a big source of uncertainty. Also, the maximum wind can occur between two adjacent grid points and that is not available through hindcasts. Weather services too, use a varying criteria in their reports.

8.10 References

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9.0 INTACT STABILITY ANALYSIS FOR SEACREST

The objective of the intact stability analysis was to assess the ability of the Seacrest to restore its equilibrium position following perturbations of its loading or environmental considerations. The analysis was two-tiered.

One part was based on totally static considerations. The loading and the position of the center of gravity of the ship were computed, and subsequently combined with hydrostatic properties to yield the metacentric heights.

The other part was a quasi-static analysis. The restoring capacity of the ship under dynamic wind load (applied statically) was evaluated based on statistical Rahola type criteria. These criteria have been set forth by the American Bureau of Shipping (ABS), under which Seacrest was classified. The application of the criteria defines a curve of the allowable vertical location of the center of gravity as a function of displacement. The ship's center of gravity had to lie below this curve to comply with the ABS rules.

Some other cases were considered in addition to the assessment of the intact stability of Seacrest. Water in the mud room, the shift of casing, and the top drive modification were studied for their effects on stability. The reduction of static stability due to a wave crest amidship was also analyzed. Those studies were performed in order to check the feasibility of different failure scenarios. In addition, the ABS criteria of dynamic stability were compared with those of other societies worldwide.

9.1 Loading of Seacrest on November 3, 1989

Weight of the ship was comprised of the following main items: lightship, liquids, major tubulars, bulk mud and cement, mooring system and cables, supplies and equipment, crew, and effects. Based on available documentation, each category was analyzed separately for the applicable conditions on November 3, 1989. The assumptions and the analysis for each item are further discussed. A detailed itemization is presented in Table 9.1.

The lightship of Seacrest; i.e., weight without any load or moveable equipment, was established by combining the effects of the modifications after delivery with the weight reported after the inclining experiment by the shipbuilder. The locations of longitudinal (LCG), vertical (VCG), and transverse (TCG) centers of gravity were also established based on the inclining experiment results and the modifications. Those modifications are described in Section 2.3. The referenced system of coordinates has its origin amidship of the baseline. The x axis coincides with the baseline pointing at the bow, the y axis points to port, and the z axis points vertically up.

A major reference source for the quantity of liquids on Seacrest the day of the accident was the drill superintendent's morning report. According to this document, there was 322.5 long tons (LT) (2,426 barrels) of diesel aboard on November 3, 1989. The fuel oil was primarily placed in No. 4 port and starboard tanks. There was also 136.6 LT (1,028 barrels) of mentor oil placed in No. 3 port and starboard tanks. Mentor oil has the same density as diesel oil, and is used as a constituent in mud drilling. The quantity of potable water was reported as 228 LT (1,459 barrels). Lubrication oil quantities were not reported; they were assumed equal to the ones considered by the shipbuilder [1]. The quantity of brake cooling water was taken to be 90 LT, as reported in tank sounding forms for the period just prior to capsize.

The quantity of liquid mud was established based on Millpark Chemical's report and the drill superintendent's recollections. The drill water on Seacrest served two purposes. It was used for the preparation of drilling mud and for permanent ballast. The consumable drill water was stored amidship in #5 and #7 center tanks, and in #6 port and starboard tanks. The morning report stated that 5,985 barrels (936 LT) of drill water was on board. In addition to this quantity tanks #6 port and starboard contained about 450 LT of drill water used as ballast. It was an enforced practice never to allow less than about 225 LT of drill water in each of the #6 port and starboard tanks. Drill water, transferred between tanks #8 port and starboard tanks, and 2-C-B and 10-C-B, was used for correction of list and trim, respectively. Its quantity was obtained from tank sounding forms. Drill water utilized as ballast was placed in tank #3-C, #1-CA-1, #2-C-V, #4-C-V, #8-C-V, and #9-C-V. The total quantity of the drill water used as a permanent ballast was taken to be about 750 LT. It was a policy of the operator and the drilling crew not to include the drill water used as ballast in their reports of consumables. These quantities represent a base condition for the day of the accident.

Instructions for severe weather conditions in the Operations Manual [9.1] dictated ballasting the ship with sea water. Consequently, two more scenarios were considered. One in which tank 9-6-V was full, and another in which tanks 2-C-B and 10-C-B were full. In both scenarios, the tank contents were kept the same as in the base case, except that tank 1-CA-1 was depleted. Tank 1-CA-1 did not contain a large quantity of drill water. Therefore, it was easier and faster for the captain to deplete it in order to eliminate an undesirable slack tank. The two additional cases, simulating the reaction of the captain to bad weather, yield a maximum displacement equal to 11,128 LT; i.e., below the full-load value.

Quantity and location of the major tubular joints on Seacrest were estimated from the Weekly Tubular Report, the shipment logs off and on the ship, the Eastman Cristensen Report, and the drill superintendent's recollections. Tubulars listed in Table 9.1 were stored in the forward and aft pipe racks, as well as in the derrick setback. A total of about 65 LT was assumed on the setback, consisting mainly of the stands of 5-inch drill pipe. The 5-inch drill pipes on the derrick setback were estimated to weight 56.8 LT. Additional weight on the setback was due to some heavy drill collars and equipment reported by Eastman Cristensen. The weight of 5-inch drill pipes on the setback was estimated as follows. The Weekly Tubular Report cites a total of 19,687 feet of 5-inch drill pipe on the ship. The drilling superintendent's morning report stated that the intended drilling depth was equal to 10,212 feet. The difference between the 19,687 feet total and the intended drilling depth represents the 5- inch drill pipe stored in the pipe racks. This is a conservative estimate, which yields a high weight on the setback; i.e., high above the baseline. The drilling depth on November 3, 1989, was 3,707 feet, as deduced from the morning report. This quantity of pipe was assumed lost in the hole. The difference between 10,212 feet and 3,707 feet (6,505 feet of 5-inch pipe) represents an upper bound estimate of drill pipe stands (1 stand = 3 joints) on the setback. It is interesting to note that the shipbuilder's analysis of loading conditions [9.1] considers the drill pipes on the setback to be stored as stands and not as joints. This arrangement of drill pipe, although it saves drilling time and space, results in raising of the ship's center of gravity.

The weight of bulk mud and cement was estimated from the drill superintendent's report. A total of 587.3 LT was considered on the six bulk mud and cement tanks between frames 49 and 52. The two tanks on frame 49 contained 168.7 LT of G-blend. The starboard tank on frame 50 1/2 contained 28.9 LT of Bentonite. The port tank on frame 50 1/2 contained 90.2 LT of casing blend; the two tanks on frame 52 contained 299.5 LT of Barite.

The weight of the mooring cables was estimated on the basis of an average length of 4,500 feet left on the drums of each winch. Mooring forces were also considered, since the center of their application lies above the expected final vertical position of the center of gravity. Mooring forces were included when they negatively affected the stability. The mooring forces were considered uniform, with a cable tension equal to 75,000 pounds.

The weight and location of supplies and equipment were estimated based on contractor's lists, shipment logs, and crew members' recollections.

Displacement of the basic loading condition was 10,653 LT, as shown in Table 9.1 Computed transverse center of gravity yields zero list. Computed longitudinal center of gravity yields negligible trim. This fact is a sound indication of realistic and reasonable weight distributions, since operational constraints require zero list and half a degree maximum trim angle. The cases considered in the stability assessment are listed in Table 9.2.

The fact that the ship was drifting on one anchor (#7) and had water in the mud room was also studied and included in Table 9.2. It was reported during the ship's pre-capsize radio communications that water had entered the mud room. The quantity of water is uncertain; a water height equal to 1.5 feet was considered reasonable, since it represents an average coaming height. It can be concluded from Table 9.2 that case 2, before the addition of the top drive and the tank conversions, is the least favorable from the stability standpoint.

9.2 Dynamic Stability Assessment

[tables in original document are omitted]

The ability of a ship to resist perturbations from its upright equilibrium position has been traditionally assessed by Rahola type criteria. According to this criteria, due to wind at certain angles, the restoring (righting) energy of the ship has to be 40 percent higher than the heeling energy. For a fixed displacement and vertical position of the center of gravity of the ship, a righting arm curve can be obtained as a function of the inclination angle. This curve is shown in Figure 9.1 as curve A. The area under curve A is the righting energy of the ship. Curve B is the heeling arm curve due to a disturbance of equilibrium (wind, weight, shift, turning force, etc.). The area under curve B represents the heeling energy. Curves A and B intersect at two angles, $_1$ and $_2$, which are the equilibrium angles of the ship under heeling moments. The second intercept, 2, is considered the upper bound for assessing dynamic stability. If $_2$ is greater than the downflooding angle (i.e., the angle at which water passes from one deck to the one underneath), the latter is taken as the upper limit in the evaluation of areas. ABS rules for Mobile Offshore Drilling Units [2] dictate that:

$$A + B = 1.4 \quad (B + C), \qquad (9.1)$$

where A, B, and C are the areas shown in Figure 9.1. The safety factor of 1.4 is required to account for probable computational errors and, most importantly, reduction of stability due to waves. ABS criterion requires consideration of heeling due to 100 knot steady winds, but it does not consider wave or gust effects. This type of criterion is universally and traditionally applied by the classification societies. It is based on statistical observations, and was initiated after Rahola's cornerstone doctoral dissertation in the late 1930's. Consequently, compliance of a ship with it does not warrant immunity from capsize.

Obviously, there is a limiting value of VCG, below which equation 9.1 is satisfied for a fixed displacement. Evaluation of this upper bound value for a range of displacements yields the allowable VCG (or KG) curve. This curve is always included in the operation manual of the ship and can be used for a quick assessment of dynamic stability. The captain has to determine VCG and displacement for a loading condition of interest. If the estimated VCG lies below the allowable curve, the ship satisfies equation 9.1 and complies with the ABS criterion for adequate dynamic stability.

Seacrest capsized under the action of wind and waves. Consequently, lack of dynamic stability was a prime candidate to explain the accident. The shipbuilder provided an allowable VCG curve which had to be verified before checking the loading condition the day of the accident. Two ingredients are coupled in order to produce the allowable curve, the righting (GZ) arm curve and the wind heeling arm. FaAA's in-house stability and hydrostatics code EUREKA was utilized to check the hydrostatic properties and righting arm curves reported by the shipbuilder in [3]. Very good agreement was found between the FaAA and the shipbuilder's results. On the other hand, the wind heeling arms reported by the shipyard [3], were significantly lower than the ones computed by FaAA. The heeling arms computed by the shipbuilder were about 70 percent lower.

The wind heeling arm was computed based on the ABS Rules for Building and Classing Mobile Offshore Drilling Units [2]. According to the rules, the heeling moment is given by:

$$M = P_i A_i h_i, \quad (9.2)$$

where A_i is the i^{th} projected area of the ship profile (total of n areas), h_i is the distance of the center of area from the half draft point above the baseline,
and P_i is the wind pressure given by:

$$P_i = 0.00338 V_k 2 C_h C_s,$$

where V_k is the wind velocity (equal to 100 knots), C_s is the shape coefficient accounting for different drag forces, and C_h is the height coefficient accounting for velocity increase with height.

Study of the analysis performed by the shipyard revealed the following fundamental mistakes:

1. The area of the derrick used by the shipbuilder was significantly lower (2025 ft^2 compared to 3104 ft^2 computed by FaAA).

2. The height coefficients utilized for the derrick areas were lower than the values recommended by ABS [2].

3. Areas that were part of the profile of the ship were omitted by the shipyard. For example, the bulkhead separating the divers' compound from the aft pipe rack was not included in the calculations.

4. The vertical subdivision of the derrick in the shipyard analysis consisted of three parts, compared with the six parts utilized by FaAA. The subdivision accounts for the exponential increase of wind velocity with height. FaAA's utilization of 50 foot-high areas will yield an accuracy of the order of 99.9 percent. This was concluded by comparing exact values with the ones corresponding to 50 foot averages. The shipyard subdivision resulted in an underestimation of wind heeling moments.

The ship profile utilized by FaAA for wind load computations is shown in Figure 9.2.

Two different cases were considered: 1) without the top drive, and 2) with the top drive. In the latter case, the profile was increased due to the 10 foot derrick extension at its top. The wind heeling arms as a function of the vessel draft are plotted for both cases in Figure 9.3, along with the arms reported by the shipyard [3].

The resulting allowable VCG (KG) curves are displayed in Figure 9.4. The curve computed by the shipyard was clearly a significant overestimate of the restoring ability of the ship. A magnification of the allowable VCG curve in the range of displacements pertaining to the day of the accident is presented in Figure 9.5. The centers of gravity for four cases are plotted on the same curve. The following conclusions can be drawn:

1. If the top drive modification and associated tank conversions were not performed, the loading of the ship on November 3, 1989 would not have fulfilled the ABS criterion of dynamic stability.

2. The ship satisfied the ABS criterion of dynamic stability the day of the accident, with or without emergency ballast. Clearly, this might not have been the case for a different loading condition in the past.

9.3 Failure Scenario Due to Inadequate Stability

The analysis presented in the previous section leads to the conclusion that the top drive modification improved the stability of the vessel. In fact, the modification and the associated tank conversions lowered the center of gravity by about 0.9 feet. The underestimation of the wind heeling arm by the shipyard resulted in an over-estimation of the ship's ability to resist wind. Under heeling moments with the loading conditions on November 3, 1989, the ship complied with the ABS requirements. Subsequently, failure scenarios were sought in an effort to explain the capsize.

The effect of water in the mud room was studied (Case 5 in Table 9.2). Water in the mud room would not raise the center of gravity significantly, since VCG lies at that height range. On the other hand, the mud room acted as a large center tank. The free surface correction was important, raising the center of gravity by 0.2 feet. The corrected VCG would be slightly above the allowable VCG curve in the case of no emergency ballast. Uncertainty of the amount of water in the mud room, the emergency ballast, and the exact loading condition of the ship, cannot justify lack of or marginal dynamic stability as the cause of the accident. Also, the wind velocity on November 3, 1989, at about the time of capsize, was approximately 50 rather than 100 knots. This velocity corresponds to wind heeling arms four times lower.

It was reported that the casing shifted during the storm. The effect of this weight shift, combined with a 50 knot wind, can be seen in Figures 9.6 and 9.7. The equilibrium angle of about 5° under the combined action of 10 foot casing shift and a 50 knot wind coincides with the steady list reported by the ship. Nevertheless, the equilibrium angle was not excessive and cannot justify the capsize.

Another possibility that was investigated was the reduction of stability (restoring ability) of the ship in a longitudinal seaway. This phenomenon is due to the change in the shape of underwater volume. It had been noted in 1938 by Kemph, and later quantified by Paulling, that the stability of a ship decreases with a wave crest amidship and increases with a wave trough amidship. This periodic variation of stability under the action of a 20 foot high trochoidal wave is depicted graphically for Seacrest in Figure 9.8. It can be seen that the stability of the ship is dramatically reduced with the wave crest amidships. However, evidence indicates that the predominant wave and wind direction were from the broadside rather than the longitudinal direction. Consequently, this effect could not have played any role in the capsize.

The static and "quasi-static" stability considerations presented in this chapter cannot justify the capsize. Further considerations of the ship dynamics under wind and waves described in subsequent chapters provide deeper insight into the sequence of events that led to capsize.

9.4 Comparison of ABS and Other Agencies' Stability Criteria

Seacrest was designed to the ABS Rules for Building and Classing Offshore Mobile Drilling Units, 1973 [2]. While investigating the capsizing of Seacrest, design stability criteria were of particular interest. Criteria from various maritime classification/regulation agencies were compared. The results of the study are summarized in this section.

Stability criteria from the following ten agencies were used in the comparison.

CODE	SOURCE NAME	COUNTRY	DATE
ABS-73	American Bureau of Shipping	U.S.A.	1973
ABS-80	American Bureau of Shipping	U.S.A.	1980
USCG	United States Coast Guard	U.S.A.	1987
IMO	International Maritime Organization	U.K.	1980
LLOYD	Lloyd's Register of Shipping	U.K.	1984
DNV	Det Norske Veritas	Norway	1989
CODE	SOURCE NAME	COUNTRY	DATE
NMD	Norwegian Maritime Director	Norway	1975
NKK	Nippon Kaiji Kyokai	Japan	1982
BV	Bureau Veritas	France	1987
RINA	Registro Italiano Navale	Italy	1981

In general, the stability criteria for mobile offshore drilling units (MODU's) from all the agencies were very similar; the organization of the criteria varied somewhat. In particular, sections specifying the extent of damage to be considered (for damaged stability) were sometimes included in chapters other than those dealing with stability. Criteria for ships have some differences from the general MODU criteria. In this section, the MODU criteria most commonly specified are first summarized, and the variations from the common criteria are described next.

The general stability criteria require that all units have positive metacentric height in calm water for all drafts and operating positions. In the intact condition, units should be able to withstand the overturning effect of the wind velocities as follows. A wind velocity of 36 meters per second, 70 knots, from any direction is to be used for all drafts and operating positions. For extreme conditions with storm operating positions, a wind velocity of 51.5 meters per second, or 100 knots, is to be used. In special cases, when the unit's operation is restricted to sheltered locations, a wind velocity of 25.8 meters per second, or 50 knots, may be used.

In the damaged condition, all units are to have sufficient stability to withstand a superimposed wind velocity of 25.8 meters per second, or 50 knots. The damaged condition to be considered is the flooding of any one main compartment. The extent of damage is to be 1.5 meters in the horizontal direction, upwards from the baseline in the vertical direction, and 3.0 meters in the lateral direction, with all piping, ventilation systems, etc., within this extent assumed damaged. In all cases, the final waterline should be below the lower edge of any opening through which downflooding may take place.

The wind force equation to be used is as follows:

$$F = 0.00338\ V_K 2\ C_h C_s A \quad \text{(lbs.)}$$

Dynamic stability is to be evaluated about the most critical axis, with cargo and equipment in the most unfavorable position. The ability to compensate for damage by pumping, ballasting, or using mooring lines is not to be considered. However, detrimental effects of mooring lines are to be considered. Free surface effects of liquids in tanks are to be considered.

An inclining test is required for the first unit of a design. The results from the first unit may be used for sister units, with the differences accounted for by calculations. All units are to have load line markings.

All agencies require stability curves to be prepared. Most require intact righting moment and wind heeling moment curves for the full range of drafts, with different positions of equipment that can be raised or lowered. Some agencies require additional curves. An example intact stability curve is shown in Figure 9.1. The range of the curves should extend to the second intercept, with positive righting moment over the full range up to the minimum of the second intercept and the downflooding angle. A cosine-shaped heeling curve may be assumed in most cases. The area ratio of the curves is to be follows:

$$\text{Area }(A + B) \geq 1.4 \times \text{Area }(B + C),$$

where the areas A, B, and C are as shown in Figure 9.1.

Most agencies allow results from wind tunnel and model tests to be used in place of the conventional method.

Variations from the above criteria are minimal, for the most part. The general approach to specifying stability criteria is the same; the differences are in the details.

While most agencies only require a positive metacentric height for intact stability, two agencies require specified minimum values. The USCG regulations require a minimum metacentric height of 2 inches, and the DNV regulations require a minimum metacentric height of 0.5 meters for all calm water drafts.

USCG, DNV, and NMD regulations do not allow for special wind velocity criteria for sheltered locations. In addition, DNV regulations do not distinguish between normal and extreme conditions, and the wind velocity used for stability calculations is specified as 51.5 meters per second, or 100 knots. This corresponds to the extreme conditions for other agencies. NKK regulations specify a coefficient of 1/16 (0.0625) in the wind force equation, while others use 0.0623.

BV regulations specify free surface conditions to be considered with the fuel tank nominally (95%) full and the largest tank (or pair of tanks) 50% full. Other agencies just generally specify that free surface effects should be considered.

Apart from the wind heeling moment and righting moment curves, some agencies require additional curves to be submitted. DNV and BV regulations explicitly require maximum metacentric height curves to be submitted. USCG regulations require cross curves of stability and floodable-length curves. NMD regulations also require cross curves of stability and maximum metacentric height curves.

While most agencies assume heeling moment curves to be a cosine function, the USCG regulations assume a cosine squared function for heeling moment. The DNV regulations consider the area ratio for the curves up to the second intercept, while others use the minimum of second intercept and downflooding angle. However, DNV regulations also allow non-progressive flooding in the range of heeling considered for the area ratio.

Several agencies have specific restrictions on the heel angle. NMD regulations specify a maximum heel angle in intact conditions under a steady wind of 12 degrees. DNV regulations specify a maximum heel angle in damaged condition under no wind of 15°. BV regulations specify that the maximum heel should allow the safe launching of life rafts. NMD regulations require that under maximum heel the waterline should not go above half the freeboard of the unheeled condition.

While most agencies have no specific limit, DNV regulations specify a minimum value for the second intercept of 30° with a 100 knot steady wind. NMD regulations also specify that the second intercept should be at a minimum angle of 30°, and preferably at an angle of greater than 35°.

DNV, NMD, and BV regulations require area ratios to be computed for the damaged condition as well. The criterion for the damaged area ratio is as follows:

Area (A + B) $\geq$ Area (B + C).

Figures 9.9 through 9.13 summarize the differences in criteria for the various agencies. On the whole, the differences are minimal, and ABS and other agencies criteria are very similar.

9.5 References

[1] Drillship Seacrest Operating Manual (FELS hull No. B148), Far East-Levingston Shipbuilding LTD, March 1977

[2] Rules for Building and Classing Mobile Offshore Drilling Units, American Bureau of Shipping, 1973

[3] Drillship Seacrest Hydrostatic Properties and Stability Calculations, Far East-Levingston Shipbuilding LTD, March 1977

10.0 CAPSIZE ANALYSIS FOR SEACREST

[Tables are deleted in the computer copy! Also, some of the algebraic symbols may be missing in various formulae because of editing!]

10.1 Objectives of the Analysis

One of the main goals of this investigation was the reconstruction of the events that led to the capsize. The analysis was divided into two phases. The first phase of the analysis was the study of the rigid body motions of the ship under the action of time-invariant forces due to wind, waves, and external attachments; e.g., cables and anchors, thrusters. This analysis was used to establish the most probable heading of Seacrest just before the capsize using a mathematical model. These results were compared to the heading deduced from the underwater survey of the capsize site.

The second phase of the analysis was study of the capsize under the combined action of wind and waves. In this study, only relatively small amplitude high frequency motions were of interest. They were induced by harmonically varying wind and wave forces, and were superimposed on the rigid-body motions at the instantaneous ship position. The methodology of analysis and the conclusions of both studies is described next.

10.2 Description of Drag Course and Heading Model

Under the action of steady forces, the ship will perform rigid body motions. The ensuing motions are expected to be large-amplitude, low-frequency oscillations decaying with time towards a steady-state value due to the presence of hydrodynamic damping. Three degrees of freedom are needed to describe the motions, surge, sway, and yaw. The system is governed by the following equations of motion:

(m + msu)=Fxsurge(10.1)

(m + msw)=Fysway(10.2)

(I + Iyw)=Myaw,(10.3)

where msu, msw, and Iyw are the hydrodynamic added masses in surge and sway, and yaw added mass moment of inertia, respectively. I and m are the mass and yaw mass moment of inertia of the ship, respectively. The local surge and sway velocities are u and v, respectively. Two different systems of coordinates, a local (body fixed) coordinate system and a global one, are defined as shown in Figure 10.1. The two systems are interrelated by typical rotation relations. Those are defined on the basis of the yaw angle, q, and the measured orientation of the anchor #7 drag marks. The drag marks determined by the side scan sonar yield an angle equal to 50° with a north to south line. Consequently, equations (10.1) to (10.3) are augmented by the following relationships:

=ucos (+ 50) - vsin (+ 50)(10.4)

=usin (+ 50) + vcos (+ 50),(10.5)

where X and Y are the global coordinates of the ship.

Fx, Fy, and M represent the sums of forces in the local x and y directions, and the resultant moment around the vertical axis (yawing moment), respectively. The hindcast weather model results were utilized to provide input parameters for the determination of the forces and moments. Table 10.1 presents the hindcast weather data just before the capsize. Based on a multidirectional wave spectrum, Hs is the significant wave height. Similarly, wave is the angle of highest wave energy concentration. After the passage of the typhoon, the sea was confused due to inertial effects. Wind and wave propagation directions were not colinear. A wave propagation direction cannot be defined clearly. An average, or most probable, wave propagation direction is represented by wave . The weather parameters in Table 10.1 represent 15 minute averages and do not reflect instant variations such as wind gusts. It can be deduced that, for a 45 minute interval, the average weather parameters remained essentially constant. The steady forces and moments can then be determined on the basis of those constant values. The contribution of each environmental factor will be further discussed.

Table 10.1

HINDCAST WEATHER DATA BEFORE CAPSIZE

Local	Hs	wave	Vwind	wind	Vcurrent	Current
Time	(ft)			(Knots)		(Knots)
1300	16.0	129.6°	54.0	158.6°	0.5	45°
1315	15.7	132.6°	54.2	156.6°	0.5	45°
0133	15.6	134.1°	54.5	156.2°	0.5	45°
1345	15.4	136.5°	53.2	159.2°	0.5	45°

10.2.1 Wind Forces

The wind forces were evaluated on the basis of the methodology set forth by ABS [1]. In general, the wind forces computed by the semi-empirical ABS method agree very well with wind tunnel measurements for zero heel angles. Two different wind directions were considered, broadside wind and wind from the bow. The resulting forces were:

Wind from the Bow:

F = 26.4 V2 (77,000 lbs. for V = 54 knots)

Broadside Wind:

F = 55.9 V2 (163,000 lbs. for V = 54 knots)

For a yaw angle, , the wind forces will be:

Fore and Aft Directions:

$Fwx = 26.4 V^2 \cos(+ 28°)$ (10.6)

Starboard to Port:

$Fwy = 55.9 V^2 \sin(+ 28°)$ (10.7)

Both expressions were derived on the basis of an average wind direction equal to 158°.

10.2.2 Wave Drift Forces

The wave drift forces are due to net mass transport present in real life waves. They represent higher order or nonlinear contributions. The wave drift forces consist of steady (time invariant) and oscillatory components. Only the former will be considered for the rigid body motion study. The American Petroleum Institute (API) has issued a directive (API RP 2P) for the design of mooring systems. The technique recommended for the computation of wave drift forces was followed.

The mean drift force for Seacrest in beam seas is given by:

FDY = 514.4 Hs2 (123,600 lbs. for Hs = 15.5 feet).

The mean drift force due to bow or stern seas may be evaluated by:

FDX = 78.4 Hs2 (18,800 lbs. for Hs = 15.5 feet).

For a yaw angle, , the wave drift forces are given by:

FDX = 78.4 Hs2 cos (10.8)
FDY = 514.4 Hs2 sin . (10.9)

Both expressions were derived under the assumption of a dominant wave direction equal to 130°.

10.2.3 Current Forces

The wind current velocity during the time of capsize was very low, and the current forces were expected to be very low compared with the ones from other environmental effects. Application of the API directive yields a force equal to 140 pounds, due to the bow current and a force equal to 3470 pounds due to a beam current. Those forces are much lower than the ones induced by wind and waves. Consequently, they can be neglected without any loss of accuracy.

10.2.4 Hydrodynamic Resistance

The main component of the hydrodynamic resistance was the one induced by friction. This is a function of Reynold's number; i.e., ship velocity and the wetted surface of the ship's hull. Resistance in surge was determined on the basis of the ITTC friction coefficient. The wave-making component of surge resistance is negligible at the low drift velocities of Seacrest. Resistance in sway can be estimated by considering the ship as a low-aspect-ratio hydrofoil. The formulation followed by Hooft [2], under the same assumption, yields for the sway resistance

$FHY = 0.15\ ru^2\ LT,$ (10.10)

where L and T are the length and draft of the ship, respectively.

10.2.5 Thruster Forces

Seacrest was equipped with two thrusters that could deliver 700 HP per thruster at 1000 revolutions per minute (RPM). These thrusters were manufactured by Schottel. It can be deduced from the thrust/speed curve provided by the manufacturer, and presented in Figure 10.2, that the ship could not exceed a speed of 8 knots when self-propelled and could not obtain a thruster force more than 17.4 LT per thruster. The thrusters could rotate from 0 to 360° and provided auxiliary maneuverability. They were not meant to provide self-propulsion and turning capacity under severe weather conditions such as those encountered on November 3, 1989.

Thruster forces were modeled as linear functions of ship speed, according to the manufacturer's thrust/speed curve. The angle, , that the thrusters formed with the centerline constitutes another unknown quantity and will be considered an input parameter.

10.2.6 Cable Force

Based on evidence and post-accident discovery, it has been established that Seacrest was drifting towards the northwest, as shown in Figure 10.1, dragging anchor #7. The force exerted by the cable on Seacrest varied with time. High-cable tension will tend to pull the ship to the southeast. When the cable slackens, the cable tension is reduced until the cable starts to become taut again. This cyclic increase/decrease of the cable tension was repeated continuously. The exact value of the cable force can be deduced based on soil mechanics principles to justify anchor dragging. In the mathematical model, constant values of cable tension were considered. Those values were assumed to be between 125,000 and 145,000 pounds. The upper bound of the cable tension was deduced on the basis of the ship going to the northwest; i.e. in general, the cable resistance was lower than wind and wave forces. The lower bound was established based on the total drift distance, since low cable tension values result in high drift distances (above the 3,300 meters measured from the pipeline to the capsize location).

10.2.7 Yawing Moment Computation

The computation of the yawing moments was straightforward after the surge and sway forces were determined. An important observation was that the point of application of the wind forces (center of aerodynamic pressures) and the point of application of the wave drift forces (center of hydrodynamic pressures) varied with time. The location of the aerodynamic and the hydrodynamic pressure centers depends on the angle of attack of the wind and waves. Ranges of centers of pressure for ships similar to Seacrest are presented in Figure 10.3. The mathematical model utilized a theoretical relationship from [2] for the definition of the position of the centers.

$$e = 0.33\ L\ (1 - /90), \qquad (10.11)$$

where e is in the wind or wave force arm and is the angle of attack of wind or wave.

10.2.8 Yaw Damping

A certain amount of damping moment due to sway (Nv) and yaw (Nr) is always present, as depicted graphically in Figure 10.4. Asymmetry of the fore and aft parts of the ship with respect to the midship plane results in unequal distribution of the hydrodynamic resistance in sway. A net yawing moment, Nv, will result as is shown in Figure 10.4. In addition, the resistance due to yaw will be a function of the distance from the centers of rotation. A net yawing moment, Nr, will result due to this functional dependence. The values of Nv and Nr utilized were obtained from PNA, [3], based on the basic geometry of the ship.

10.2.9 Model Verification

The validity and robustness of the mathematical model was assessed by a simple case. Seacrest was subject to the action of wind only. In the absence of resistance provided by cables and/or thrusters, the ship should have reached a final equilibrium position with the wind from the broadside. This is the physical tendency of all bodies in the path of a free stream. The reasons for this tendency are shown in Figure 10.5. When the body equilibrates broadside to the free stream, there are two stagnation points, S: one upstream and another downstream of the flow. A slight perturbation of this equilibrium position will move the stagnation points (points of higher pressure) in such a way that a restoring couple is developed. The opposite is true when the body is placed in a streamline fashion with respect to the flow.

The resulting motions and final equilibrium position of the ship, under the action of wind only, are shown in Figure 10.6. The steady angle between the cable and ship centerline was equal to 62°. The angle between wind and cable was 28°, assuming 158° wind direction and 130° as the direction of the drag marks. Consequently, it can be deduced from Figure 10.1 that the predicted angle between the ship centerline and the wind was 90°; i.e., the model is physically robust.

10.2.10 Results

The effect of each environmental parameter on the ship response was considered separately. Seacrest was subject to the combined action of wind and waves with its thrusters in operation, but without the resistance provided by cable #7. It can be seen in the results shown in Figure 10.7 that the ship equilibrated almost broadside to the wind. The final equilibrium angle between the ship centerline and the cable was equal to 65.4°. It is then concluded that wind forces have a dominant effect, and the thrusters do not provide sufficient resistance to turning broadside to the wind.

If a cable tension equal to 125,000 pounds was applied to Seacrest, the centerline would form an angle equal to 22°, with the cable at the equilibrium position (Figure 10.8). Consequently, the ship would form a 50° angle with the wind. The cable was extremely effective against broadside to the wind equilibrium.

If the ship was subject to wind and waves only, it would oscillate through an angle of 45° around broadside to the wind equilibrium; a steady heading was not reached for the values of damping considered in this model (Figure 10.9).

The sensitivity of the response was subsequently assessed for varying thruster angle . The resulting yaw oscillations are presented in Figures 10.10 to 10.17. The following conclusions can be drawn:

1. The ship will perform large-amplitude, slowly varying (2.5 to 3 minute period) oscillations. This result is consistent with other results reported in the literature.

2. The ship may reach a steady equilibrium angle, depending on thruster angle .

3. For thruster angles between 180° - 360°, the ship oscillates to the port. For thruster angles between 0 - 180°, the ship oscillates to the starboard. Survivor testimony confirmed that the wind just before the capsize was coming from the starboard. Consequently, the ship had to oscillate to the starboard side.

4. The amplitude of the oscillations increases significantly as the thruster angle, , deviates from 0 to 180°.

5. The slowly varying oscillations might reach or exceed 90°. During the oscillation, the ship would be subject to beam winds and waves. An underwater survey of the debris at the capsize location has yielded a ship heading almost normal to the drag marks. This is verified by the mathematical model. The ship can reach an angle of 90° with respect to the cable due to its oscillatory, slowly varying yaw.

The position of the ship for thruster angle equal to 0°, 30°, and 45° is presented in Figures 10.18, 10.19, and 10.20, respectively. It can be concluded that deviation of the thrusters from the centerline will increase the fishtail-type motion of the ship, as well as reduce the drift distance.

The effect of the cable tension on the yaw oscillations can be observed in Figures 10.21 and 10.22. Increasing of the cable tension by about 20 percent will almost halve the final equilibrium angle between cable and ship centerline. The increase in cable tension is not as effective, though, in decreasing the amplitude of the initial oscillations.

The position of the thrusters raised a number of questions, since they were found facing in opposite directions after capsize (Figure 10.23). The major question was whether this configuration was intentional or a consequence of the capsize. It was obvious from the direction of the thrusters, as found after the accident, that their configuration would have increased the angle of the ship with the wind. The ship would have been more broadside to the wind. It would not, therefore, have been a recommended configuration. On the other hand, comparison of the response of the post-accident configuration with the responses for = 0° and = 45° (Figure 10.24) reveals that the post-accident position of the thrusters yielded almost comparable response with the one for = 0°. A comparison of all possible perturbations from the accident configuration, shown in Figure 10.25, yielded only one more favorable configuration of the thrusters; i.e., one which would have resulted in less broadside to the wind equilibrium.

The most favorable thrusters position for the pre-capsize conditions was the one with = -135°. In this case, the direction of the thrust had two synergistically beneficial effects. It reduced the starboard oscillations and increased the resistance to wind and waves. It can be seen in Figure 10.17 that this configuration resulted in an equilibrium angle of about 12° between cable and ship centerline; i.e., the less broadside position.

The conditions assumed in the model were static. The weather variability considered was minimal. In practice, continuous changes of the thruster position may have been necessary in order to respond to continuous changes of weather parameters.

10.2.11 Conclusions

The main objective of the capsize analysis was to determine why the ship capsized. It was established that Seacrest encountered unusually severe weather for an extended period of time and finally capsized. It was also proven that the ship fulfilled the requirements of dynamic stability set forth by ABS. Survivability of Seacrest was studied and assured under 100 knot winds. The loss of this drill ship was one more proof that compliance with the ABS dynamic stability criteria (followed by all other classification societies) does not provide automatic immunity to capsize. The main reasons were the decoupling of the effects of wind and waves and the oversimplification of the problem to a static rather than a dynamic one.

10.3 Risk Analysis

Two positions of the ship, with respect to the waves, encompassed a high risk of capsize. One was the ship riding a wave crest amidship, due to the dramatic reduction in stability explained in Chapter 9. At the same time, a high heeling moment was needed to lead into capsize. This fact implies that the directions of propagation of wind and waves were different by about 90°. Since waves are driven by the wind, they normally propagate in the same direction. However, if the wind is variable in space and time, as in the case during a tropical cyclonic storm, the response of the waves is delayed due to inertial effects. Consequently, the average wave and wind propagation directions did not coincide, but they were close to each other before capsize.

A graphical representation of the ship heading and the hindcast wave and wind propagation directions is presented in Figures 10.26 to 10.29 for four time instants. It can be seen that waves propagate from more than a 180° arc. The length of the arrows in the figures is proportional to the spectral wave energy content for each direction in 15° increments. The plots indicate an increasing tendency of the wind and average wave propagation directions to reach each other, up to the time of capsize at 1350. At the same time, the wind velocity and wave spectral energy increased. Seacrest also tended to align herself more broadside to the wind towards the capsize time. The mathematical model described in the previous section and the physical evidence indicated that the most probable position of the ship during capsize was almost broadside to the wind. Beam winds were more detrimental to Seacrest than waves were. The reason is that the tall derrick amidship resulted in a high roll mass moment of inertia, which made it more difficult to roll the ship under beam waves. At the same time, the derrick increased the profile of the ship. Thus, the force and heeling moment due to the beam winds were increased.

The risk of capsize in beam winds can be assessed by three different parameters. The significant wave height and wind velocity are shown plotted in Figures 10.30 and 10.31, respectively. The hindcast weather data accurately reflect the continuous worsening of the weather just before the typhoon passed over Seacrest; the subsequent relative calmness while the ship was inside the eye of the typhoon; and, finally, the worsening of weather after the ship got out of the eye. It is interesting to note that Seacrest encountered the worst weather conditions before its capsize, and yet it survived. The dominant (average) wave and wind directions, as well as their relative angle, , between them are presented in Figure 10.32. It has been observed that as wave and wind propagation directions approach each other, the risk due to beam winds and waves increases. Consequently, the risk or severity function, RF, of capsize in beam winds can be defined as:

RF = . (10.12)

The values of risk function RF, defined by equation 10.12, between 0900 and 1500 are plotted in Figure 10.33. The plot reflects the fact that the risk of capsize increased as the eye of the typhoon was about to pass over Seacrest. The risk went down, almost to zero, while Seacrest was inside the eye, and reached a maximum value at 1330, just before capsize. The risk theory described above is a confirmation of the need for synergistic action of the risk parameters. Wave height, wind velocity, relative wind, and wave angle have to occur at the proper combination. The risk function as defined in equation (10.12) is indeed a realistic means of assessment of capsize risk.

10.4 Frequency Domain Analysis

The objective of the study is to analyze roll motion of the Seacrest when under the action of the winds and waves from the beam direction. Traditionally, in seakeeping problems like this one, naval architects apply the so called "strip theory" to study the ship motions under standardized wave spectra. The motions of interest here were high-frequency (fast varying) ones, and should not be confused with the ones described in the previous sections.

The wave (weather) input of the analysis was generated by the hindcast weather model, and it is presented in the form of wave energy content (spectral density) as a function of frequency for every direction from 0 - 360° in 15° increments in Figures 10.34 and 10.35. It is clear that the differing wind and wave propagation directions at the time of capsize does not allow simplification of the spectrum through the use of cosine square or similar spreading functions.

The FaAA in-house seakeeping code SHIPMO was modified to accept a general multidirectional wave spectrum. SHIPMO will compute the statistics (significant, root means square, and average values, etc.) of the ship response to the input spectrum. Our interest was focused on the roll response, since it was the mode of failure.

SHIPMO is a general-purpose seakeeping code, based on some basic assumptions of twodimensionality (ship theory) and linearity (frequency domain). The major parameter in roll response problems is the viscous roll damping. Typically, the determination of roll damping involves the examination of the individual mechanisms that lead to damping. Both experimental and theoretical considerations are involved. In the case of Seacrest, there were many mechanisms that would induce very high roll damping: its high beam-to-draft ratio and boxlike shape, the bilge keels, the skeg, the moonpool, and the overhanging riser. The analysis was performed by defining a range of damping ratios as percent of critical rather than computing roll damping. The values defined ranged from 3 to 10 percent of the critical damping ratio. Due to its built-in anti-roll devices, Seacrest had a roll damping ratio equal to at least 10 percent of the critical.

The resulting roll amplitudes as functions of wave frequency and damping ratio are presented in Figure 10.36 for a 20 foot beam wave. It can be seen that the roll amplitudes are low, even at harmonic resonance conditions for the most likely 10 percent damping ratio case. The natural frequency of roll for Seacrest was about 0.45 rad/sec. A wave of that frequency yields the maximum roll amplitude. The roll responses weighted by the multidirectional wave spectrum, over the whole frequency range, yield the roll response spectra shown in Figure 10.37. The significant value of roll is less than 5° in all cases. This represents the average of the one third maximum roll responses.

The roll response of Seacrest due to waves alone was low, because of the following facts:

1. The ship had a high roll mass moment of inertia due to the presence of the derrick. Placement of a large mass high above the baseline dramatically increased the inertia of the ship. The roll gyradius of Seacrest was at least 40 percent of the beam of the ship.

2. The ship had many built-in anti-roll mechanisms that led to high roll damping.

3. The dominant wave frequency (modal frequency) prevailing at the time of the accident was far from the natural frequency of roll. It can be concluded from Figure 10.38, which represents the wave energy content as a function of direction for different wave frequencies, that the modal frequency was around 0.73 rad/sec.

The roll responses presented so far have been only those that were under the action of waves. In addition, there are other simplifying assumptions in standard frequency domain codes like SHIPMO. The most important one is that the shape of the submerged volume of the ship does not change. Consequently, it is assumed, in the context of linear theory, that the restoring capacity of the ship does not change as it heels. This assumption is valid for low responses, but becomes critical for severe seas.

It has been stated that beam winds were more detrimental than beam waves on Seacrest. A study was made on the effect of the prevailing beam winds on roll. A typical Kaimal-type wind spectrum was defined for wind velocity of 55 knots (prevailing before capsize according to the hindcast weather model) and gustiness defined by the hindcast weather data. The Kaimal spectrum is shown in Figure 10.39. The wind heeling moment can be written in general as:

$$M = C\,(V + Vg\ \mathrm{sint})^2, \qquad (10.13)$$

where C is a constant; V is the steady wind velocity; is the wind gust frequency, assuming harmonic variation; and Vg is the wind gust velocity amplitude. The assumption of harmonic variation of the wind turbulence is a legitimate one, since any type of gust can, in general, be analyzed in its Fourier series components. Equation (10.13) can be further written as:

$$M = CV^2\,(1 + 2\ \mathrm{sint} + ()^2). \qquad (10.14)$$

If we assume that the gust velocity is, for example, one fourth of the steady wind velocity, it can easily be deduced that the last term on the right-hand side of equation (10.14) is eight times lower than the first term, whereas the second term could be two times lower. Consequently, the last term of equation (10.14) can be dropped as a higher-order term. The remaining linearized expression of the wind heeling moment lends itself to the idea of linear response and energy spectra. Computation of the roll response amplitude operators for unitary gust winds and utilization of the Kaimal wind spectrum yield the roll response spectra due to gusty beam winds. The significant roll response due to gusty winds is about three times higher than the one imposed by waves.

The combination of wind and wave action can lead to capsize. Unfortunately, a linear frequency domain analysis cannot yield quantitative results, since the wind and wave responses cannot be added algebraically. They cannot be considered to be acting synergistically; the phase angle between them is unknown. A more sophisticated mathematical model is needed to account for continuous variation of restoring capacity and to consider the simultaneous action of wind and waves. Such a model is described in the next section.

10.5 Nonlinear Roll Response

The linear wave or wind response model cannot yield a quantified prediction of capsize. A more accurate mathematical model of roll under the action of the beam waves and/or beam winds was derived. This model relied on numerical techniques (Runge-Kutta) for time integration. Consequently, it accounted for nonlinear effects that the model described in the previous section could not address. The equation of motion in roll can be written in general:

$$(I + Iy)\ R + bR + \ GZ(R)\ R = MEXT\ (t) - I\ , \qquad (10.15)$$

where I is the roll mass moment of inertia, Iy is the added roll mass moment of inertia, b is the roll damping (taken as equal to 10 percent of critical), and is the ship displacement. GZ is the restoring arm that changes with the angle of heel. The GZ dependence on heel has been derived by the hydrostatics code for a given displacement and a given vertical position of the center of gravity. The condition involving water in the mud room was chosen to represent the conditions before capsize.

In a local system of coordinates, R is the relative angle of roll, i.e., the roll with respect to the waves. This local system is defined by the tangent on the wave elevation and its normal, as shown in Figure 10.40. If the wave slope is denoted by , then the absolute roll angle, , is given by:

= + R. (10.16)

The fundamental assumption in the derivation of equations (10.15) and (10.16) is that the breadth and the draft of the ship were very small in comparison with the length of the impinging wave. In this case, variation of the wave curvature over the breadth of the ship can be neglected, and a fixed value of the wave slope can be defined. MEXT represents the time-varying heeling moment due to a gusty wind. There is no limitation on the algebraic form of this moment. In this model MEXT is given by:

$$MEXT = Mo [1 + Csin (2 (t - to)/T)]^2, \qquad (10.17)$$

where Mo is the steady wind heeling moment, C is the gust factor, to is the time when the harmonic gust started, and T is the duration of the gust. C can take values up to 0.5, i.e., instantaneous wind velocities can be 50 percent higher than the sustained ones.

Several cases were considered in the analysis. In all cases, a beam wave 32 feet high was acting. The height of 32 feet is based on the statistics of the extremes, which dictate that the maximum long-term value observed in a Gaussian process (like the sea elevation) is about twice as high as the significant one. The hindcast significant wave height was 16 feet. Consequently, in this study the most extreme wave was considered. Note that Ochi's short-term extreme could yield a little bit higher wave, but in general 32-foot waves are consistent with eyewitness testimony that the waves reached the helideck.

The period of the wave was taken almost as equal to the natural period of roll. This is an extremely conservative assumption, since it represents the worst possible wave. On the other hand, it has been explained in the previous section that the probability of encountering waves of their period was low. Of course, in the nonlinear model represented by equation (10.29), the natural period changes continuously in time, since GZ (i.e., the system stiffness) depends on the roll angle. A wave with a period close to the natural period of roll has a length of about 814 feet. Correction factors to account for wave curvature are close to unity; i.e., equations (10.15) and (10.16) are valid.

In the first case considered, the ship was subjected to the beam wave only. The roll response for this case is depicted in Figure 10.41. The roll amplitude is about 20°, but the ship will not capsize.

In the next application, a steady 54 knots beam wind was added. It can be concluded from the results shown in Figure 10.42 that the addition of a steady wind did not change the amplitude of roll oscillation of the previous (wave-only) application. It only shifted the equilibrium (mean) position to the port side.

The results for a gusty wind with a gust duration equal to 15 seconds are shown in Figure 10.43. The gust had been initiated at such a time as to act synergistically with the 32 foot high wave. The model does not predict capsize. The same gust was subsequently applied, but its duration was increased to 20 seconds. As it is shown in Figure 10.44, these conditions led to capsize in about two cycles of rolling. An increase in the gust duration led to capsize.

A 15 second long gust was combined with a wave whose period was closer to the natural period of roll (defined in the vertical position). As it is shown in Figure 10.45, this condition also leads to capsize.

The detrimental effects of an impulsively applied heeling moment were explored by studying the case of a suddenly applied gust. In this application, a wind heeling moment with a gust of 15 seconds duration was suddenly applied while the ship was at its extreme starboard position. It can be concluded from the results presented in Figure 10.46 that the ship will capsize in less than a cycle.

The mathematical model presented so far can be further refined by considering the change of displacement due to heaving and/or the change of density due to alternating on a crest or a trough of a wave. Nevertheless, the nonlinear model presented leads to the following important conclusions.

1. Steady wind and/or waves of forces observed during the typhoon were not sufficient to capsize the ship.

2. Turbulence (i.e., gustiness) of the wind was the major contributor to the capsize. Gustiness has detrimental effects. The study has proven that the gust had to be combined with the proper wave, act at the proper time, and be of certain duration and intensity in order to lead to capsize. In all cases considered, the gust factor was equal to 0.5. The ship, in general, did not roll heavily (consistent with survivors' testimony). The proper combination of the natural elements occurred at 1350 and the ship capsized. The random nature of gusts justifies the capsize at 1350 and not earlier.

11.0 SEARCH AND RESCUE

The Search and Rescue (SAR) effort began on November 3, 1989 and continued at sea through November 12, 1989. Several organizations participated in SAR, including the Thai Fishing Association, The Royal Thai Navy and Unocal. The Royal Thai Navy and Thai fishermen were directly responsible for rescuing six survivors of the Seacrest incident. Four of the survivors were adrift until November 5, 1989, at which time they were rescued by Thai fishermen. The remaining two survivors were rescued by the Royal Thai Navy on November 6, 1989. During the course of the SAR effort, Unocal directly assisted or rescued several Thai fishermen, who were also victims of the storm.

The SAR effort consisted of several parallel efforts which were directed by the Emergency Control Center in Bangkok, and the Marine Controller on Satun LQ. During the early phase of the effort, through November 6, 1989, the boats pattern searched areas which were adjacent to Platong field. The helicopters searched on radials which extended out from the overturned Seacrest and progressed outward as areas closer to the Seacrest were covered. The effort was concentrated in the northeast and northwest quadrants.

After November 6, 1989, Unocal was aware of the approximate location, in the northwest, of the bodies and began pattern searching the area. Helicopters began flying out of Surat Thani, Coastal Thailand, which resulted in more efficient use of flight time. The helicopters mainly assisted by sighting objects and then by directing search boats to the appropriate position.

Unocal pursued searching the coastal provinces based on reports of additional survivors and casualties of Typhoon Gay. Problems with communications and logistics were experienced, since Typhoon Gay had disrupted the infrastructure of the coastal provinces.

11.1 Organization

Unocal Thailand is a major supplier of natural gas to the Thai government. This natural gas is recovered from several gas fields which require continual exploration, drilling, production and maintenance support. In order to meet these requirements, Unocal has developed an intricate network of systems which assure continuous production. Many of these systems are located offshore in the Gulf of Thailand, approximately 240 nautical miles south of Bangkok. These offshore facilities include three central processing platforms, a condensate storage facility and living quarters for the numerous personnel. People, operations materials and all supplies are transported in and out of the field by support vessels and helicopters. In addition to the fixed facility/platform logistic requirements, the mobile construction/drilling vessels require support.

The following discussion of the Emergency Control Center staff and Offshore staff is not designed to provide a complete overview of the Unocal Thailand organization. It is, however, the intention that the reader become familiar with the varied responsibilities.

11.1.1 Field Staff

Each of the four major operations groups, Logistics, Drilling Department Operations, Production Department Operations, and Construction Operations, have offshore staff which report to the onshore manager. All of the fixed platforms and drilling barges/tenders are supplied and supported by support vessels and helicopters. Both the support vessels and helicopters are under the direction of the Logistics group, which includes the Onshore Marine Coordinator and the Offshore Marine Controller. On the contracted barges/tenders, Unocal maintains a company representative, "company man," who oversees operations. For the period during the storm the areas of responsibility and the reporting relationships are shown schematically in Figure 11.1.

11.1.2 Emergency Control Center Staff

The Emergency Control Center was organized at approximately 1000 November 3, 1989, and located in the tenth floor conference room across from the radio/telex room in Unocal's Bangkok Headquarters. The center was staffed as outlined in the Emergency Procedures Manual with the objective being to provide assistance to offshore staff. The center was equipped with communications equipment, maps, drawings and status boards [1]. The initial staff and their associated responsibilities are given in Table 11.1.

Table 11.1

EMERGENCY CONTROL CENTER STAFF [1]

Rich Keller	Onshore Emergency Coordinator
Alex Forbes	Bangkok Logistics Coordinator
Mike Majer	Marine Control Coordinator
B.Davis/C. Perry	Drilling Department Operations
R. Nordquist/C. Costelloe	Production Department Operations
Danny West	Communications Operations
Ian Lippiat	Construction Operations
T. Muir/K. Bradley/B.Roethke	Assistance

The center was provided with dedicated phones, each for a specific purpose. These are detailed in Table 11.2.

Table 11.2

DEDICATED PHONES [1]

Press/Public Relations
Marine Management/Marine Controller
Emergency Coordinator/Offshore Facilities
Bangkok Logistics Coordinator/Unocal Songkhla
General Use by Other Support Functions

Maps of the fields and the Gulf of Thailand were mounted on boards in the center. Details of the effort, including the position, description, and the party that sighted survivors, casualties or debris, were recorded on these display boards. Drawings of the Seacrest hull were maintained and updated with information as it was obtained from the divers. In addition to these maps and drawings, various status boards were maintained. These contained the information which was recorded on the maps, but in tabular form. The status boards were updated on a daily basis and were later transcribed into the Emergency Control Center log [1].

11.2 Communication

11.2.1 Routine Internal Communication

Bangkok Headquarters (HQ) has a radio room that is equipped with several systems for communicating with offshore facilities, offshore vessels (drill barges/tenders and support vessel), and Songkhla Base. The systems, which are maintained by the Bangkok radio room, are shown schematically in Figure 11.2.

Bangkok HQ and Songkhla Base are linked by channels leased from the Telephone Organization of Thailand (TOT), which are part of Unocal's telephone network (shown schematically in Figure 11.3); an undersea cable leased from the Communications Authority of Thailand (CAT) and used for data transmission; and, High Frequency Single Sideband Radio (HF SSB Radio). The CAT and TOT links for Unocal, Thailand, Ltd. are shown in Figure 11.4

Bangkok HQ and Songkhla have several links with the main offshore facilities. These main facilities are Platong Living Quarters (LQ), Satun LQ, and Erawan LQ. Telephone, telex, and FAX linkages are part of Unocal's telephone network and are maintained over the CAT DOMSAT (satellite link) leased channels. This link is part of the internal communication network shown in Figure 11.4. HF SSB Radio also links Bangkok HQ, Songkhla Bases, and the main offshore facilities.

In addition to the telephone network (FAX and Telex) and HF SSB Radio, the main offshore facilities have marine VHF radios for communication with helicopters and support vessels. Figure 11.5 details the communication systems available offshore.

The Marine Controller's office is located on Satun LQ and is equipped with telephone, HF SSB Radio, and marine VHF radio. This allows the Marine Controller to communicate with onshore facilities, offshore facilities, drilling barges/tenders, boats, and helicopters.

11.2.2 Emergency, Internal Communication

Four dedicated telephone lines were provided for use by the Emergency Control Center staff. These were functional at 1030 November 3, 1989. They securely linked:

- the onshore Emergency Coordinator with offshore facilities;
- the onshore Marine Management with the offshore Marine Controller; and,
- the Bangkok Logistic Coordinator with the Songkhla Base.

The others were used for by support functions and public relations [2].

At 1319 on November 3, 1989, the microwave system linking Platong and Satun fields was interrupted by the loss of the Platong primary antenna. The communication link was restored at 2015 on the same day [2].

The TOT lines connecting Bangkok HQ and Songkhla were interrupted at 1130 November 4, 1989. The TOT lines are shown in Figure 11.6. In an effort to restore voice communication between Bangkok HQ and the Songkhla Base, Unocal converted the CAT undersea cable to voice transmission. This cable is shown in Figure 11.6. This link is normally used by Unocal for data transmission only [2].

HF SSB Radio was used to monitor the Thai Fisherman Association's frequency after 2200 November 5, 1989. Both Bangkok HQ and Platong LQ monitored this frequency [2].

At 1100 on November 8, 1989, a CAT-leased satellite link between Songkhla Base and Erawan LQ was placed in service. Another line for data transmission was added at 1700 November 9, 1989. These links were being start-up tested prior to the typhoon [2]. Both are shown in Figure 11.6.

11.3 Chronology of Events Related to Search and Rescue

This chronology is intended to draw together the elements of Search and Rescue (SAR). The individual elements (support vessels, helicopters, and land search parties) are treated separately in a subsequent section (11.4 Searches). Section 11.4 references charts of the Gulf of Thailand which include the areas searched for each day of the effort. These charts, Figures 11.7 through 11.15, may be useful when reading this chronology.

November 3, 1989

1330 Until 1700

At 1330, the eye of the typhoon was centered at approximately 9°40N 101°20E, which was approximately 4 nautical miles from the pre-storm Seacrest location. Winds near the eye of the storm were 60 knots, with gusts up to 90 knots.

The last known contact with Seacrest was made at 1326, and was between the Marine Controller and the "company man" aboard Seacrest [3]. The "company man" stated that anchor cable #1 was broken, cable #7 was not broken as reported earlier, and that cable #4 and #5 were slack [4].

After 1326, no other contact was made with Seacrest. Efforts to contact Seacrest by handheld Marine VHF Radio from Platong LQ failed. Handheld Marine VHF was used earlier to contact Seacrest when the HF SSB radio and Marine VHF base station had failed due to a loss of power (from 0950 until 1040) from the ship's electrical generator. At 1400 Pacific Scimitar confirmed that contact with Seacrest was lost [5]. At 1455 the Erawan LQ recorded in its radio log that communication was interrupted [6].

At 1458, the Marine Controller contacted Platong LQ and inquired whether they could contact Seacrest; their response was , "No, have been trying" [3].

Gray Guard reported at 1530 that, "strbd (starboard) main engine O.K.," and was then ordered to proceed to the Seacrest location [7]. At 1643, the Marine Controller asked the Gray Guard to search for Seacrest using radar. The Marine Controller then tried to contact Seacrest and responded, "no joy (cannot make contact)" [3].

At 1650 Erawan LQ radio operators recorded, "still lost contact," when trying to contact Seacrest [6].

<u>1700 Until 2000</u>

Once the weather began to moderate, support vessels closer to the pre-storm Seacrest position were requested by the Marine Controller to search for Seacrest using radar. At 1718 Gray Guard reported, "...6 echoes on radar not 7" [3]. This was confirmed by Westertor at 1745, "...Seacrest is no longer seen on my radar..." [8]. At 1530 Gray Guard was ordered by the Marine Controller to proceed to the Seacrest location [7]. At 1800 Westertor was dispatched to the pre-storm Seacrest location by the Marine Controller [8].

At 1820, Platong LQ reported seeing, "...flash light at the vicinity of 'PWC'" [9]. This report was substantiated in both the Erawan LQ and SSB radio logs [6, 3]. It was suspected that the light was from Seacrest.

At 1910, a Marine Controller contacted Avonlake and asked the master, if possible, to proceed to the pre-storm Seacrest location. Shortly thereafter, the Marine Controller contacted Avondale, Avonpark, and Gray Sword, asking them also to go to the pre-storm Seacrest location [4]. All of them managed to turn their vessels and proceed.

At 1930, a conversation between someone from the Royal Thai Navy and the Platong LQ radio operator took place. The pre-storm position of Seacrest was given [9]. At 1957 Platong LQ recorded that a Royal Thai Navy "warship" was in the field [3].

While en route to Seacrest, Westertor reported seeing a fishing boat on radar at 1944 10 miles south of Platong [3]. At 1945 Westertor communicated that they could not see Seacrest visually or by radar [10].

<u>2000 Until 2400</u>

Avonlake arrived at the pre-storm Seacrest location at 2040 and found only Seacrest's mooring buoys. At the same time, Westertor was searching Platong field. Avonlake was directed by the Marine Controller to search Kaphong field platforms "A" and "B" for survivors. This field is adjacent to Platong field, and the platforms are located northeast of the pre-storm Seacrest location. During the time period from 2130 until 2220, Avonlake confirmed that there were no survivors on Kaphong platforms "A" and "B" [11].

At 2147 Westertor reported seeing a flashing light north of the pre-storm Seacrest location. Westertor investigated, but the light soon disappeared. At 2200 Westertor was back at the pre-storm Seacrest location and had begun using the echo sounding system to check the area for submerged objects, debris, or possibly the Seacrest [8].

Avonpark arrived at 2300 and began assisting Avonlake and Westertor [12]. At 2315 Avondale arrived and began searching [13].

At 2345 the Marine Controller directed Westertor to form a search party using Avonlake, Avonpark, and Avondale. The boats were to proceed 20 nautical miles northeast of Kaphong platform "A", and were to be spaced 1/2 nautical mile apart, with Westertor as the flagship [11].

<u>Other Events of November 3</u>

After several attempts to communicate with Seacrest (the last known communication was at 1326), the Marine Controller requested that Gray Guard search for the Seacrest using radar. At approximately 1718, both Gray Guard and Westertor confirmed that Seacrest was not in the radar scan [3, 6]. Westertor was dispatched at 1800 to the pre-storm Seacrest location, while Gray Guard assisted the drifting drilling tender, Robray T-4 [4, 7].

After confirming that Seacrest was not at the pre-storm location, Westertor began searching using radar and an echo sounder. Other vessels were dispatched to assist in SAR and arrived before midnight. At 2345, the Marine Controller organized a boat search to the northeast.

November 4, 1989

<u>0000 Until 0800</u>

Avonlake, Avonpark, Avondale, and Westertor proceeded to the northeast [13]. At 0135, Westertor spotted something on radar 20 nautical miles to the northeast. It was later determined to be a freighter heading south [3, 4]. The Gray Sword arrived at Platong field at 0145 and set a course to the northeast to join the search party [14]. At 0306 Gray Sword joined the search team that continued to the northeast [6]. Westertor then left the search party and proceeded south to assist the drifting Robray T-4 [5]. At 0600 the search party altered its course from northeast to due east [1, 13, 11, 12].

At 0715 the search party was northeast, approximately 20 nautical miles from Platong field at position 10°N 101°09E [14]. Then Gray Sword was directed by the Marine Controller to a new position heading 285° [14]. At 0730 the party changed course to 230° [13].

At approximately 0800 the helicopter GIMQ (IMQ), which had departed Songkhla at 0612 to begin SAR, reported spotting the capsized Seacrest and an empty life raft 10 miles northwest of its working location. IMQ confirmed this shortly afterwards, and the Marine Controller broadcasted this information to all stations [15, 4].

<u>800 until 2400</u>

At 0815 the Marine Controller directed the boat search party to position 9°46N 101°18E, the site of the capsized Seacrest [11].

Gray Guard was dispatched at 0900 to pick up the surface air diving system and the remote operated vehicle (ROV) from the pipeline laying barge DB-15. This equipment was later used to support SAR at Seacrest [4].

IMQ spotted what was thought to be six possible Seacrest survivors at about 0910 [10]. It was later determined that there were seven survivors, all fishermen. At 0955 IMQ dropped two life rafts to the fishermen [4]. The survivors were picked up at 1100 by Avonlake, Avondale, and Asie IV [9, 11, 4, 16].

At 1148 the repair of storm damage suffered by GIMM (IMM), the other S-76 helicopter, was complete [15]. Using IMM and IMQ, Unocal was able to search a 20 nautical mile radius area, centered at the overturned Seacrest. Radials were flown at headings of 335°, 315°, 270°, 225°, 180°, 135°, 090°, and 45° [15, 2, 17, 18, 19]. When flying radials, the helicopter would fly out 20 nautical miles and return on a 5 nautical mile parallel track at an altitude of 500 feet. In addition to the 20 nautical mile radials, IMQ made two flights out to 25 nautical miles and one out to 35 nautical miles, due north [20]. The effort was concentrated mostly in the northeast and northwest quadrants.

At 1247 Eric Emerson, Drilling Engineer, and Robert Ireland, a consultant to Unocal, returned to Platong LQ to get tools for knocking on the Seacrest, since they were unable to hear any response due to the helicopter noise the first time [10]. At approximately 1310 they returned to the Seacrest with a third person and repeated the knocking with "heavy tools or hammers" for approximately 30 minutes, but received no response [5, 4].

<u>Other Events of November 4</u>

The boat search on November 4 was conducted out to 20 nautical miles northeast of Kaphong platform "A" and was later conducted in the vicinity of the overturned Seacrest. Avonpark, Avonlake, Avondale, Westertor (until 0310 on November 5), and Gray Sword all participated in the effort, which continued through 1810 on November 4.

The overturned Seacrest and one life raft were spotted by IMQ at 0800 at 9°44N 101°18E, 10 nautical miles northwest of its working location [15, 4].

Unocal's IMQ and IMM assisted in SAR covering most of the area around the pre-storm Seacrest position, out to 20 nautical miles. IMQ departed Songkhla to begin searching at 0612. IMM was grounded with storm damage on Erawan LQ until 1148. Both helicopters were instructed to fly 20 nautical mile radials out from the Seacrest and concentrate in the northeast, northwest, and then southwest quadrants.

In addition to Unocal's aircraft, the Royal Thai Navy had three aircraft in the field, all engaged in SAR.

SAR at the capsized Seacrest was initiated at 0900, the time at which the Gray Guard was dispatched to DB-15 to retrieve diving equipment and the ROV. The Gray Guard departed DB-15 with the equipment at 1524 and arrived at Seacrest at 1910. The Jaramac 45 assisted Gray Guard by running anchors. By 2245 the first dive was completed at Seacrest. The diver noted that the helideck was missing; the roof from the accommodation was missing; the derrick was missing; and one body was found in a life jacket, tied to the hand rail [3, 10]. A second dive was made, and additional damage was reported. Diving was discontinued after 2337 because of the strong current which made it unsafe to dive or use the ROV) [3, 10]. In none of those diving operations was structural damage to the hull of Seacrest found.

A total of 12 fishermen and 5 refugees were rescued on Baanpot platform "A". They were given food and water [11, 10].

November 5, 1989

0000 Until 1800

IMQ lifted off for SAR at 0613. At 0630 IMQ reported its position as 40 nautical miles northeast (045°) of Seacrest. The next mission IMQ flew was 50 nautical miles to the northwest (315°) [10]. IMM returned to the field for SAR at 1055, after staying overnight in Songkhla [19].

At 0110, "Searching 0-30 miles from SC position" was recorded in the Satun LQ Radio Log [15]. This message was from IMM and IMQ, confirming Unocal's SAR plan to search the two northern quadrants out to 30 miles based on projected drift at sea and a discussion with the Royal Thai Navy. After the 30 mile radius area was covered, the helicopters were to search out beyond 30 nautical miles, if time permitted [21].

At 1545, IMQ spotted red and blue drums and red boards 30 nautical miles northwest (300°) of the Seacrest. It was speculated that these were from the Schlumberger (a contractor on Seacrest) unit [10]. A drum was also sighted 22 nautical miles northeast (045°) of Platong [19].

1800 Until 2400

The Royal Thai Navy contacted Unocal's Emergency Control Center at about 1855 regarding Seacrest survivors. The message relayed was, "fishing vessel between Erawan and Satun has 3 survivors from Seacrest" [10]. This triggered a boat search in the southern gas fields involving nine support vessels. At 1928 Satun LQ broadcasted the reported position as "lat. 08.30', long. 101.30'35 miles from Baanpot" [6].

At 2130, the names of four Seacrest survivors were received by Emergency Control [22]. At 2145 the position reported for the four survivors was "lat. 10°36.80, long. 101°37'73" [101°37.73]E [7]. This position was approximately 50 nautical miles northeast of Platong. At about 2245 the SAR effort in the southern gas fields was called off.

Avonbeg was directed to 10°53N 101°43E at 2249 [23]. This position is 17 nautical miles northeast of the reported Seacrest survivors pick-up position "lat. 10°36'80", long. 101°37'73" [101°37.73']E [7]. The targeted location was beyond the reported pick-up location in order to allow for continued drift to the northeast [24, 25]. Avonpark was dispatched shortly afterward and departed at midnight [12]. Avondale followed shortly after midnight (0040) [13].

At 2300 Gray Sword departed Platong LQ to pick up Seacrest survivors at position 10°19.32N 100°45.65E. This northwest position was reported as the location of two Thai fishing boats, Kor Chokeamnuaychau and Sor. Panicharon 10, with the four Seacrest survivors aboard [9]. Unocal questioned the feasibility of a northeast survivor pick-up location (10°36.80N 101°37.73E) and their subsequent relocation to the reported northwest position (10°19.32N 100°45.65E). It was determined however, that in the time frame involved, 1530 - 1855, this was possible, since the fishing boats could have averaged the required minimum rate of 8 knots [24, 25].

<u>Other Events of November 5, 1989</u>

Gray Guard was having problems with the current at Seacrest; therefore, the decision was made to move DB-15 to the Seacrest location to support SAR. Jaramac 45 and J-26 (Nusa Ende) departed at 1400 [20], with DB-15 in tow, and arrived at Seacrest at 1900 [26, 27].

By 1035 two bodies had been discovered on Seacrest. These were later recovered at 2225. ROV surveys for hull integrity, winch inspection, and body location were also performed [28]. The surveys did not reveal any structural damage on the hull.

November 6, 1989

<u>0000 Until 0600</u>

At 0240 Erawan LQ received a message from the fishing boat "Chokeamnuay," which had one of the four Seacrest survivors, which said, "If you need to searching could search at 10°35'90"N 100°39'26"E" [6]. This was the northwest pick up position, which had been reported earlier as the approximate position of the fishing boats with Seacrest survivors.

Three of the Avon boats (Avonbeg, Avondale and Avonpark) were en route to the northeast search position, 10°53N 101°43E. Gray Sword pulled up along side the "K. Chokamonaychai" fishing boat at 0300, picked up one Seacrest survivor, and then departed for the Royal Thai Navy Khirirat to pick up three additional Seacrest survivors. At 0400, Gray Sword maneuvered alongside Khirirat, retrieved the three survivors, and then departed at 0415 for Platong LQ. At 0905, Gray Sword arrived at Platong LQ with the four Seacrest survivors [14].

<u>0600 Until 1200</u>

IMM departed Erawan LQ for SAR at 0605 [19]. At 0700 IMM reported its position as 70 nautical miles northwest of Platong LQ. At 0620 Avonlake informed Satun LQ that it was "proceeding to position 10°35.90N 100°39.26E, ETA 1200" [15]. Avonlake was subsequently (at 0625) dispatched to the northeast and recorded in its deck log, "Depart for coordinate 10-53N 101-43E [11]. From the information received it was unclear whether the Seacrest survivors were picked up in the northeast or the northwest.

At 0839, IMQ departed Platong LQ for SAR at a heading of 20° and a position 50 nautical miles away. IMQ actually went out 65 - 70° [15] [19, 17].

At 0830, Emergency Control learned, "H. Lte (from Harold Light on PLQ): From <u>our</u> boat captain who picked up the survivors: 10°35.90N 100°39.26E." This message confirmed that the pick up location and the other debris and bodies were actually northwest of the capsized Seacrest [10].

Also at 0830, Emergency Control learned from Pattersen [Pattison] from the U.S. Embassy that a plane for SAR was available in Subic (Philippines) and could be in Thailand by about 1700 [10]. Unocal accepted this offer, but the assistance was subsequently rejected by the Royal Thai Navy [29].

At 0915, Avonbeg reported back the northeast location (10°53N 101°43E) to the Marine Controller that nothing from Seacrest was spotted in the area. Avonpark, Avonbeg, and Avondale had all arrived by 0900 and "fanned out" to search the area [23, 13, 12].

At 1030 Emergency Control received a message that three survivors had been picked up by a fishing trawler and were being transferred to a longtail boat, SP25, headed to Rayong at 7 knots. Unocal made provision for receiving them in Rayong, but nothing else was heard about either SP25 or Seacrest survivors. [22, 10].

Avonbeg, Avonpark, and Avondale returned to position 10°53N 100°43E sometime before 1033 [23]. At 1100 the Marine Controller ordered these boats to proceed west to 10°49N 100°34E [13, 12]. Avonlake, only 14 nautical miles from the other boats, altered its course at 1100 to 282° and headed for the northwest location (10°53N 100°43E) [11]. At 1105 the Jaramac 26 departed for "43'NW (43 nautical miles northwest) from Seacrest DB-15 position" to join the SAR party in the northwest [27].

<u>1200 Until 2400</u>

At 1225 IMM transmitted the message, "Found fishing boat heading 330° 75 miles fm [from] Platong LQ" to Satun LQ [15]. Platong LQ recorded that the crew of the fishing boat was waving [17]. At that time IMQ was also flying in the northwest, out to 90 nautical miles. IMQ reported seeing debris, but could not identify any of it as being from Seacrest [10].

At 1347, Unocal was contacted regarding the Royal Thai Navy's recovery of two Seacrest survivors and the sighting of possible Seacrest casualties. The casualties were reported as being six Thai nationals and one expatriate. The reported position was 10°36.4N 100°24.83E. The two survivors were sent to Sattahip aboard the Royal Thai Navy T-110 [15].

The sighting of Seacrest bodies was confirmed at 1355 by the Royal Thai Navy Khirirat. All seven bodies spotted were wearing life jackets [6]. At 1402 IMM was instructed by the Marine Controller to proceed to this position [9]. IMQ followed at 1455 out to 70 (or 80) nautical miles at a heading of 310° from Platong LQ [17].

At 1459 Khirirat reported ten additional Seacrest casualties in the area [9, 6]. At 1505 the Marine Controller redirected the Avon boats, which had been headed due west (270°), to the new position slightly southwest, 10°51N 100°45E [13, 12, 9].

At 1550 the Jaramac 45 departed from the gas fields to assist the SAR party in the northwest [30, 31].

<u>Other Events of November 6, 1989</u>

Eight dives were completed during the day. By 0028 the upper and weather deck levels were checked, but no survivors or bodies were found. At 0356 another dive was initiated in an effort to attach air hoses to the Seacrest. After two additional dives, the Seacrest was stabilized using compressed air [28].

An ROV survey was completed at 0110. No "major" hull damage or bodies were located [28].

At 1142 the fifth dive of the day was made. The dive was completed by 1302 after recovering the ship's safe and locating two bodies in the captain's cabin (one was recovered). On the next dive, at 1339, two additional bodies were located and recovered. The body not recovered during the 1302 dive, was also recovered. The seventh dive commenced at 1600 in an effort to survey the main deck accommodation level. The main deck accommodation level was checked and an additional body was located and recovered, bringing the total to five bodies for the day [28].

At 2000 the last ROV survey for the day was initiated. Cable #5 was inspected. The ROV survey was completed at 2030 [28].

November 7, 1989

At 0000 the search party consisted of Avonlake, Avonbeg, Avondale, Avonpark, Jaramac 26, and Jaramac 45. The search party was en route to 10°38N 100°12E. [25 and 11] After departing Unocal's gas fields at 1942 November 6, Gray Guard was en route to 10°36N 100°25E [7].

The search party reached position 11°N 100°E at 0740 and proceeded to search according to the strategy that had been established in the Emergency Control Center at about 0530 [11].

With the vessels spread out to maximize the area of visual search and to take advantage of the morning sunlight, the party moved due south at a rate of 8 to 10 knots [23, 22]. At 0900 the party turned due west (270° heading) and proceeded at a rate of 10 knots [27, 31, 23].

At 0915 IMM spotted a fisherman at a location, "310° fm [from] PLQ 80 miles approx" [15]. At 0930 IMM and IMQ were in the area. IMM dropped a life raft and a Royal Thai Navy frogman to assist the survivor [10].

At 0945 Jaramac 45 was dispatched from the SAR party to assist the frogman and fisherman (position 10°35N 100°25E) [31, 11]. While en route, the Jaramac 45 recovered an unused Seacrest life jacket (1115, position 10°37N 100°8E). At 1320 Jaramac 45 arrived at 10°35N 100°25E but did not find anything [31].

At 1400, the Royal Thai Navy Khirirat reported that at 1145 at position 10°47N [10°40.5N] 100°23.8E they had found "... 1 set of radio transmitting emergency signal has a name of 'Seacrest' 3 En" [15, 9]. This was possibly a Seacrest EPIRB (Emergency Position Indicating Radio Beacon). At 1450 Emergency Control learned that the Royal Thai Navy would not confirm this report [22, 10]. At 1420 the fisherman, who had been spotted by IMM at 0915, and the frogman, who had been dropped by IMM, were rescued by a fishing boat "Vilaisin 12" [15] or "Wilaisin 12" [9].

Avonlake picked up one Seacrest life jacket, another undesignated life jacket, and a life ring at 1425. At 1438 IMM directed Avonlake to a location with 10 drifting bodies [11].

Between 1530 and 1830 the search party recovered 25 bodies [13]. Of these bodies, 18 had on Seacrest life jackets [22, 10]. These bodies were transferred to Avondale for transport to Songkhla [13].

The search party anchored at position 10°33.7N 100°23.1E for the evening [7].

<u>Other Events of November 7</u>

The search party proceeded to the northwest, position 11°N 100°E, and at 0745 began searching. This position was selected in an effort to allow for drift. Between 1530 and 1830, 25 bodies were recovered in the southeast (in the vicinity of 10°30N 100°20E). Eighteen of the 25 bodies had on Seacrest life jackets.

At 0900 Unocal received word that the Royal Thai Navy had six ships in the area of Unocal's search party [15].

At the Seacrest, surface salvage operations continued; towing points and penetration valves were attached to the hull. A total of ten dives were conducted between November 4 and 7, 1989. During the total accumulated bottom time of 545 minutes, all external areas, including the main deck, weather deck and upper accommodation, were searched. The bridge and associated cabins were also checked. A total of seven bodies were recovered from the Seacrest through November 7, 1989 [28].

November 8, 1989

Asie 7 arrived at 0320 and moored alongside Avonbeg [32]. In addition to these boats, Avonpark, Avonlake, Jaramac 26, Jaramac 45, and Gray Guard were present, with Gray Guard in command [23, 12].

Searching resumed at 0700 on a course due south (180°) from position 10°33.7N 100°23.1E [7]. Avonlake followed Khirirat for communication purposes [10]. The other six boats were spaced two miles apart, all to the west of Gray Guard. IMM was to begin searching to the south then the west [22]. The party continued on this course until 0950, to position 10°16N 100°24.4E. The party then turned due west (270°), and at 1200 changed course due north (360°) [7].

At about 1230 Avonbeg and Avonpark each picked up a body. These were located by "WSW chopper... [helicopter]." Avonpark described one body as, "multi tattoo unidentified 'fisherman," and Avonbeg described the other as, "confirmed Seacrest life jacket" [22].

At 1230 Khirirat departed from the search area at 30 knots. Avonlake then resumed searching with the SAR party [22].
The search party continued north until 1305, when they changed course to the west-northwest (300°) At 1340 they changed to a more northern course (340°), and at 1415 resumed course due north (360°). At 1815 the party moored for the evening at position 10°53N 100°1.7E [7].

The two bodies recovered by Avonbeg and Avonpark were transferred to Asie 7 at 1820. Asie 7 departed for Songkhla at 1900 [31].

<u>Other Events of November 8</u>

During the course of the day, the search party recovered two bodies, one was a fisherman and the other was from Seacrest. These bodies were spotted by one of the SAR helicopters, either IMM or IMQ.

IMM flew three SAR missions out of Surat Thani, with a total flight time of 9 hours 33 minutes, and flew one mission along the east coast of Thailand, including the coastal islands east of Chumphon [19]. IMQ flew one SAR mission out of Surat Thani with a flight time of 2 hours and 26 minutes. There was no diving at Seacrest [28].

November 9, 1989

At 0730 the search party, consisting of Avonlake, Avonpark, Avonbeg, Jaramac 26, Jaramac 45, and Gray Guard as flagship, departed position 10°55N 100°8E. The heading of the party was due south (180°) [7, 33, 30, 23, 12]. At 1205 the Avonbeg picked up a "badly decomposed" body wearing a Seacrest life jacket at 10°25.5N 100°13E. This pick up was documented in the Emergency Control Center log at 1145 [22]. Avonbeg departed for

Songkhla at 1230 with the Seacrest body [23]. Jaramac 26, ordered back to the field to assist DB-15, and departed at 1235 [27].

At 1405 the search party was in the vicinity of 10°15N 100°09E, where it changed course to due west (270°) [7].

At 1645, near position 10°12N 99°57E, the party changed course to due north (360°). The party reached position 10°18.6N 99°59E and dropped anchor for the evening at 1818 [7].

<u>Other Events of November 9</u>

The search party started the day with six boats and completed the day with four, after Avonbeg and Jaramac 26 departed at mid-day. Avonbeg departed for Songkhla with one Seacrest body, which had been recovered at 1230.

At 1500 the Royal Thai Navy reported that they would abandon the SAR effort on the November 10 [10].

IMM flew four SAR missions, with a total flight time of 10 hours 6 minutes. IMM reported spotting bodies on the beach of Kho Mattra (an island) at 1515 [22]. IMM flew most of the missions in the vicinity of the search boats. IMQ flew three SAR missions with an elapsed flight time of 4 hours and 4 minutes. These flights were also primarily in the vicinity of the search boats [19].

November 10, 1989

The search party moored at position 10°18.6N 99°59E overnight. The party consisted of four boats, Avonpark, Avonlake, Gray Guard, and Jaramac 45 (which had returned from Platong LQ during the night) [31, 7, 12, 11].

Asie 7 departed Songkhla at 2315 on November 9, 1990, with members of Portekteng (a Thai organization to aid in the handling of the badly decomposed bodies) [32, 10].

At 0335 Gray Vanguard left Erawan LQ to join the search party [34].

At 0630 the search party began line searching on a course due north (360°) [7]. Shortly after, at 0650, Avonpark discovered a body wearing a Seacrest life jacket and stood by it until Asie 7 arrived at 1330 [12, 22]. The remainder of the search party continued searching on a track to the north [8]. At 0755 Gray Guard spotted two life jackets, one Seacrest and the other marked "Marmaid" [22]. The search party reached position 10°33.9N 99°58.6E at 0944; then changed course to due west (270°). They arrived at position 10°34N 99°55E at 1030 and then proceeded on a course due south (180°) [7].

Gray Vanguard and Asie 7 reached the search area at 1300 and 1320, respectively [34, 32]. Asie 7 proceeded to the position where Avonpark was standing by the Seacrest body, and at 1325 recovered the corpse. Avonpark then departed for the reported location of another body [12]. At 1420 Gray Vanguard took over leadership of the search party, and Gray Guard departed for Platong LQ [34, 7].

Asie 7 recorded the recovery of three additional bodies, one of which was wearing a Seacrest life jacket. These bodies were picked up at 1350, 1430, and 1804, respectively [32].

At 1820, Asie 7 recorded the transfer of four corpses to Gray Vanguard [32]. There is a discrepancy in the actual number of corpses transferred, since Gray Vanguard recorded the transfer of five [34]. The Portekteng Foundation People were also transferred to Gray Vanguard at this time [33, 31].

Other Events of November 10

Both IMQ and IMM departed for the search area early, 0604 and 0827, respectively. They flew in the vicinity of the boats and IMQ reported sighting bodies as early as 0755 [22]. They flew a total of five missions, with an elapsed flight time of 14 hours and 27 minutes [19].

A total of five corpses, two wearing Seacrest life jackets, were recovered (later substantiated by the final body count).

November 11, 1989

The search party, consisting of the Avonlake, Avonpark, Jaramac 45, Asie 7 and Gray Vanguard, headed due north at 0600 [34, 33, 12]. Gray Vanguard sighted an unmarked body at 0725 (10°08N 99°50E), but did not recover the body [34, 22]. The search party reached 10°30N at 0740 and then headed west (270°) [29, 33].

At 0830 Avonlake was directed to Lang Suan by the Marine Controller [11].

IMM began assisting the search party at 0730. It flew two missions for a total flight time of 7 hours and 42 minutes. IMQ flew one mission at 1322 with a flight time of 2 hours and 49 minutes [19]. At 0900 a body, life jackets, and rip tides were reported near position 10°21N 99°44E [22, 10]. These were recorded as sightings by IMQ, but were actually made by IMM (IMQ was on field duties) [19].

During the course of the day, several bodies and life jackets were sighted and recovered. Asie 7, Avonpark, and Jaramac 45 all sighted bodies which were later picked up by Gray Vanguard (with the exception of the 0725 Gray Vanguard sighting) [34, 12 and 32]. Only one of eight bodies recovered by the Gray Vanguard was logged as wearing a Seacrest life jacket (recovered at 1345) [34].

The search party moored for the evening at 1830 (10°22N 99°55E) [34].

Other Events of November 11

The search party started the day with five boats total and finished with three, Gray Vanguard, Jaramac 45, and Avonpark. Several life jackets and bodies were spotted and recovered. Nine bodies were sighted by boats. Of the eight that were recovered, only one was wearing a

Seacrest life jacket.

The helicopters flew a total of five SAR missions, with a total flight time of 10 hours and 31 minutes. IMQ flew only one SAR mission and provided logistics support all day [19].

Several dives were made to inspect the winches on Seacrest and to try and find additional bodies [21]. At 1205 the divers from the Royal Thai Navy reported three additional bodies at Seacrest. These were reported as having been found beneath the bridge in the stairwell to the engine room [22]. This discovery brought the total number of bodies recovered from the overturned Seacrest to ten.

November 12, 1989

Avonpark, Gray Vanguard and Jaramac 45 remained on SAR. They departed 10°22N, 99°56.5E at 0600 on a southerly course [31]. One body was recovered by Gray Vanguard at 0645 at 10°19.5N, 99°55.7E [34]. Gray Vanguard informed the Emergency Control Center that the body did not have a life jacket, but there were many life jackets in the area (Gray Vanguard reported "1-35 jackets on board" [22].

At 0720 Gray Vanguard recorded recovering another jacket at 10°16.23N, 99°56.38E [34].

The search party proceeded west at 0800 (10°10N, 99°53E) and at 0830 the search party headed due north (10°9.14N, 99°52E) [31, 34].

Gray Vanguard recovered one body with a life jacket nearby at 0945 at 10°18.07N 99°52.3E [22]. At 1000 the group then proceeded west and at 1025 turned due south at 10°20N 99°47E. At 1135 the group reached 10°10N 99°47E and proceeded west [31].

At about 1240 the search was called off [34]. The group stopped searching at 10°17N 99°46E [12].

11.4 Searches Performed

The SAR effort was comprised of many coordinated searches. These searches included efforts by support vessels, which executed pattern searches; helicopters, which searched radials from the capsize and later areas in the vicinity of the support vessels; and land searches, based on information from local government and police agencies. In an effort to describe these coordinated searches, each element (support vessels, helicopters, and land search parties) is detailed in subsequent sections.

11.4.1 Support Vessels

Support vessels were in the Gulf of Thailand on Search and Rescue from November 3 until November 12, 1989. The search party ranged in number from three to nine boats. These vessels were directed by the Marine Controller, the Emergency Control Center, and the lead vessel of the search party. The direction was based on reported sightings from the Royal Thai

Navy, Thai Fishing Association, and helicopters.

November 3, 1989

At 1530 the Gray Guard wad dispatched to the pre-storm Seacrest location, but had difficulty (mechanical and weather). By 1745 the absence of Seacrest from its pre-storm working location was confirmed. At 1800 Westertor was dispatched by the Marine Controller to investigate Platong field. Other vessels were dispatched to Platong field and arrived before midnight. At 2345 the Marine Controller organized a boat search to the northeast.

November 4, 1989 (Refer to Figure 11.7)

At 0000 the search party, which consisted of Avonpark, Avondale, Avonlake, and Westertor (search leader), departed Platong field and headed to the northeast. At 0310 Westertor was replaced by Gray Sword. These boats searched in the northeast and at the location of the capsized Seacrest. The search was terminated at 1815.

November 5, 1989 (Refer to Figure 11.8)

After receiving a message regarding Seacrest survivors near Erawan and Satun fields, a nighttime search consisting of nine boats was initiated. Vessels searched the complete east and west sides of Unocal's gas fields. The report was later determined to be erroneous, and another report of survivors in the northeast was reported. This prompted a search to the northeast.

November 6, 1989 (Refer to Figure 11.9)

At 2249, November 5, 1989, Avonbeg was dispatched to the northeast of Unocal's fields (10°53N 101°43E). By 0910 Avonbeg, Avonpark, and Avondale were searching this northeast location. Nothing related to Seacrest was found. This position was later determined to be erroneous, and the actual Seacrest survivor pick up location was to the northwest.

At 1100, Avonbeg, Avonpark, Avondale, and Avonlake were dispatched on course to the west. Jaramac 26 and Jaramac 45 joined by the end of the day.

November 7, 1989 (Refer to Figure 11.10)

The search party continued to search through the evening. By 0745, the search party, consisting of the Avonpark, Avonbeg, Avondale, Jaramac 26, and Jaramac 45, had reached 11°N 100°E. The party followed a pattern that was devised by Emergency Control personnel and was designed to take advantage of the early morning light [22].

By 1430, the group was southeast of the area searched in the morning. The group split up in an effort to recover Seacrest casualties that had been found in the area.

At 1830, the search party was anchored at 10°33N 100°23E for the evening.

November 8, 1989 (Refer to Figure 11.11)

The search party, consisting of the Avonpark, Avonbeg, Avonlake, Jaramac 26, Jaramac 45, Asie 7, and Gray Guard, departed 10°33N 100°23E. The group traveled 17 nautical miles south and then turned west. They travelled 17 nautical miles west and then turned north. The party finished the day at 10°53N 100°02E.

November 9, 1989 (Refer to Figure 11.12)

The group started out with Avonpark, Avonbeg, Avonlake, Jaramac 26, Jaramac 45, and Gray Guard. Avonbeg departed at 1230. The party started out at 0730 at 10°55N 100°13E and headed due south. At 1400 the party reached 10°15N 100°9E and turned west. After traveling 12 miles west the group turned north and traveled 7 miles. At 1818 the search party stopped at 10°18N 99°59E for the evening.

November 10, 1989 (Refer to Figure 11.13)

Avonpark, Avonlake, Gray Vanguard, Jaramac 45, and Asie 7 departed 10°18N 99°59E at 0630. Gray Vanguard had arrived during the evening. All vessels were under the command of Gray Guard. The party headed due north and traveled 16 nautical miles before turning west. They moved approximately 3 nautical miles west and then turned south. They reached 10°10N 99°55E after moving 25 nautical miles south. At 1330 the party was travelling south, at 10°18N 99°55E. Avonpark rejoined the group at 1830 (10°18N 99°49E). They anchored for the evening. Avonpark and Gray Guard departed during the day, leaving the search party under the direction of the Gray Vanguard.

November 11, 1989 (Refer to Figure 11.14)

Avonpark, Avonlake, Jaramac 45, Asie 7, and Gray Vanguard started searching at 0600 (10°18 99°50E). Several life jackets and bodies were spotted and recovered. Eight bodies were recovered; only one was wearing a Seacrest life jacket. Avonlake and Asie 7 departed during the day, leaving the search party of three boats.

The group anchored at 1830 near 10°22N 99°53E.

November 12, 1989 (Refer to Figure 11.15)

At 0600 the three remaining vessels, Avonpark, Jaramac 45, and Gray Vanguard, started searching at 10°22N 99°56E. They searched an area bounded on the north and south by 10°20N 10°10N, and 99°46E. This is a 10 nautical mile by 10 nautical mile area (100 square nautical mile area). The search was called off at 1240 (10°17N 99°46E).

11.4.2 Helicopter

At the time of the typhoon, Unocal had on contract, through Okanagan helicopters, two

Sikorsky S-76 helicopters and one Sikorsky S-61 helicopter (OLH). Unocal's Emergency Coordinator (Controller), and the Bangkok Logistics Coordinator, consulted with Okanagan's Base Manager, and a Safety Consultant of Survival Rescue Services (formerly with the Canadian Military), and decided to utilize the two S-76 helicopters for SAR. The S-61 helicopter was to be used for transporting essential personnel and equipment for the gas fields and SAR at the Seacrest. The S-76's were selected for SAR offshore on the basis of their better all-around visibility, and the larger S-61 would be used principally for transport [35].

All helicopters were grounded on November 3, 1989 because of strong winds and poor visibility. IMM's blades were damaged during the typhoon and were repaired on Erawan LQ on November 4 [35].

IMQ departed Songkhla Base at 0612 on November 4, 1989 to begin SAR in the fields [19]. At about 0800 IMQ sighted the overturned Seacrest approximately 10 nautical miles northwest of its pre-storm location [15, 4].

IMM lifted off of Erawan LQ at 1148 (November 4, 1989) to begin SAR. Both IMM and IMQ were instructed to fly radials out to 20 nautical miles from the capsized Seacrest [19]. IMQ flew one mission due north and out to 35 nautical miles. These radials are shown graphically in Figure 11.16.

On November 5, 1989 the search area was extended out to a circular area centered at the capsized Seacrest and 30 nautical miles in radius. The helicopters were to search this area first, concentrating in the two northern quadrants, and then beyond as time permitted [15, 21]. IMQ flew two missions beyond 30 nautical miles, one 40 nautical miles to the northeast and the other 50 nautical miles to the northwest [27]. The combined search radials and areas of the 4th and 5th are detailed in Figure 11.17.

On November 6, 1989 the helicopters began flying longer missions out to the northeast and northwest. At 0700 IMM was searching 70 nautical miles to the northwest of Platong LQ. IMQ departed at 0840 to search 50 nautical miles (IMQ actually went 15 to 70 nautical miles) to the northeast of Platong LQ. At 0914 IMM departed Platong LQ to search in the northeast [17].

At 1030, after the Seacrest survivor pick up location was confirmed, IMQ departed for a point 70 nautical miles in the northwest (10°39.90N 100°39.26E). At 1133 IMQ departed PLQ for the northwest survivor pick up position. At 1225 IMM spotted a wrecked fishing vessel, with survivors (fishermen), in the northwest [15, 17]. For the rest of the day SAR was concentrated in the northwest. The radials which were flown are shown graphically in Figure 11.18.

IMM was fitted with an auxiliary fuel tank (completed 0534 November 7, 1989), which gave IMM one additional hour of flight time over the three hour standard [34]. In addition to increasing IMM's flight time, Unocal was able to obtain permits for flying out of Surat Thani (coastal Thailand, refer to Figure 11.19) These changes increased the time that the helicopters could spend searching in the fields. The flight times for IMQ and IMM are given in Figures 11.20 and 11.21, respectively.

After November 6, 1989, the helicopters began flying pattern searches in the area to the northwest of Unocal's fields and in the vicinity of the search vessels. They assisted in the search by spotting debris and casualties/survivors, and then by directing the search vessels to the sighting.

11.4.3 Land Searches

Unocal dispatched land teams to search for victims who might have washed ashore in the coastal provinces. Two teams were dispatched to the west coastal provinces of Chumphon and Prachuapkhirikan. The bodies of seven expatriates, which were Seacrest crew members, were recovered. Another land team was dispatched to search in the east coastal province of Trad, near the Kampuchea (Cambodian) border. No Seacrest victims were recovered in the Trad Province.

11.4.3.1 Prachuapkirikan and Chumphon Provinces (Land Team 1) [36].

November 9, 1989

A group of three Unocal representatives, Wiboon C., Jurin A., and Nuttawut L., departed Bangkok and arrived in Hua Hin.

November 10, 1989

Land Team 1 searched Hua Hin Hospital, the police station, the Red Cross office, and the town hall, and found no Seacrest survivors.

They contacted police at Pak Nam Pranburi and observed there were no survivors or victims in the area.

The team asked the head of police at Prachuapkirikan about Seacrest survivors or victims. After he contacted all the police stations in the province, only Bang Saphan police reported any casualties, 15 victims, all suspected to be fishermen.

Land Team 1 reported back to Bangkok and received a request that they head south to Chumphon, where survivors were reported. They arrived in Chumphon at 0430 and contacted Khun Voravut, second Lieutenant at the Police Station, who concluded that the Bangkok Emergency Coordinators had misunderstood the message. The police had requested the names of the Seacrest victims, but did not report that they had Seacrest survivors.

They searched for survivors at the local hospital and found none. The team searched Chumphon Foundation, where victims in this area were kept. Khun Boonnam, the officer, said he had received 80 victims, all local Thai fishermen.

November 11, 1989

Land Team 1 met with Major General Pravet, the director of the Institute of Medical Jurisprudence, Police Hospital, Bangkok. The Major General was there to perform the autopsies. He reported that there were six expatriate victims in Lang Suan who were suspected to be from the Seacrest crew. The team contacted Bangkok and made arrangements to transport the bodies to Bangkok (seven bodies, an additional body found during the day). Land Team 1 reported to Bangkok at 2230.

November 12, 1989

Khun Boonnam reported from Chumphon that he received a victim suspected to be an expatriate from the Seacrest. Arrangements were made to recover the body.

Major General Pravet requested that local police report suspected victims of the Seacrest incident to Unocal.

Conclusions of Land Search Team 1

There were no Seacrest victims found in the coastal provinces prior to November 9, 1989. Other storm and Seacrest victims were expected to be found from Bang Saphan to Lang Suan (along the coast). It was difficult to identify victims; only distinctions between Thais and expatriates could be made.

Suspected victims of the Seacrest incident were sent to the Bangkok police station. A special team was sent to Chumphon to transport victims, since the local authorities were overworked. Assistance was given to the Bangkok police in identifying victims by sending the physical records of the crewmen.

<u>11.4.3.2 Chumphon Province (Land Team 2)</u>

November 10, 1989

Sakol Saengthong, Cherdchai Panas-ampon, and Prasit Chiaprasert left Hua Hin at 0800 and arrived in Bang Saphan at 0900.

In Bang Saphan they met with the head of the hospital, Dr. Manoj, and he reported that bodies were found on a nearby beach; however, they were all claimed by local Thais as relatives.

They went with the doctor to the Police Station and discovered that 40 bodies were found the day before, but had been transported to Chumphon province. All of the bodies were found with no clothing and were probably Thai fishermen.

The team arrived in Tung Maha by late afternoon and discovered that 20-30 bodies were found and sent to Chumphon. They arrived in Chumphon at night and reported to the hospital. No victims/survivors were found at the hospital; all victims were sent to the Chumphon Foundation. At least 80 bodies were at the Foundation.

Land Team 2 met up with Land Team 1 at the police station and phoned Unocal, Bangkok by satellite phone. The police reported that 12 bodies were found at Tung Tako and were sent to Lang Suan. Six were Thai and six were expatriates.

November 11, 1989

The search party met with Major General Pravet, and he provided a list of identified bodies. Arrangements were made to send seven expatriate victims to Bangkok.

November 12, 1989

A report of an additional Seacrest body was made during the day. Arrangements were made to transport this body to Bangkok. Local police were informed of how to discriminate between Thai and expatriate bodies; they were instructed to report casualties to Bangkok.

November 13, 1989

The search party arrived in Bangkok and suggested that Unocal make arrangements to pick up the additional body which was found the day before.

During the afternoon they received a report that two additional bodies were found on Matra Island in Chumphon. Arrangements were made for recovering the bodies.

<u>11.4.3.3 Trad Province (Land Team 3)</u> [29]

November 30, 1989

The search party, Bamrung M., Skol S., and Narong K., arrived in the Trad Province by 2000. They made arrangements to meet with Khun Bunluh at 0830 the following day.

December 1, 1989

Land Team 3 met with Khun Bunluh and his friend at 0840. They rented a car at 1000 to survey the beach which was parallel to the Buntud Mountains, these separate Thailand and Kampuchea (Cambodia). A native of the area indicated that no Seacrest survivors were found in the area.

They arrived at Klong Yai at 1230 and asked fishermen about Seacrest crew (about 50-100 boats use this nearby pier daily). No one knew of any Seacrest survivors.
At 1530 they departed Klong Yai for Haad Sarn Chao, port city. After arriving, a native was questioned, and he indicated that no Seacrest victims were reported. They returned to the hotel at 1620 after covering 200 kilometers (round trip).

December 2, 1989

At 0800 the group returned to Klong Yai; there was no additional news. They left Klong Yai at 1030 and went to Tarn Prayabhichai army base, near the Thai-Kampuchea border. They questioned Sergeant Sakchai K. and local people about Seacrest victims, but no one knew anything.

At 1300 they hired a boat with a Thai guide that could speak Khmer and went to Ban Pakklong. The effort was observed by Khmer soldiers. No additional information was obtained. The team returned to Trad at 1800.

December 3, 1989

At 0800 the team departed for Laem Ngop and arranged for a boat to search at Ko Chang and other small islands in the area. They departed for Ko Chang at 1030 with the village leader, who knew the islands very well. They arrived at Ko Chang at 1230 and proceeded to search, which included the islands of Ko Ngam, Ko Saluk, Ko Krapong and Ko Mai-Sei. No one knew anything about Seacrest victims. They departed Ko Chang at 1800.

December 4, 1989

At 0800 the group departed for Laem Ngop. They took a boat from Laem Ngop at 1000 and searched the islands of Ko Panaed, Ko Mai Tung, Ko Khum, Ko Rang and Ko Kut. No Seacrest victims were found on any of the islands. They arrived at the hotel at 2000.

December 5, 1989

The land team departed for Klong Yai at 0800 to check on the progress in gathering information from local fishermen. No indication of Seacrest victims was obtained. They reported to Khun Chavanut in Bangkok at 1400.

December 6, 1989

The group was instructed to return to Bangkok and arrived at 1900.

11.5 Other Efforts

<u>11.5.1 Royal Thai Navy</u>

November 3, 1989

Khun Chavanut Vongsayan, Assistant Manager, Government Relations, maintained contact with several government agencies; the Royal Thai Navy (RTN) was one of these. Captain Anand, at the Naval Operation Center, was contacted at 1125 by Khun Chavanut. He was told that the ship nearest to the storm and fields, Po-Sarm-Ton, was ordered back to base due to the severe weather. In addition to this he was told that the RTN had sent a medium size aircraft over the storm for general observation.

At 1315 Captain Pimol, of the Naval Operation Center, called to inquire about the general situation. Khun Chavanut informed him of the situation. Khun Chavanut later contacted Captain Pimol and requested assistance with the drifting Robray T-4 drilling tender. He also provided the following details:

Gross Tonnage- 4,142
Length - 284 ft.
Breadth - 60 ft.
No engine
Generator
VHF AM 129.4 Mhz.
Marine Radio (Channel 16)
Grey Color, 89 crew member (66 Thai Nationals) [35]

At 1530, Khun Chavanut contacted several government agencies regarding the situation and requested their assistance. The agencies and persons which were contacted are: Prime Minister of Intelligence Center, Khun Pareuhas; Emergency Reconstruction Assistance, Ministry of Interior, Khun Kiattisak; Search, Rescue and Accident Investigation Branch, D.O.A., Khun Thong; and, Naval Operation Center, Captain Taveechai [38].

November 4, 1989

Khun Chavanut maintained contact with the previously stated agencies. He made a special request at 0830 for Navy Divers. Captain Chai (RTN) agreed and made arrangements for two groups of six divers each. These groups were headed by Sub Lieutenant Sompis and Sub Lieutenant Punna. Unocal transported the divers as required by helicopter to the Seacrest [38].

During the day Khun Chavanut was contacted by: Captain Eakasak, Naval Gulf of Thailand Operations, Captain Chai, Naval Operation Center; and Captain Somwang, Chief of Naval Gulf Protection. They said that an RTN fleet consisting of the Khirirat, Po-Sarm-Ton, Vithayakom, T-11, T-17, Sattakud Ships, and others were searching in the general vicinity of the Seacrest incident [38].

Khun Chavanut maintained contact with the aforementioned agencies for the entire period of search and rescue [38].

Many additional resources were expended by the RTN during SAR. A list of the Naval fleet and aircraft used is provided in Table 11.3 [38].

Table 11.3
List of Thai Naval Fleet and Aircraft Involved in the Search and Rescue for Typhoon 'Gay' Victims

FLEET

	NAME	TYPE
1.	The Royal Khirirat	Frigate
2.	The Royal Phosamton	Ocean Mine Sweeper
3.	The Royal Witthayakhom	Missile Fast Attack Craft
4.	The Royal Songkhla	Gun Fast Attack Craft
5.	The Royal Tongpliu	Patrol Chaser
6.	The Royal Thong Kaeo	Utility Landing Ship
7.	The Royal Pa-Ngan	Tank Landing Ship
8.	The Royal Lanta	Tank Landing Ship
9.	The Royal Phra Thong	Tank Landing Ship
10.	The Royal Sattakut	Inland Landing Ship
11.	The Royal Rin	Tug Boat
12.	The Royal Rang	Tug Boat
13.	The Royal Sichang	Tank Landing Ship
14.	Tor 11	Motor Patrol Gun Boat
15.	Tor 16	Motor Patrol Gun Boat
16.	Tor 17	Motor Patrol Gun Boat
18.	Tor 23	Fast Patrol Craft
19.	Tor 24	Fast Patrol Craft
20.	Tor 110	Fast Patrol Craft
21.	Tor 210	Fast Patrol Craft
22.	Tor 213	Fast Patrol Craft
23.	Tor 214	Fast Patrol Craft
24.	Tor 215	Fast Patrol Craft
25.	Tor 220	Fast Patrol Craft
26.	Tor 221	Fast Patrol Craft
27.	Tor 224	Fast Patrol Craft
28.	Tor 226	Fast Patrol Craft

AIRCRAFT

1. T-337
2. S-2F
3. F-27
4. Nomad
5. Helicopter-Bell 212
6. Helicopter-Bell 214 St

11.5.2 Request for U.S. Assistance

On November 5, 1989 Unocal contacted the U.S. Embassy's duty officer to report that seven survivors were recovered. The Unocal representative then inquired about obtaining U.S. Naval "assets" to assist in the on-going SAR effort [29]. Also on November 5, Khun Chavanut was instructed to contact the RTN and notify them that Unocal was requesting, through the U.S. Embassy, U.S. aircraft support. Captain Chai, of the RTN, "indicated...that the Royal Thai Navy was of the opinion that Thailand, being a sovereign country, should seek outside assistance only when the situation could not be handled by Thai authorities." He also said that the situation was, "under control and, if outside assistance should ever be required, the Royal Thai Navy would be the party to contact and request necessary assistance from friendly countries" [35].

On November 6, 1989 the U.S. Embassy's Defense Attache's Officer (DAO) contacted the RTN and the U.S. Naval Station, Subic Bay, Philippines with regard to SAR assistance. The U.S. Navy indicated that patrol aircraft could be there as early as Monday evening. The RTN assured the DAO that no assistance was required [29].

Unocal was informed by the U.S. Embassy of the RTN's position and indicated that they were prepared to discuss the situation at higher levels in the Thai government. Unocal withdrew their request for assistance late Monday, November 6, 1989 [29].

11.5.3 Other Air Support

Early in the SAR, Unocal recognized the need for fixed wing air support. This need was recognized after consultation with Bob Ireland, Okanagan Helicopters, Consultant (ex-Canadian military). Mr. Ireland indicated that fixed wing air support could search more area and faster than helicopters After the fixed wing spotted debris, victims, etc., the helicopters could be directed in for close range pattern searching [35].

In addition to requests for U.S. and Thai fixed wing support, Unocal pursued other avenues. On November 5 and November 6, 1989 Unocal made several contacts including: the Thai Flying Club (Bill Heineke and Khun Tira); Thai Flying Services (Khun Taweedej); and, Bangkok Airways (Chuck Blue) [34]. The Thai Flying Club was able to offer five DB20 aircrafts, subject to Department of Aviation approval. These were ruled out, since they were only single engine aircraft with limited endurance. The Thai Flying Service's aircraft were already chartered by the U.S. Embassy Bangkok Airways had a large backlog and could not provide aircraft [35].

11.5.4 Request for Helicopter Support from Esso, Malaysia

Esso, Malaysia had several S61's based at Kurte in Kuantan, east coast Malaysia. Unocal contacted Esso Exploration Operations Manager, Mr. Schaeffer, at the Dusit Thani hotel, Bangkok. Mr. Schaeffer was aware of the situation through Schlumberger Company (they had missing personnel). He instructed Unocal to contact his supervisor, Leon Smith. Unocal attempted to contact Mr. Smith, but was unable due to communication problems.

The effort was abandoned after consulting with Unocal's Government Relations people, because of the difficulty in obtaining permission [35].

11.6 References

[1] Emergency Control Center Report (FaAA Record #7001)

[2] Communication Links During/After Typhoon Gay, 11/03/89-11/09/89 (FaAA Record # 4005)

[3] Single Side Band Radio Log, 11/03/89-11/05/89 (FaAA Record #4002)

[4] Marine Controller Report [Report from Eddie Kiak, 11/02/89-11/06/89 (FaAA Record #4030)

[5] [Pacific Scimitar] Deck and Operations Log, 11/01/89-11/11/89 (FaAA Record #3020)

[6] Erawan LQ [Radio Log], 10/29/89-11/06/89 (FaAA Record #4029)

[7] [Gray Guard] Deck Log, 11/01/89-11/13/89 (FaAA Record #3018)

[8] [Asie 7] Deck Log, 11/01/89-11/13/89 (FaAA Record #3026)

[9] Platong LQ Radio Log, 10/31/89-11/11/89 (FaAA Record #4028)

[10] Rich Keller's Personal Log Book, 10/31/89-11/30/89 (FaAA Record #7003)

[11] Avonlake Deck Log, 11/01/89-11/13/89 (FaAA Record #3025)

[12] Avonpark Deck Log, 11/01/89-11/13/89 (FaAA Record #3024)

[13] Avondale Deck Log, 11/01/89-11/13/89 (FaAA Record #3023)

[14] [Gray Sword] Deck Log, 11/01/89-11/13/89 (FaAA Record #3017)

[15] Satun LQ Radio Log, 10/31/89-11/12/89 (FaAA Record #4018)

[16] Asie 4 Deck Log, 11/01/89-11/13/89 (FaAA Record #3019)

[17] Radio Log [of Helicopter for CMM, OLH and IMM], 10/31/89-11/09/89 (FaAA Record #4032)

[18] Helicopter Logs from Erawan LQ, 10/31/89-11/05/89 (FaAA Record #4040)

[19] Helicopter Log, 11/02/89-11/13/89 (FaAA Record #8030)

[20] Seacrest Tragedy Search and Rescue Operations: A Comprehensive Report of Unocal Effort's Nov 3rd Through Nov 12th, 1989, 11/02/80-11/12/89 (FaAA Record #8043)

[21] Seacrest Search and Rescue Activity Re: Concentration of Air Searches, 11/04/89-11/06/89 (FaAA Record #8052)

[22] Log Book on Search and Rescue Activities, 11/05/89-11/12/89 (FaAA Record #7000)

[23] Avonbeg Deck Log, 11/01/89-11/13/89 (FaAA Record #3022)

[24] Map 2 of Search and Rescue Area (FaAA Record #8017)

[25] Boat Search Patterns Night of Nov 5 and Morning of Nov 4, 11/05/89-11/06/89 (FaAA Record #8050)

[26] Rapid Deployment of Diving/ROV Spread, 11/04/89-11/05/89 (FaAA Record #8057)

[27] [Nuse-Ende] Daily Boat Log, 11/01/89-11/15/89 (FaAA Record #3005)

[28] Seacrest Search and Rescue Report, Seacrest Hull Search and Recovery Operation Report Outline and Activity Log, 11/04/89-11/15/89 (FaAA Record #8054)

[29] Copy of Letter from USA Embassy Re: Unocal Sea Efforts, 11/03/89-11/06/89 (FaAA Record #8051)

[30] Chief Officers Log Book [Jaramac 45], 11/01/89-11/06/89 (FaAA Record #3008)

[31] [Jaramac 45] Daily Boat Log, 11/01/89-11/16/89 (FaAA Record #3009)

[32] [Asie 7] Deck Log, 11/01/89-11/13/89 (FaAA Record #3021]

[33] Chief Officers Log Book [Nusa-Ende DB15], 11/01/89-11/15/89 (FaAA Record #3004)

[34] [Gray Vanguard] Chief Officer's Log Book, 11/01/89-11/13/89 (FaAA Record #3015)

[35] Seacrest Search and Rescue Activity Re: Obtaining Additional Air Support, 11/04/89-11/12/89 (FaAA Record #8053)

[36] Seacrest Tragedy Search and Rescue Operations: Survivor Casualty and Debris Report Recorded In Emergency Control Room Unocal Thailand Ltd., Bangkok, 11/03/89 - 11/12/89 (FaAA Record #8036)]

[37] Beach Party Search Report, Trad Province, 11/30/89 - 12/06/89 (FaAA Record #8035)]

[38] Chronological Report of Actions Taken by Chavanut Vongsayan During the Seacrest Incident (FaAA Record #8046)

12.0 APPLICATION OF NATIONAL SEARCH AND RESCUE MANUAL SEARCH METHODOLOGY TO SEACREST

The National Search and Rescue (SAR) manual provides procedures for planning and executing searches for lost persons or objects. These procedures make use of input data such as the last known position, trajectory, and destination of the search object and environmental factors, such as weather conditions and water currents, that can influence the future position of the object. The methods described in the SAR manual were used to estimate the drift trajectories of Seacrest crew members lost at sea during Typhoon Gay.

The purpose of this exercise was to determine if the procedures in the SAR manual would have been useful in locating Seacrest victims. In order to accurately evaluate the value of the SAR manual procedures, only data available to searchers at the time of the incident were used in implementing the method. More accurate predictions of the drift might be possible if additional data were used, but this addition would be contrary to the purpose of this study.

12.1 Implementation of SAR Procedure

The SAR method requires as input data the last known location and the nature of the lost vessel; the time at which the vessel was lost; the weather before and after the vessel was lost; and information about sea currents, tidal currents, and surf currents. Wind enters into the computations in two ways: (1) by "blowing the water," i.e., generation of currents in the water (called wind currents, (WCs), and (2) by "blowing the object," called leeway. The total drift of an object in open water results from the sum of the sea, tidal, surf, and wind currents, and from the leeway. It was necessary to make assumptions about missing or incomplete data in order to implement the SAR manual procedures. These assumptions were:

1. The instant at which members of the Seacrest crew began to drift was unknown. Therefore, it was assumed that the time at which the Seacrest capsized was 1326 (the time of the last radio contact with Seacrest) and that the crew members began to drift at 1330.
2. The initial position of Seacrest crew members was unknown. Therefore, it was assumed that the initial position from which the crew members began to drift was at or near the last known position of Seacrest (101°21.37N 9°42.25E).
3. The SAR manual procedures require wind data every six hours. When this data were not available, reasonable estimates of the wind speed and direction were made, based on the available data. The rationalization for these estimates is discussed in greater detail below.
4. No data were available for surf currents. The contribution of surf currents was negligible because the Seacrest capsized where surf currents are small far from shore.
5. No data were available for the sea currents or tidal currents. Their contributions were not included in the calculations because the SAR manual does not specifically deal with situations where data are lacking. These currents, unlike surf currents, can be significant, and omission of these currents can introduce errors.

12.2 Drift Calculations

With the above simplifications, drift is determined by two components, wind current and leeway. The calculation of each of these components is described below.

Wind blowing across the surface of the water generates currents in the water. SAR procedures recommend inclusion of wind current calculations in situations involving water depth of over 100 feet and distances greater than 20 miles from shore [1]. Since the Seacrest was in open water and was over 60 miles from land, wind currents were taken into account. The wind current contribution depends on the history of wind over the previous 48 hours and on geographical latitude.

The calculations followed the methods in the SAR manual [1]. The basic method is demonstrated briefly here.

Wind speed and direction during each 6 hour period for the preceding 48 hours are needed in order to predict the wind generated water currents for the period of interest. In these calculations, the example data shown in Table 12.1 will be used. For each period, the wind direction is shifted by a specified angle, and the wind speed is reduced by a specified factor to give a new wind direction and speed for that period. Figure 5.6 in the SAR manual is used to determine the changes in wind direction and speed that occur in each period. A separate column is given in Figure 5.6 for each 10° increment in latitude. The values should be obtained from the nearest 10 degree latitude column of Figure 5.6, rather than interpolating values. In the example shown here, the wind direction/speed is 135°/5 knots for Period 1 at 9° N latitude. The 10° latitude column of Figure 5.6a, reproduced as Figure 12.1, dictates that the wind direction should be shifted by 190° and the speed should be multiplied by 0.028 to obtain a resultant wind current direction/speed of 325°/0.14 knots for that period. This process is repeated for each of the other seven periods. The resultant wind current vectors from each of the eight 6 hour periods are resolved into north-south and east-west components, and the components are summed to give the resultant components. These components are converted back to direction/speed values to obtain the resultant wind current vector.

Leeway is the drift of an object resulting from the object being blown by the wind. Leeway increases with the amount of free surface exposed to the wind and decreases with the amount of submerged surface causing drag on the object. Leeway velocity is calculated for different objects using formulas given in the SAR manual [1]. Four different scenarios are considered for persons drifting after the Seacrest accident:

(1) the "swimmer," a free-floating person;
(2) the surfer, a person who floats with the aid of some wreckage debris of size similar to a surfboard;
(3) the "raft with drogue," a person who floats on a raft equipped with a drogue or sea anchor; and
(4) the "raft without drogue," a person who floats with the aid of a raft with no sea anchor.

These four scenarios require four different leeway calculations. The appropriate formulas for calculating leeway velocities for these objects are reproduced in Figure 12.2. The leeway velocity is zero for submerged objects or floating persons ("swimmer"). The leeway direction is assumed to be the same as the wind direction, but large variations can occur. In the SAR manual, the formulas are limited to wind speeds from 5 - 40 knots. In this application, the formulas were extrapolated to wind speeds greater than 40 knots because the manual did not specify an alternative method. The data contained no wind velocities of less than 5 knots. Figure 12.2 demonstrates the calculation of leeway velocities for wind conditions of Period 1.

The leeway contribution is added vectorially to the wind current to obtain the total drift of the objects. This is demonstrated in Figure 12.3. These velocities are used to predict drift during the 6 hour interval centered around Period 1; i.e., from time 0900 - 1500 on November 5. This entire process is repeated for every 6 hour interval to update drift velocities for the missing persons. The drift distance is obtained by multiplying the drift velocity by the drift time.

12.3 Results

Two "levels" of weather data were identified in this study: "Regional" and "Field" data. The Regional data were derived primarily from Thai Meteorological Department Weather Service forecasts [2] and are probably the most readily available set of weather data that search planners could have assembled. Supplemental data were also obtained from a radio log [3] that contained weather reports transmitted from observers in the vicinity of Seacrest.

The Field data were obtained from the deck logs of boats in the vicinity of Seacrest. These data would give you a more complete weather picture, but they would also require more time and effort to assemble.

12.3.1 Predictions Based on Regional Data

Wind data for "Regional" weather were obtained from two sources: (1) a log of radio communications during the typhoon and (2) local weather forecasts. The radio log was useful because vessels in the vicinity of Seacrest reported wind conditions over the radio. During the typhoon, the wind direction changed dramatically over distances of 10 nautical miles. Because of this, the wind conditions reported onshore or by distant vessels might not be representative of the wind at Seacrest. For this reason, wind data during the storm were obtained chiefly from reports by Seacrest or the Platong drilling platform, which was located three nautical miles away from Seacrest prior to the storm. Before and after the storm, when wind conditions were more uniform, data were obtained from Thai Meteorological Department weather reports. A summary of the available weather data is shown in Table 12.1.

The procedures in the SAR manual require weather data every six hours. The Regional data were incomplete in this respect, and it was necessary to generate the missing data by making reasonable estimates about the wind conditions. These estimations were made primarily in the period before the storm when wind speeds were low, so the procedure should not be overly sensitive to errors in these estimations. The resulting set of wind data that was used for subsequent calculations is shown in Table 12.2.

Table 12.1

ORIGINAL WEATHER DATA

Original Weather Data

Date/Time	Wind Dir ° 0 = true N.	Wind Speed KNOTS	Source of Data
11-01 1200	45	5	Direction from Upper Winds (600m) Forecast Data, Speed estimated
11-02 1200	45	10	Direction from Upper Winds (600m) Forecast Data, Speed estimated
11-03 0941	45	85	Direction from Seacrest radio report @0916
11-03 1041	45	85	Direction from Seacrest radio report 0916, speed from Seacrest radio report 1041
11-03 1152	45	35	Direction from Seacrest radio report at 0916, speed from Seacrest radio report at 1041
11-03 1217	45	0	Seacrest radio reports no wind
11-03 1326			Winds back up, last radio contact with Seacrest
11-03 1545	225	80	Direction assumed from location of storm, speed from Platong radio report
11-03 1829	225	40	Direction assumed from location of storm, speed from Platong radio report
11-03 1950	225	30	Report from Platong
11-04 1247	130	15	Direction from forecast, speed from Platong report
11-04 2200	112	5	Report from Seacrest location
11-05 1200	135	10	Direction from Upper Winds (600m) Forecast Data, Speed estimated

Table 12.2

COMPLETE REGIONAL WIND DATA SET
USED IN SEARCH AND RESCUE CALCULATIONS

DATE/TIME	Wind Dir, ° 0 = true N.	Wind Speed KNOTS
11-01 1800	45	5
11-02 0000	45	5
11-02 0600	45	10
11-02 1200	45	10
11-02 1800	45	20
11-03 0000	45	40
11-03 0600	45	80
11-03 1200	45	0
11-03 1800	225	50
11-04 0000	225	30
11-04 0600	225	20
11-04 1200	130	15
11-04 1800	121	10
11-05 0000	112	10
11-05 0600	135	10
11-05 1200	135	5
11-05 1800	135	5
11-06 0000	135	5

Four different scenarios were considered: "swimmer," "surfer," raft with drogue (sea anchor), and raft without drogue. The "swimmer" is representative of a floating person. The swimmer was assumed to float, but not to swim. The "surfer" is representative of a person who floated with the assistance of debris from the incident, the debris being similar in size to a surfboard. Again, it is assumed that the surfer did not actually surf. Finally, the two raft models represent persons who drifted in rafts of various designs.

The trajectories calculated for each of these scenarios are shown in Figure 12.4. The origin is the position of Seacrest at the time and position that it was assumed to capsize (1326 November 3, 101°21.37N, 9°42.25E). The next point along each curve is the position of the person or raft at 0600 on November 3. Each subsequent point is the new location after an additional 6 hours of drift. In all of these scenarios, the objects were predicted to drift to the northeast by distances from 35 nautical miles for persons in the water to 76 nautical miles for persons in rafts. The wind current is the same in all four situations, so the difference between them is due to differing leeway.

<u>12.3.2 Predictions Based on Field Data</u>

Field wind data were extracted from the log books of boats stationed near Seacrest during the typhoon (see Table 12.3.). Wind data were reported in the boat logs as a wind direction (northeast, for example) and a Beaufort wind force.

Table 12.3

WIND DATA FROM THE FIELD IN THE VICINITY OF SEACREST

Wind Data from the Field in the Vicinity of Seacrest.

DATE	TIME	WIND DIR.	WIND FORCE (AT ASIE IV)	NUMBER OF BOATS
Nov. 1, 1989	1800	NE	7	3
Nov. 2, 1989	0000	NE	7	3
Nov. 2, 1989	0600	NE	7	3
Nov. 2, 1989	1200	NE	7	3
Nov. 2, 1989	1800	NE	8	3
Nov. 3, 1989	0000	NE	8	3
Nov. 3, 1989	0600	??	8	
Nov. 3, 1989	1200	??	11	
Nov. 3, 1989	1800	??	9	
Nov. 4, 1989	0000	SE	8	6
Nov. 4, 1989	0600	SE	5	4
Nov. 4, 1989	1200	SE	4	5
Nov. 4, 1989	1800	SE	4	4
Nov. 5, 1989	0000	SE	3	3
Nov. 5, 1989	0600	SE	3	3
Nov. 5, 1989	1200	SE	3	4
Nov. 5, 1989	1800	SE	3	2
Nov. 5, 1989	0000	SE	3	2

Included in the table are the number of observers (boats) in the vicinity whose boat logs were used in determining wind direction. Wind forces are those reported by Asie IV, a boat that was close to the Seacrest location during the storm. Beaufort wind forces were converted to wind speeds using a chart from the American Practical Navigator, the contents of which are reproduced in Table 12.4. The chart gives a range of speeds for each wind force number; the mean speed from each range was used in subsequent calculations. The conversion from wind force to wind speeds is summarized in Table 12.4.

Table 12.4

CONVERSION FROM WIND FORCE TO WIND SPEED

Table 12.4. Conversion from wind force to wind speed.

Beaufort Force NumberWind Speed Range, Knots
Wind Speed Used in Calcs, Knots under and overN/A

It was assumed that the searchers were familiar with the typical wind flow patterns generated by typhoons. In the northern hemisphere, these storms generate winds that circulate in a counter-clockwise direction when viewed from above. Also, the wind observed near the eye of the storm is in a tangential direction, while that observed far from the storm is radial directed, flowing towards the eye of the storm.

In Table 12.3, the wind data for November 3 from 0600 - 1800 are incomplete. The weather on this day was erratic due to disturbances from the nearby storm. Conflicting weather reports were obtained from neighboring boats because wind data during this period were very dependent on position, and because the boats had limited means for accurately determining their position and wind. For this study, attempt was made to reconcile inconsistencies in the data using engineering judgment. Two scenarios resulted from this analysis. Their development is detailed next.

There were four boats in the vicinity of Seacrest on November 3: Gray Vanguard (GVG), Gray Sword (GS) , Gray Guard (GG), and Asie I (A4). The attached figures show the positions and wind direction reports of these boats. As discussed in the main text, these locations and weather reports may not be accurate.

At 0600 three boats reported a northwest wind, while the fourth reported a northeast wind (see Figure 12.5). The three wind reports in agreement are assumed to be accurate. Assuming that they were close enough to the storm to experience tangential wind, this places the storm northeast of these boats. The boats had started steaming to the south about two hours earlier, and their true position may have been south of that indicated on the attached figures. Two scenarios are reasonable: (1) Gray Sword, Gray Guard and Aise 4 were indeed to the south; Gray Vanguard was further north and was reporting an accurate wind direction; and the storm was to the southeast. In this case, Seacrest probably experienced a northeast wind similar to Gray Vanguard. Otherwise, (2) the positions of the boats were accurate, and all of the boats, including Seacrest, experienced a northwest wind. Figure 12.6 is a sketch showing a possible location of the storm at 0600 November. 3.

At 1800 all of the neighboring boats reported a southwest wind (Figure 12.7). It is assumed again that they were close enough to the storm to see tangential winds. It is further assumed that Seacrest was even closer to the storm than the other ships (i.e., the storm was to the northeast) and must have seen a tangential wind in the same direction, southwest (Figure 12.8). The closeness of the boats to the storm was supported by the report that Aise 4 went through the eye of the storm at about 0900. Seacrest was closer, since it went through the eye of the storm at 1200.

At 1200 there was little agreement on wind direction among the boats (Figure 12.9). This was close to the period that Seacrest passed through the eye of the storm. Seacrest reported northeast winds at 1152. The wind direction for this time period was taken as the vector average of that before and after the storm. For scenario (2) above, Seacrest saw a northwest wind before and a southwest after the storm, with a resulting west wind. For scenario (1) above, Seacrest saw a northeast wind before and a southwest after the storm, with a resulting vector average of zero wind. It is unlikely that all of the wind seen by the Seacrest "canceled out," but it is possible that the cumulative effect of the erratic winds during this six hour period was to leave the ship reasonably close to its original position.

The four survivor scenarios that were considered before for regional data are also treated here: "swimmer," "surfer," raft with drogue, and raft without drogue.

The trajectories calculated for each type of survivor are shown for the two wind data scenarios in Figures 12.10 to 12.11, respectively. The two scenarios are distinguished by the wind data input for November 3. The origin is the position of Seacrest at the time and position that it was assumed to capsize: 1326 November 3, at position 101°21.37N, 9°42.25E. In the first scenario, the objects were predicted to drift 44 nautical miles on a heading 30° true from the origin for persons in the water and 84 nautical miles on a heading 358° true for persons in rafts. In the second scenario, the objects were predicted to drift 28 nautical miles on a heading 28° true for persons in the water and 71 nautical miles on a heading 352° true for persons in rafts.

12.4 Summary

The SAR method predictions depended on the details of the weather scenarios that were used as input. Results predicted that persons floating freely in the water would drift 18-35 nautical miles northeast of their original location in 35 hours and 26-43 nautical miles northeast in 59 hours. Likewise, persons in rafts would drift 45-78 nautical miles north-northeast in 35 hours and 68-78 nautical miles north in 59 hours.

12.5 References

[1] National Search and Rescue Manual, Vols. 1 and 2, pgs. 5, 7, 8, 9

[2] Gulf of Thailand, Typhoon Gay, Track of Typhoon Based on Thai Meteorological Data and Oceanroutes Data, Map (FaAA Record #1034)

[3] Single Side Band Radio Log, 11/03/89-11/05/89 (FaAA Record #4002)

[4] Summary of Support Vessel Activity, 11/02/89-11/12/89 (FaAA Document #3027)

13.0 TRAJECTORY ANALYSIS FOR PERSONS IN THE WATER

13.1 Scope of the Analysis

Seacrest was located at 9°46N, 101°18E when it capsized at about 1350 on November 3, 1989. When the ship overturned, most of the crew members were swept into the sea. A group of crew members was found 62.5 miles away at 10° 35.9N, 100°39.26E at 0800 on November 5, 1989. Another group was found 69.1 miles away at 10°36.4N, 100°29.83E at 1347 on November 6, 1989.

The large distance between the rescue and capsize locations was puzzling, given the natural improvement of the weather after the passage of the typhoon. In addition to the large drift, there were questions about the range and pattern of the search and rescue operations, which were initiated and directed by Unocal after the accident. Clearly, a mathematical model was needed to simulate the trajectory of the floating crew members. The analytical prediction model of the drift trajectories can be utilized, after validation, to study and evaluate various search and rescue scenarios.

13.2 Mathematical Model

A body floating in the ocean experiences forces resulting from the environmental conditions. It then assumes a six-degree-of-freedom motion, depending upon the magnitude and direction of the forces. The motion components considered in a drift trajectory study are the surge, sway, and yaw. It can be assumed that yaw will be insignificant for a human body in the water. Consequently, the governing equations of motion degenerate into the following expressions of Newton"s law:

$$m = Fx \qquad (13.1)$$
$$m = Fy, \qquad (13.2)$$

where m is the inertial and hydrodynamic mass of the drifting body; Fx and Fy are the force components in the global x and y directions, respectively; and and are the global accelerations.

The forces are induced by the action of the wind, waves, and currents. Each force component formulation is further described.

The current force is given by the semi-empirical expression of the drag equation:

$$Fx = 1/2\ w\ CD\ A\ (Uc -)|Uc - | \qquad (13.3)$$
$$Fy = 1/2\ w\ CD\ A\ (Vc -)|Vc - |, \qquad (13.4)$$

where w is the water density; CD is the drag coefficient; A is the projected submerged area; and are the body velocities in the x and y directions; and Uc.and Vc are the current velocity components in the x and y directions, respectively. It has been assumed that the current encounters the same projected area in the x and y directions. Throughout this study, the drag coefficient due to friction and pressure drag was assigned a fixed value equal to one.

The wind force was given by expressions similar to equations (13.3) and (13.4), after replacing w with the air density, A with the area above the water, and Uc and Vc with the wind velocities. The wind forces were very low due to the low density of air and the low above the water area of a drifting body. They were included in the model, but they can be neglected without any loss of accuracy.

The wave induced forces, also referred to as wave-drift forces, a consequence of the mass transport properties of a real life wave. The wave-drift forces are proportional to the product of wave height and wave slope. They are significant contributors only if induced by steep, high waves. The magnitude of the wave-drift force (in the dominant direction of wave propagation) was calculated by the following expression:

Fw = rw g B[_ìµ S () CDR () d]/12. (13.5)

This expression is valid for a cylindrical shape similar to a human body. B is the width of the body, is the wave frequency, CDR is the drift coefficient, and S is the power spectral density. The functional dependence of CDR on frequency, , is depicted in Figure 13.1 from [13.1]. Spectral representation of waves were taken by modeling the sea state with a two-parameter ITTC spectrum. The wave spectrum is defined by the significant wave height and the modal period. Accordingly, the integral in equation (13.5) weights the contribution of each wave frequency on the drift force.

Environmental data were available for a five mile grid spaced over the Gulf of Thailand. For each grid point, wind velocity, wind direction, significant wave height, mean period, and wave angle were hindcast at 15 minute intervals during Typhoon Gay. Velocity and current direction at each grid point were available at hourly intervals.

The equations described in the mathematical model were solved by Runge-Kutta numerical interaction. Thus, the location of the crew with respect to the capsize location was obtained at regular time intervals. This provides a locus of the crew in the water.

At each step, environmental properties were interpolated from the four grid points surrounding the crew location and chosen from the record of the corresponding time interval. Thus, these properties changed every 15 minutes for all grid points. Current values were updated at the surrounding grid points each hourly interval. During each 15 minute interval, integration was performed until a steady state was reached. The transient phase was typically very short - - on the order of two to three seconds. Subsequent time marching was simulated by assuming accelerations equal to zero during the steady-state phase of the interval.

13.3 Drift Predictions

Trajectory simulations were performed with various combinations of forces on the body as well as with input parameters. The cases considered were: a) current, wind, and wave forces; b) current and wave forces; and c) current forces. The mass varied from 140 to 160 pounds, and the width of the body changed from 2 to 3 feet (keeping constant the projected area). Results for a few of the cases considered are presented in Table 13.1; these results are presented in 6 hour intervals.

A different presentation of the results is shown in Figures 13.2 to 13.9. In these figures, the search paths of boats and helicopters are presented on a geographical map of the capsize area. The locations where survivors were found are also indicated. The path of a drifting body predicted by the mathematical model is illustrated on the map in 6 hour intervals (last points correspond to a 4 hour interval). Figures 13.2 and 13.3 depict a basic case compared with a current-only scenario. Figures 13.4 and 13.5 are necessary magnifications of the area in order to follow the trajectories predicted by the current only model. The effect of the width of the body is presented in Figures 13.6 and 13.7. Finally, the contribution of wind forces to the drift trajectory is graphically depicted in Figures 13.8 and 13.9.

Table 13.1

SENSITIVITY ANALYSIS OF DRIFT TRAJECTORIES

Case 1: Current and wave forces only, mass of the body = 160 lbs., width = 2 feet

Time (hrs)	x(nm)	y(nm)	Longitude	Latitude
0	0	0	101°18"	9°46"
6.0	-7.427	5.668	101°10.4"	9°51.7"
12.0	-12.802	13.071	101°4.9"	9°59.1"
18.0	-16.981	19.552	101°0.7"	10°5.6"
24.0	-20.562	24.741	100°57"	10°10.7"
30.0	-23.672	29.209	100°53.8"	10°15.2"
36.0	-26.544	33.321	100°50.9"	10°19.3"
42.0	-29.285	37.269	100°48.1"	10°23.3"
46.0	-30.992	39.710	100°46.4"	10°25.7"

Table 13.1 (Continued)

SENSITIVITY ANALYSIS OF DRIFT TRAJECTORIES

Case 2: Current and wave forces only, mass of the body = 160 lbs., width = 3 feet

Time (hrs)	x(nm)	y(nm)	Longitude	Latitude
0	0	0	101°18"	9°46"
6.0	-11.367	7.878	101°6.4"	9°53.9"
12.0	-19.012	17.835	100°58.6"	10°3.8"
18.0	-26.021	28.402	100°51.4"	10°14.4"
24.0	-32.163	37.599	100°45.2"	10°23.6"
30.0	-37.322	45.163	100°39.9"	10°31.2"
36.0	-41.698	51.498	100°35.5"	10°37.5"
42.0	-46.048	57.269	100°31"	10°43.3"
46.0	-48.889	60.863	100°28.1"	10°46.9"

Case 3: Current and wave forces only, mass of the body = 160 lbs., width = 2.5 feet

Time (hrs)	x(nm)	y(nm)	Longitude	Latitude
0	0	0	101°18"	9°46"
6.0	-9.244	7.135	101°8.6"	9°53"
12.0	-16.426	16.507	101°1.2"	10°2.5"
18.0	-22.041	25.089	100°55.5"	10°11.1"
24.0	-26.929	32.316	100°50.5"	10°18.3"
30.0	-30.984	38.488	10°46.4"	10°24.5"
36.0	-34.455	43.949	100°42.8"	10°29.9
42.0	-38.040	49.079	100°39.2"	10°35.1"
46.0	-40.295	52.151	100°36.9"	10°38.2"

Table 13.1 (Continued)

SENSITIVITY ANALYSIS OF DRIFT TRAJECTORIES

Case 4: Current forces only, mass of the body = 160 lbs., width = 2 feet

Time (hrs)	x(nm)	y(nm)	Longitude	Latitude
0	0	0	101°18"	9°46"
6.0	-0.353	-1.368	101°17.6"	9°44.6"
12.0	1.245	-0.977	101°19.3"	9°45.0"
18.0	2.394	-0.878	101°20.4"	9°45.1"
24.0	3.139	-1.237	101°21.2"	9°44.8"
30.0	3.692	-1.787	101°21.8"	9°44.2"
36.0	4.141	-2.380	101°22.2"	9°43.6"
42.0	4.528	-2.976	101°22.6"	9°43.0"
46.0	4.763	-3.375	101°22.9"	9°42.6

Case 5: Current , wind and wave forces, mass of the body = 160 lbs., width = 2 feet

Time (hrs)	x(nm)	y(nm)	Longitude	Latitude
0	0	0	101°18"	9°46"
6.0	-7.977	6.390	101°9.9"	9°52.4"
12.0	-13.814	14.262	101°3.9"	10°0.26"
18.0	-18.294	21.156	100°59.3"	10°7.2"
24.0	-22.170	26.730	100°55.4"	10°12.7"
30.0	-25.455	31.472	100°52"	10°17.5"
36.0	-28.370	35.858	100°49.1"	10°21.9
42.0	-31.183	40.014	100°46.2"	10°26"
46.0	-32.956	42.571	100°44.4"	10°28.6"

Table 13.1 (Continued)

SENSITIVITY ANALYSIS OF DRIFT TRAJECTORIES

Case 6: Current, wind and wave forces, mass of the body = 140 lbs., width = 2 feet

Time (hrs)	x(nm)	y(nm)	Longitude	Latitude
0	0	0	101°18"	9°46"
6.0	-7.977	6.390	101°9.9"	9°52.4"
12.0	-13.814	14.262	101°3.9"	10°0.26"
18.0	-18.294	21.156	100°59.3"	10°7.2"
24.0	-22.165	26.730	100°55.4"	10°12.7"
30.0	-25.455	31.472	100°52"	10°17.5"
36.0	-28.370	35.858	100°49.1"	10°21.9"
42.0	-31.177	40.014	100°46.2"	10°26"
46.0	-32.956	42.571	100°44.4"`	10°28.6"

13.4 Conclusions

The following conclusions can be drawn based on the results of the sensitivity analyses and the information from the field on search and rescue.

1. There is excellent agreement between the predicted drift trajectories and the actual ones. The rescue locations and the predicted drift trajectories are in agreement with respect to both drift direction and magnitude. The rescue location of the first group of survivors should only be considered. This is due to the fact that the second group was picked up after 72 hours of elapsed time. Hindcast weather data are not available beyond 60 hours from the capsize time. Extending the time frame of hindcast weather data was not considered necessary for purposes of verification.

   When the storm subsided, the tidal currents dominated the drift because the wind, current, and wave velocities were low. Then, drift simulation would not be accurate in predicting the trajectory. Therefore, the location of the group which was found 72 hours later could not be compared against the model. However, both groups were found by searches in close proximity.

2. The distance traveled by a body depends strongly on its mass and width. Heavier and wider bodies (representing in effect survivors holding onto debris) will travel farther from the capsize location. Heavier bodies reach steady-state velocities later than lighter ones. Wider bodies are subject to higher drift forces.

3. Wind forces have negligible effects on drift trajectories.

4. A consideration of current forces only yields trajectories within a five mile radius from capsize location. Consequently, in contrast to what is typically recommended and accepted as the "state of the art" in search and rescue operations, wave drift is the dominant "drift driving" force component. This is justified by the dominance of high and/or steep waves during drifting in severe weather.

5. The unusually high contribution of wave drift forces initiated drift at very high velocities (of the order of two knots for the first six hours). The survivors drifted away from the ship within a short time after the accident. It can be easily deduced from the results of the simulations that survivors were drifting outside the search paths of the boats and helicopters on November 4 and 5, 1989.

14.0 STORM OPERATING PROCEDURES

Several factors contribute to the survival of a ship"s passage through a typhoon. Company policy and the captain"s education and experience play a significant part in the master"s choice of ship handling procedures. Accurate foreknowledge of the storm"s intensity and direction of travel affect the captain"s ability to make timely decisions. Vessel seaworthiness contributes to the action a master must take to successfully weather a storm. Seacrest"s particular situation cannot be based on textbook format of storm operating procedures.

Storm ship handling techniques are discussed in industry references, and manuals addressing the policy of the ship owner/operator. "Instruction for Operation of the vessel during Adverse Weather Condition", Section 3.5 in the Seacrest Operations Manual (Figure 14.1) mentions vessel trim and securing of ventilation, door and hatch openings. Life saving equipment, evacuation procedures, escape routes and fire fighting equipment are detailed in other sections of this manual. Unocal Thailand"s "Emergency Procedures Manual" does not address heavy weather ship handling (Figure 14.2). However, when company policy regarding specific marine procedures is undefined, Unocal Thailand refers ship officers to a list of references in its "Safety Policies and Procedures Manual" (Figure 14.3).

Of the references listed in Figure 14.3, at least <u>Knight"s Modern Seamanship</u> discusses storm ship handling techniques. Heavy weather ship maneuvering procedures are also described in the industry references listed in Figure 14.4. These are used by ship"s officers operating vessels in the U.S. Merchant Marine, Navy, and Coast Guard. Figure 14.5 is a summary of ship handling recommendations in cyclonic storms from references listed in Figure 14.4. An assumption of these recommendations is that the ship is free running. No mention of ships at anchor or at sea in heavy weather is found. In addition, available horsepower, a major parameter for typhoon ship handling, is not discussed.

Gay developed into typhoon strength from a tropical storm very few hours before its advent on Seacrest. The path and development of Gay was monitored by Thai Met, Oceanroutes, and other meteorological bureaus in the area. None of their reports contain a typhoon forecast. Thailand television networks issued a mere fishing boat warning the evening of November 2, 1989, whereas the morning report of the reputable Oceanroutes weather service in Singapore characterized the oncoming storm as a "rock "n roll shaker". In conclusion, there was not a timely forewarning of the advent of Gay. A timely forecast could have allowed more preparation time, or even evacuation and/or escape from the path of the typhoon.

Given the fact that the weather developed into typhoon strength shortly before its eye reached Seacrest, a fundamental question arises. Should the ship have cut its anchors and sailed away from the drilling site, or should it have remained at the site? This decision was heavily influenced by two factors; namely, the unpredictability of the path of a typhoon and the low propulsive power of Seacrest. Seacrest was equipped with two thrusters which could yield a maximum of 8 knot speed under ideal conditions of the hull and weather. It can be surmised that Seacrest could not have developed more than 8 knots. Those thrusters were placed, primarily, to enhance maneuverability rather than to provide self propulsion in adverse weather. Consequently, they could not be relied on to provide the high speed needed to bring the ship out of hit range. On the other hand, the escape route under imminent typhoon encounter is highly uncertain. Historical data of paths of typhoons indicate that the direction of travel of a typhoon can be continuously changing in spiraling patterns. It is felt that since there was not adequate warning time, the decision to stay by the Seacrest master was justifiable. The decision to evacuate the ship had to be made by the master as well. Given the short warning time, it is preferable to face a typhoon on board a larger intact vessel than onboard more vulnerable smaller vessels or lifeboats.

The decision to face the typhoon with all anchors was a wise one. The mooring cables are excellent means to provide resistance to roll, since they increase the stiffness and damping of the boat. In addition, the mooring winches of Seacrest could automatically disengage the windward or leeward anchors, depending on the direction of the weather. The beneficial increase of the ship"s resistance to the weather due to the presence of mooring lines at proper locations has been demonstrated by the fact that the ship faced the most severe weather conditions when it first encountered the typhoon. At this time the ship had all anchors and it survived. After failure of the anchor lines it drifted, dragging anchor #7. The analysis described in Section 10 demonstrates that the resistance to broadside to the wind equilibrium provided by the cable tension was superior to the one by the thrusters. Lack of anchor #7 would most likely have accelerated the capsize. Although not backed by analysis, it can be stated that had the mooring lines not failed, Seacrest may have survived the typhoon.

In conclusion, the decision to stay at the site and fight the typhoon in the moored configuration was justifiable given the inadequate warning time of the advent of the typhoon and the low self propulsion capacity; i.e., low maneuvering ability in adverse weather of Seacrest.