March 26, 2011

Japanese Rules for Nuclear Plants Relied on Old Science

By NORIMITSU ONISHI and JAMES GLANZ

TOKYO — In the country that gave the world the word tsunami, the Japanese nuclear establishment largely disregarded the potentially destructive force of the walls of water. The word did not even appear in government guidelines until 2006, decades after plants — including the Fukushima Daiichi facility that firefighters are still struggling to get under control — began dotting the Japanese coastline.

The lack of attention may help explain how, on an island nation surrounded by clashing tectonic plates that commonly produce tsunamis, the protections were so tragically minuscule compared with the nearly 46-foot tsunami that overwhelmed the Fukushima plant on March 11. Offshore breakwaters, designed to guard against typhoons but not tsunamis, succumbed quickly as a first line of defense. The wave grew three times as tall as the bluff on which the plant had been built.

Japanese government and utility officials have repeatedly said that engineers could never have anticipated the magnitude 9.0 earthquake — by far the largest in Japanese history — that caused the sea bottom to shudder and generated the huge tsunami. Even so, seismologists and tsunami experts say that according to readily available data, an earthquake with a magnitude as low as 7.5 — almost garden variety around the Pacific Rim — could have created a tsunami large enough to top the bluff at Fukushima.

After an advisory group issued nonbinding recommendations in 2002, Tokyo Electric Power Company, the plant owner and Japan's biggest utility, raised its maximum projected tsunami at Fukushima Daiichi to between 17.7 and 18.7 feet — considerably higher than the 13-foot-high bluff. Yet the company appeared to respond only by raising the level of an electric pump near the coast by 8 inches, presumably to protect it from high water, regulators said.

“We can only work on precedent, and there was no precedent,” said Tsuneo Futami, a former Tokyo Electric nuclear engineer who was the director of Fukushima Daiichi in the late 1990s. “When I headed the plant, the thought of a tsunami never crossed my mind.”

The intensity with which the earthquake shook the ground at Fukushima also exceeded the criteria used in the plant’s design, though by a less significant factor than the tsunami, according to data Tokyo Electric has given the Japan Atomic Industrial Forum, a professional group. Based on what is known now, the tsunami set off the nuclear crisis by flooding the backup generators needed to power the reactor cooling system.

Japan is known for its technical expertise. For decades, though, Japanese officialdom and even parts of its engineering establishment clung to older scientific precepts for protecting nuclear plants, relying heavily on records of earthquakes and tsunamis, and failing to make use of advances in seismology and risk assessment since the 1970s.

For some experts, the underestimate of the tsunami threat at Fukushima is frustratingly reminiscent of the earthquake — this time with no tsunami — in July 2007 that struck Kashiwazaki, a Tokyo Electric nuclear plant on Japan’s western coast.. The ground at Kashiwazaki shook as much as two and a half times the maximum intensity envisioned in the plant’s design, prompting upgrades at the plant.

“They had years to prepare at that point, after Kashiwazaki, and I am seeing the same thing at Fukushima,” said Peter Yanev, an expert in seismic risk assessment based in California, who has studied Fukushima for the United States Nuclear Regulatory Commission and the Energy Department.

There is no doubt that when Fukushima was designed, seismology and its intersection with the structural engineering of nuclear power plants was in its infancy, said Hiroyuki Aoyama, 78, an expert on the quake resistance of nuclear plants who has served on Japanese government panels. Engineers employed a lot of guesswork, adopting a standard that structures inside nuclear plants should have three times the quake resistance of general buildings.

“There was no basis in deciding on three times,” said Mr. Aoyama, an emeritus professor of structural engineering at the University of Tokyo. “They were shooting from the hip,” he added, making a sign of a pistol with his right thumb and index finger. “There was a vague target.”

Evolution of Designs

When Japanese engineers began designing their first nuclear power plants more than four decades ago, they turned to the past for clues on how to protect their investment in the energy of the future. Official archives, some centuries old, contained information on how tsunamis had flooded coastal villages, allowing engineers to surmise their height.

So seawalls were erected higher than the highest tsunamis on record. At Fukushima Daiichi, Japan's fourth oldest nuclear plant, officials at Tokyo Electric used a contemporary tsunami — a 10.5-foot-high wave caused by a 9.5-magnitude earthquake in Chile in 1960 — as a reference point. The 13-foot-high cliff on which the plant was built would serve as a natural seawall, according to Masaru Kobayashi, an expert on quake resistance at the Nuclear and Industrial Safety Agency, Japan's nuclear regulator.

Eighteen-foot-high offshore breakwaters were built as part of the company's anti-tsunami strategy, said Jun Oshima, a spokesman for Tokyo Electric. But regulators said the breakwaters — mainly intended to shelter boats — offered some resistance against typhoons, but not tsunamis, Mr. Kobayashi said.

Over the decades, preparedness against tsunamis never became a priority for Japan's power companies or nuclear regulators. They were perhaps lulled, experts said, by the fact that no tsunami had struck a nuclear plant until two weeks ago. Even though tsunami simulations offered new ways to assess the risks of tsunamis, plant operators made few changes at their aging facilities, and nuclear regulators did not press them.

Engineers took a similar approach with earthquakes. When it came to designing the Fukushima plant, official records dating from 1600 showed that the strongest earthquakes off the coast of present-day Fukushima Prefecture had registered between magnitude 7.0 and 8.0, Mr. Kobayashi said.

“We left it to the experts,” said Masatoshi Toyoda, a retired Tokyo Electric vice president who oversaw the construction of the plant. He added, “they researched old documents for information on how many tombstones had toppled over and such.”

Eventually, experts on government committees started pushing for tougher building codes, and by 1981, guidelines included references to earthquakes but not to tsunamis, according to the Nuclear and Industrial Safety Agency. That pressure grew exponentially after the devastating Kobe earthquake in 1995, said Kenji Sumita, who was deputy chairman of the government's Nuclear Safety Commission of Japan in the late 1990s.

Mr. Sumita said power companies, which were focused on completing the construction of a dozen reactors, resisted adopting tougher standards, and did not send representatives to meetings on the subject at the Nuclear Safety Commission.

“Others sent people immediately,” Mr. Sumita said, referring to academics and construction industry experts. “But the power companies engaged in foot-dragging and didn’t come.”

Meanwhile, the sciences of seismology and risk assessment advanced around the world. Although the United States Nuclear Regulatory Commission has come under severe criticism for not taking the adoption of those new techniques far enough, the agency did use many of them in new, plant-by-plant reviews, said Greg S. Hardy, a structural engineer at Simpson Gumpertz & Heger who specializes in nuclear plant design and seismic risk.

For whatever reasons — whether cultural, historical or simply financial — Japanese engineers working on nuclear plants continued to predict what they believed were maximum earthquakes based on records.

Those methods, however, did not take into account serious uncertainties like faults that had not been discovered or earthquakes that were gigantic but rare, said Mr. Hardy, who visited Kashiwazaki after the 2007 quake as part of a study sponsored by the Electric Power Research Institute.

“The Japanese fell behind,” Mr. Hardy said. “Once they made the proclamation that this was the maximum earthquake, they had a hard time re-evaluating that as new data came in.”

The Japanese approach, referred to in the field as “deterministic” — as opposed to “probabilistic,” or taking unknowns into account — somehow stuck, said Noboru Nakao, a consultant who was a nuclear engineer at Hitachi for 40 years and was president of Japan’s training center for operators of boiling-water reactors.

“Japanese safety rules generally are deterministic because probabilistic methods are too difficult,” Mr. Nakao said, adding that “the U.S. has a lot more risk assessment methods.”

The science of tsunamis also advanced, with far better measurements of their size, vastly expanded statistics as more occurred, and computer calculations that help predict what kinds of tsunamis are produced by earthquakes of various sizes. Two independent draft research papers by leading tsunami experts — Eric Geist of the United States Geological Survey and Costas Synolakis, a professor of civil engineering at the University of Southern California — indicate that earthquakes of a magnitude down to about 7.5 can create tsunamis large enough to go over the 13-foot bluff protecting the Fukushima plant.

Mr. Synolakis called Japan's underestimation of the tsunami risk a "cascade of stupid errors that led to the disaster" and said that relevant data was virtually impossible to overlook by anyone in the field.

Underestimating Risks

The first clear reference to tsunamis appeared in new standards for Japan's nuclear plants issued in 2006.

"The 2006 guidelines referred to tsunamis as an accompanying phenomenon of earthquakes, and urged the power companies to think about that," said Mr. Aoyama, the structural engineering expert.

The risk had received some attention in 2002, when a government advisory group, the Japan Society of Civil Engineers, published recommended tsunami guidelines for nuclear operators.

A study group at the society, including professors and representatives from utilities like Tokyo Electric, scrutinized data from past tsunamis, as well as fresh research on fault lines and local geography, to come up with the guidelines, according to a member of the study group who spoke on condition of anonymity, citing the sensitivity of the situation.

The same group had recently been discussing revisions to those standards, according to the member. At the group's last meeting, held just over a week before the recent tsunami, researchers debated the usefulness of three-dimensional simulations to predict the potential damage of tsunamis on nuclear plants, according to minutes from those meetings. "We took into account more than past data," the member said. "We tried to predict. Our objective was to reduce uncertainties."

Perhaps the saddest observation by scientists outside Japan is that, even through the narrow lens of recorded tsunamis, the potential for easily overtopping the anti-tsunami safeguards at Fukushima should have been recognized. In 1993 a magnitude 7.8 quake produced tsunamis with heights greater than 30 feet off Japan's western coast, spreading wide devastation, according to scientific studies and reports at the time.

On the hard-hit island of Okushiri, "most of the populated areas worst hit by the tsunami were bounded by tsunami walls" as high as 15 feet, according to a report written by Mr. Yanev. That made the walls a foot or two higher than Fukushima's bluff.

But in a harbinger of what would happen 18 years later, the walls on Okushiri, Mr. Yanev, the expert in seismic risk assessment, wrote, “may have moderated the overall tsunami effects but were ineffective for higher waves.”

And even the distant past was yielding new information that could have served as fresh warnings.

Two decades after Fukushima Daiichi came online, researchers poring through old records estimated that a quake known as Jogan had actually produced a tsunami that reached nearly one mile inland in an area just north of the plant. That tsunami struck in 869.

Norimitsu Onishi reported from Tokyo, and James Glanz from New York. Ken Belson and Hiroko Tabuchi contributed reporting from Tokyo.