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Zumanjaro's orange track and gondolas are supported on the face of the Kingda Ka Tower. *Photo: Ron Wyatt*

ZUMANJARO: DROP OF DOOM

HOW SCARY IS BUILT

STRUCTURAL ENGINEERS HELP PUSH THE LIMITS OF AMUSEMENT PARK RIDES.

BY RICHARD C. MALONEY, P.E., WITH MARALIESE BEVERIDGE

FROM THE DAYS of the vaudevillian sideshows to the iconic Coney Island parachute jump, people have loved being scared. Amusement parks have spent millions inventing ways to twirl, spin, gyrate, toss, hang, and turn riders topsy turvy with action-packed thrill rides. But behind the scenes of the thrill is serious engineering. A recent article in the Asbury Park Press, a newspaper local to the Six Flags Great Adventure theme park in Jackson, N.J., raised the question, "Can bigger, better, faster still be achieved? Or have we reached the peak?" One rider quoted in the article, describing the park's newest thrill ride — Zumanjaro: Drop of Doom, which drops riders 415 feet straight down — said, "When you think you're done screaming, you're still falling."

In 2005, Six Flags introduced the Kingda Ka roller coaster at Great Adventure, which is still the tallest roller coast in the world and fastest in North America. A hydraulic launch rockets riders horizontally from 0 to 128 mph in 3.5 seconds, where the momentum then carries them straight upward vertically 90 degrees into a quarter turn. Riders crest the coaster's tower 456 feet from the ground, then plunge vertically into a 270-degree (three-quarter) spiral. The train swoops down a valley and climbs a 129-foot second hill, leaving riders feeling weightless before making a left turn back into the station.

Think that's a thrill? Still pushing the limits of amusement park rides, Six Flags opened the Zumanjaro ride on July 4, 2014 — the tallest drop ride in the world. At 415 feet vertically, the Zumanjaro drop track was designed to fit on the face of the existing steel tower that supports the vertical loop of the Kingda Ka tower. The ride hauls thrill seekers to the top of the tower in three gondolas in less than 30 seconds, then the gondolas descend simultaneously, dropping independently in less than 10 seconds and as fast as 90 mph.

Like the tip of an iceberg, all that can be seen of the foundation system is the top of the shared concrete pedestal that provides support to two of the newly added support columns. Hidden below the surface is a 36-foot by 36-foot by 5-foot-thick concrete footing.

Structural design

The Kingda Ka roller coaster stretches outward from the edge of the park's Golden Kingdom area, launching riders a quarter-mile to the east before they conquer the tower loop located at the far eastern end of the ride. The tower that supports Kingda Ka's vertical loop is an impressive and overpowering presence as you enter the park's grounds. The 456-foot tower originally consisted of three main columns with more than 50 horizontal and diagonal steel pipes that formed a triangular truss structure that provides support, not only to the forces induced by the roller coaster cars, but also to safely resist environmental loads such as wind, snow, ice, and earthquake on the track and tower. The original Kingda Ka design included three massive concrete footings, one under each main tower leg. These footings were each 55 feet by 55 feet by 8 feet thick — the size necessary to safely distribute the bearing pressure onto the existing soil, as well as contain enough deadweight to resist the overtopping loads.

With such a massive structure already in place, and only a small portion of the structure's area utilized by the roller coaster track, Larry Chickola, Six Flags chief corporate engineer, crafted the idea of making more use of the tower structure by strengthening it to support the installation of three additional vertical tracks for what was destined to become Zumanjaro. With the face of Kingda Ka's tower essentially unused, it seemed to be the perfect fit — hence, the next great Six Flags idea was born.

With the commitment to make this dream a reality, Chickola reached out to Intamin Ltd., the designer of Kingda Ka and its tower structure, to see if such an idea was possible. The tower was deemed capable of supporting the proposed drop tower ride; however, it would require additional supporting columns. The additional loads from the drop tower ride itself, as well as the additional wind and earthquake loads that the drop ride introduces to the existing tower, required additional tower support.

Analysis of the existing structure and the proposed track structure resulted in the addition of 226,226 pounds of structural steel reinforcements to the tower, including six new ground-supported diagonal columns added around the tower's base. The new drop ride would also require its own support elements, including a winch to pull the riders up and supports for the three tracks that raise the gondolas. The new drop ride consists of three gondolas, each containing eight seats for a capacity of 24 riders at a time.

What the riders don't see: A footing under construction with multiple layers of steel reinforcement placed prior to receiving 24 trucks worth of concrete.

Maser Consulting P. A., whose current structural specialists have provided engineering consultation for all of the large coasters for the park for 20 years, was called upon to provide engineering for this project, including design of the foundation supports for the new tower elements, ride elements, and engineering for various other ride-related items.

How it was done

All six new tower columns contained large loads that required foundation support. The new diagonal columns project off of the tower's main columns, landing at the ground in pairs, with their baseplates only a few feet from each other. Two of the column pairs contained combined loads that required concrete footings 36 feet by 36 feet by 5 feet thick.

During construction of the original Kingda Ka footings, with its thick foundations, natural groundwater became an issue. The excavation for these footings extended more than 10 feet into the ground, requiring installation of well points to temporarily draw the water down. Such an effort was costly and slowed construction. In order to avoid this prior experience, the depth of the new foundations was minimized by utilizing shorter pedestals and a larger foundation footprint, which would allow a shallower concrete footing — requiring compensation of additional steel reinforcement due to the shallower but wider footings. These design considerations made it possible to perform construction without lowering the groundwater and ultimately resulted in more efficient construction.

The third pair of new diagonal columns, along with the winch and three drop ride tracks, all required foundation support in areas that were littered with existing ride foundations. Between the 55-foot by 55-foot foundations of the original tower construction, the continuous row of ride footings from the ride launch area, and the large mat foundation of the launch house, it was impossible to avoid existing footings. Maser Consulting's engineers performed studies on the existing foundations and the revised loadings to these footings from the newly configured tower structure, which resulted in a different load distribution with more tower loading being distributed to the newer footings. They also analyzed the loads from the new columns and structures to develop a final design that allowed the new footings to fit within and on top of the existing footings while staying within the limits of the site's soil properties and the applicable ride and building codes.

At all of the new tower column locations, the ride anchor bolts, which are preferably limited to being cast into the concrete pedestal that sits atop the concrete footing, needed to be extended into the footings themselves due to the shorter pedestals and the array of existing footings that needed to be circumvented. Maser Consulting's final designs enabled concrete working mats to be cast under the footings, which allowed proper support and alignment of the 7-foot, 5-inch-long anchor bolts, which needed to be held to a 1/8-inch tolerance while being swallowed by a wave of concrete being poured into the large footings. The winch and drop ride track footings rest on and off of the original tower footings. These foundations were designed with special considerations because of the differential bearing conditions.

Rider queuing

In addition to the ride foundation support system, Maser Consulting provided engineering for the local engineering needs. This included working hand-in-hand with the park's planners to design a ride layout that attracts potential riders from the park's midway, and gets them to and from the ride with a safe and pleasant experience. Since riders need to load the Zumanjaro ride at the base of the Kingda Ka tower, rider safety was a driving force with ride access design.

In today's parks, addressing the multiple needs of riders includes queuing riders who pay a premium to reduce ride wait time into a bypass lane, providing dedicated single-rider lanes to maintain 100-percent efficiency in ride occupancy, and providing fully compliant ADA ride access. An open-air shade structure protects all queuing riders as well as all ride operators. The queue structure, with its multiple lanes, starts 370 feet from the ride load point.

At the rider access to Zumanjaro's gondolas, Maser Consulting designed a pneumatically powered retractable roof structure that is synched to close over the ride to protect riders and operators during the ride load and unload operations.

Every winter, the ride vehicles are diligently broken down for maintenance, and regular structural inspections are performed to keep riders safe so they can be thrilled over and over again. While the debate on pushing the limits of amusement park rides will continue, make no mistake: It isn't magic — it's engineering.

Watch a video of Zumanjaro: Drop of Doom in action at www.youtube.com/watch?v=nvdvovMsTmA.

RICHARD C. MALONEY, P.E., a senior associate and department manager of the Structural Group at Maser Consulting P.A., has more than 20 years of experience leading a team of structural engineers that has provided services for amusement rides in various locations for Six Flags and other major theme park clients, including for five of the top six roller coasters in Time magazine's "2013 Top Ten Roller Coasters in the U.S." list (http://techland.time.com/2013/09/19/the-top-10-roller-coasters-in-the-u-s). **MARALIESE BEVERIDGE**, public relations specialist for Maser Consulting P.A., has more than 20 years of diversified media relations experience.