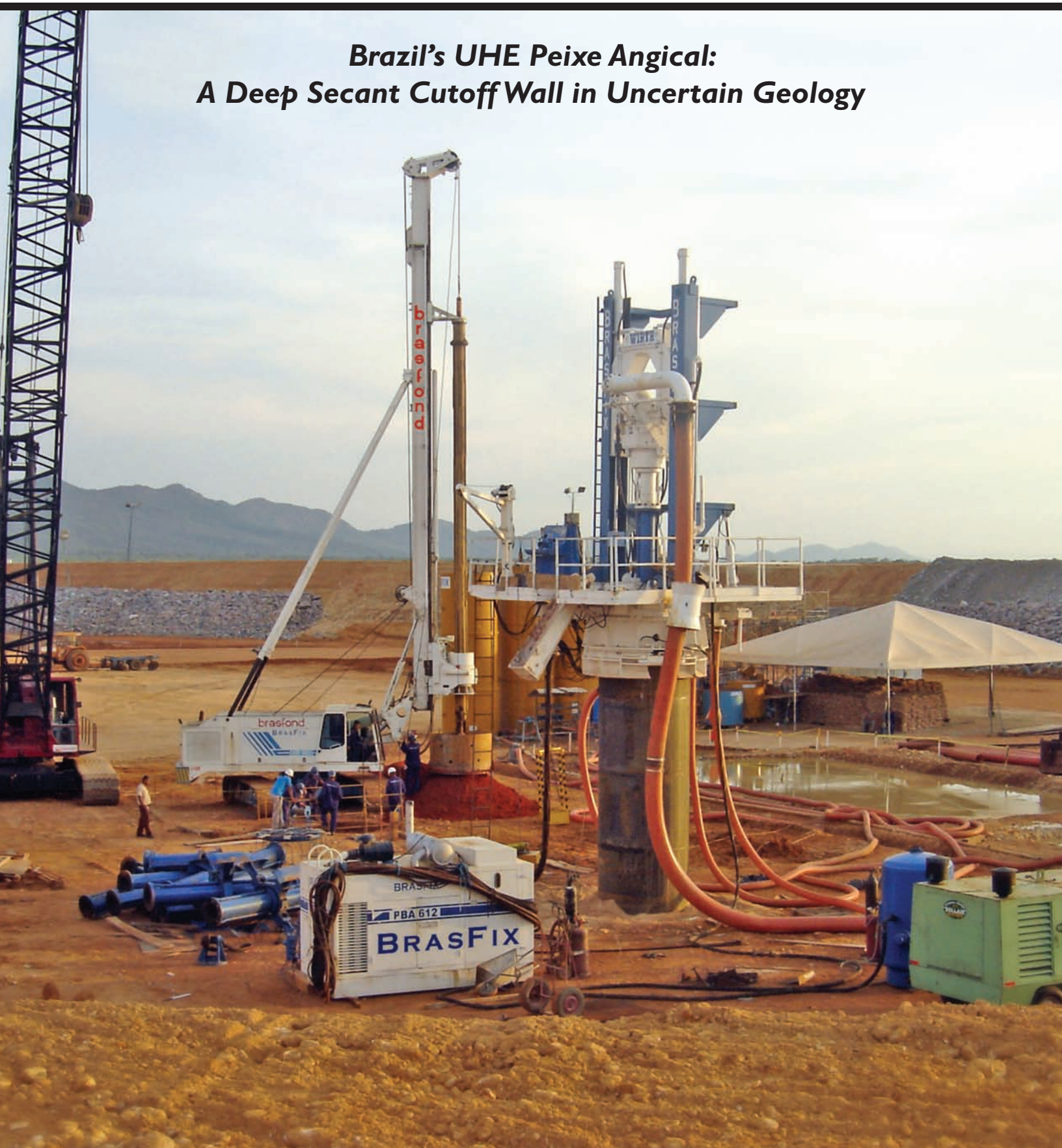
DEEP FOUNDATIONS INSTITUTE
DFI
DEEP FOUNDATIONS
Winter 2009
The Magazine of the Deep Foundations Institute

Brazil's UHE Peixe Angical: A Deep Secant Cutoff Wall in Uncertain Geology



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DEEP FOUNDATIONS

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Regular Features:

The DFI … that's what's great!

I've been a coach, a participant and a spectator in many athletic and business events, so I've experienced both the highs and lows of these events. Add the inevitable "crowd effect" —100,000+ people packed into the stadium, those on the playing field, in the conference room or on the jobsite — and it's quite a ride for those charged with making leadership decisions. I'm sure this sounds familiar to many of you. It also sounds a lot like today's economic, political and business environment, right? Each day brings challenges to our educational system, industry, business, and to us. Before taking the field, entering the office, or just facing each day, I start with a simple (and often humbling) question, "…ok Rudy, what do you have that's good?"

Rudy Frizzi
President
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One thing I say is: "The DFI!" Thanks to the hard work and dedication of our Past President Seth Pearlman, the Executive Committee, Trustees, and Executive Director Theresa Rappaport and her staff at HQ, our organization is in great hands. Also, due to the hard work and commitment of our committees and committee chairs, the DFI continues to be a true Institute. We are a consensus organization of engineers, contractors, educators, equipment/material suppliers and "end-users" taking a leadership role in intra-disciplinary deep foundations collaboration and technology transfer in the United States and abroad. I strongly encourage all our members to participate in our committees. They are your information source and gateway for information on the latest in the deep foundations industry.

The DFI is constantly looking to give back to you, the members, and one such way is to provide forums to meet and collaborate with fellow leaders in researching, educating, developing and building the latest and greatest the deep foundations industry has to offer. All these concepts were embodied in our most recent Annual and International Conference on Piling and Deep Foundations in New York City, where more than 575 members from around the world gathered. It was also there that I was honored to formally take the position of president of our organization.

There are several topics on which I'll focus my future messages. I'll update you on some great things many of you are doing for our organization, and what our organization is doing for you.

First, I believe it's all about keeping the DFI our "organization of choice." I personally thank each and every one of our corporate and individual members for renewing your DFI membership. You and I have invested much in the DFI, including: active committee development and participation, consensus document preparation and spirited discussion at our meetings and seminars. Our organization will continue to work hard to provide return to you, our members.

Our organization is a collaborative Institute. We are actively engaged in task forces and meetings and events with other geo-organizations; recognizing and respecting their missions, while maintaining our own.

We are working hard to keep all the great folks we've got engaged — those in our industry, along with the students in our trade schools, colleges and universities. Many have wondered what's being done to make sure there will be well prepared and qualified engineers in the future. Through the DFI Trust, our organization is actively supporting both educators and the students, who are the future of our industry.

Being a true Institute, the DFI will continue to present the latest in design and construction innovations that continue to evolve in our industry. Take a look at the latest *DFI Journal*, or the list of upcoming seminars to see our organization at its innovative best!

You and I have invested much in the DFI, including: active committee development and participation, consensus document preparation and spirited discussion at our meetings and seminars.

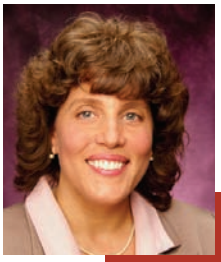
I'm sure many of you recognize our world is figuratively "flattening" and "shrinking." The DFI is actively involved with our international partners to provide meetings and other endeavors throughout the world to facilitate deep foundations education and technology transfer.

Finally, in preparing for the future, we need to recognize that environmental and ecological sustainability are key to our survival. Our organization's Sustainability Committee is actively involved in reviewing how this issue impacts our industry and members, and how we can develop education and technology to address this important issue.

In closing, I am, and I hope you are as well, blessed with great family, friends, and business and professional colleagues. We're all well-served when we take time each day to recognize them. Reflecting on the many benefits of active membership in our organization helps me through my day when I think, "…active involvement in DFI, that's what's great!"

The Journey Continues

In late 2006 when I began my journey as executive director of DFI, I was joined by incoming President Seth Pearlman. We both found our roles expanding and our commitment to the organization growing as we delved deeper into what makes DFI tick. Seth, having been a very active member for 30 years, and I having been an employee of DFI for 10+ years, had seen the inner workings and commitment from staff and volunteer members that had led DFI down a successful path. Our goal was to see that success continue under our leadership. We both knew that couldn't happen without growing and changing with the needs of the DFI members.



Theresa Rappaport
Executive Director
trappaport@dfi.org

You (members) have sent a message that you and your company are progressive and that you seek advanced technology, new ideas and a better way... Together we can attain greater success, reach our goals and create new ones.

Seth and I, with the assistance of the board members and committee chairmen, took a detailed look at the strengths and weaknesses of the services DFI offers to members. We found that DFI is a valuable industry resource that is fulfilling its mission as a vehicle for members to improve the planning, design and construction of deep foundations. DFI's offerings of consensus documents, committee-organized educational events and opportunities for industry members to connect with each other remain the cornerstone of how the mission is achieved.

The goal then became to elevate the content of these offerings and expand into new areas to make DFI "the industry organization of choice." We have begun to fulfill that goal by issuing the *DFI Journal*, forming three new committees — Codes and Standards, Sustainability and Ground Improvement — and encouraging collaboration between DFI committees for new and improved events, such as Super Pile. This is just the beginning of efforts in place to move the organization forward.

Our incoming president for 2009, Rudy Frizzi, will continue the journey Seth and I started out on a couple of years ago. Rudy is extremely committed to the same goal of making DFI the industry organization of choice. When he was chairman of the DFI Augered Cast-in-Place Pile Committee, he and I formed a strong working relationship. I was DFI's assistant director at the time, and one of my main responsibilities was liaising with the committees and supporting their activities. At that time I saw the spark and determination that Rudy possesses. He always gave his all to the committee work, which was considerable. At that time, ACIP Piles were relatively new to the industry. He and the other committee members worked toward many goals with definitive deadlines, and Rudy always kept everything on schedule and moving forward.

DFI is fortunate to have Rudy as its new leader. He is both forward thinking and organized, and I believe he will see that new ideas are advanced to completion. Additionally, I suspect he will bring forward for discussion new initiatives, which will likely take root and grow during his term.

Rudy is also serving in his new role as a member of the DFI Educational Trust Board. He will be an asset in supporting their goals to promote deep foundation careers to students and provide financial assistance to students for their education in various engineering and construction fields.

While DFI and its members prepare for a coming year filled with unknowns, due to the volatility of the economy, we should all feel confident that we are in good hands. Rudy, supported by Seth, as well as the other officers and board members, is determined to continue to provide an organization where the members lead the way. He has repeatedly expressed his delight in being a member of an organization where his active involvement has made his personal and professional life more fulfilling.

We encourage you to find those same feelings of accomplishment by getting more involved in DFI, your industry organization of choice. The more you get involved, the more benefits you and your company will reap. Your membership will become more valuable through the professional associations you make with other members and the DFI resources you will directly affect when you join a committee and contribute to its activities.

We thank you for renewing your DFI membership and pledging your commitment to the deep foundations industry. You have sent a message that you and your company are progressive; that you seek advanced technology, new ideas and a better way. Rudy and I are glad you are taking the DFI journey with us. Together we can attain greater success, reach our current goals and create new ones.

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Offshore

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Overview of the jobsite

UHE Peixe Angical: Secant Cutoff Wall in Uncertain Geology

UHE Peixe Angical is a 452 MW hydroelectric power plant located on the Tocantins River in Tocantins, Brazil. In 1999, geologists began feasibility studies to estimate the river's hydroelectric potential, and the decision was made to proceed with the construction of a power plant. In 2002, after extensive investigation, the studies indicated geological homogeneity at the site for the dam, except for an anomaly detected on the left margin, and construction began on the $1.2 billion project.

AUTHORS:

Francisco Caputo, Eng., Director, Brasfix

Armando Caputo, Eng., Superintendent, Brasfond Group

Dario Libano, Administrative Director, Brasfond Group

As the work began, the complex ground conditions presented several serious difficulties. The solution was unlike any undertaken before in Brazil—a 100-m-long secant cutoff wall, with 76 1.8-m-diameter piles of up to 78 m deep. All were placed in a six-month period.

In the preparation for the detailed construction plans, further studies in the area of the anomaly better defined the geology so that a treatment program could be developed. The feasibility study had detected silicified rock with high permeability in one area, and an injection curtain was designed with five injection lines. In the other area with an anomaly, further investigation revealed a permeable marble formation that was 50 m thick. Here, a specific injection program with three injection lines was developed.

The injections started in February 2005 in the marble formation area. By July of that year, only the primary and secondary holes were drilled from the three lines, resulting in a space between injections of 1.50 m. By the end of July, the drilling was halted. The contractor had identified a thick area of heterogeneous material below the transition zone that was characterized

Centralizing the casing

by a mixture of soil, fractured rock and hard fractured rock. The anomalies were detected while drilling, and both the general contractor and the designer concluded that the phenomenon of "piping" was taking place.

Constructing a positive cutoff wall became a priority.

Seepage Problems

When the injection program first started in 2005, the drilling intercepted an aquifer with measured water flows in some holes reaching the volume of 120 m^3/h.This affected the injections as the material injected would either reflux and come back to the surface or would simply disappear in the hole. As a consequence, further surveys were conducted in the area.

The petrographic analysis of the rock extracted indicated the presence of carbonatic rock, classified as dolomitic marble, with the presence of karstic fissures. During August of that year, new surveys were made in that zone so that the dimensions of the formation could be identified.

By May 2006, approximately 3,600 m of new surveys were conducted, four times as many as the 900 m of surveys made during the feasibility studies.

During the investigation, drilling the heterogeneous material was very difficult because a significant number of drill strings were lost in the hole. Furthermore, there were low levels of return of samples, existence of cavities, total loss of drilling fluid, abrupt variations of the rock and great instability of the drilled holes. These results revealed the great complexity of the region, making it even more difficult to understand the geologic and geotechnical composition of the zone.

After injecting 187 holes (5 and 6 in diameter), totaling 9,524 m, the contractor injected 1,301 tons of material with a consumption rate of 136.6 kg per meter. The project consultants were confident that these injections were partially successful in treating the rock, but they did not improve the geomechanic characteristics of this material. The possibility of erosive processes, such as piping, was still likely.

The consultants studied three alternatives that could provide a permanent solution for the anomaly. The first was jet grouting, which was eliminated due to the uncertainties of its efficacy given the failed attempts in the injection program.

The second alternative was to use the "hydromill," which was also eliminated due to the fact that the reservoir would start filling at the same time of the construction of the cutoff wall.

The third alternative was proposed by the foundation contractor, Brasfix, a **Brasfond Group** company. They offered the idea of a secant wall with piles of 1.8 m in diameter, using Wirth pile top rigs. Both the general contractor and the project designers approved this concept.

The Final Secant Cutoff Wall

The final project was the cutoff wall made with secant piles, approximately 100 m in length, up to a depth of 78 m and 1.8 m in diameter. The large diameter significantly reduced the possibility that two piles might not overlap. The contractor extended the drilling beyond the projected depth many times so that either the bedrock was reached or, when this was not accomplished, where consistent material was penetrated.

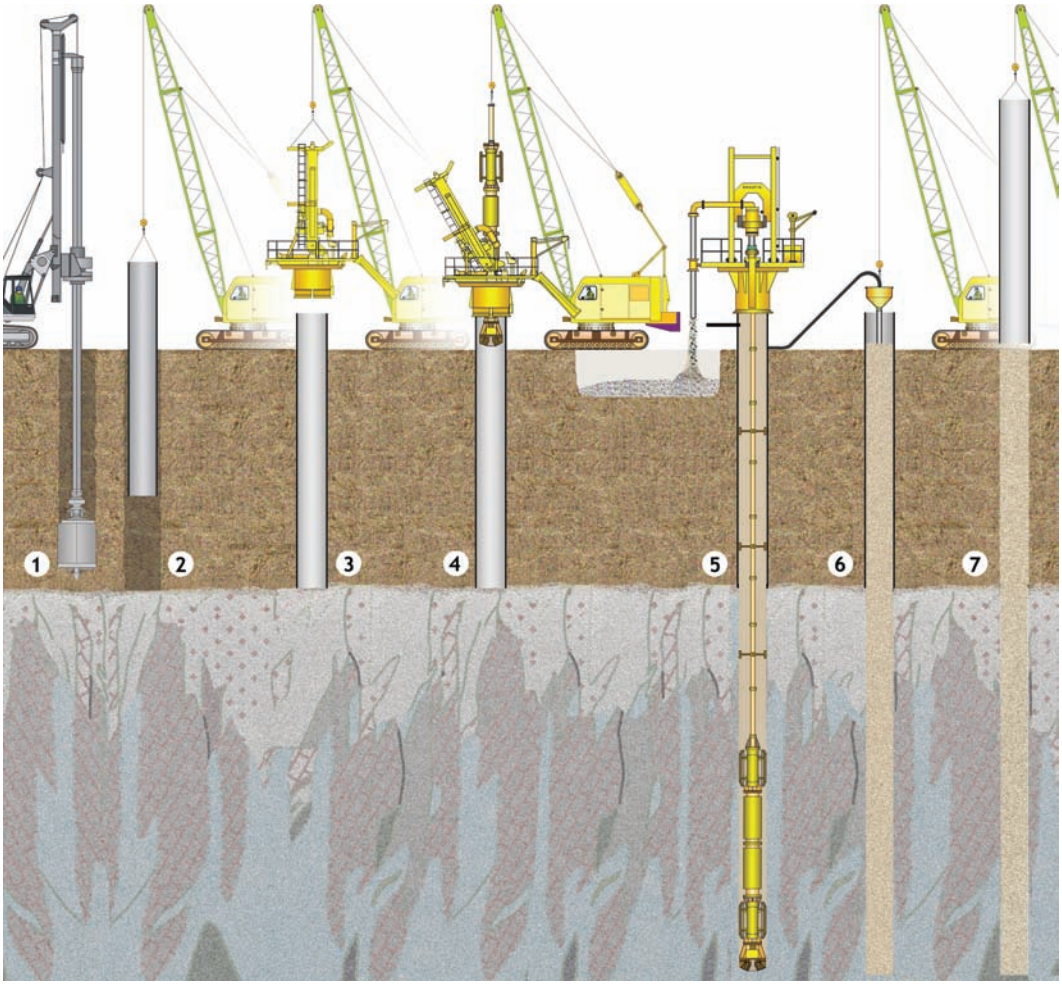
The overlap between piles varied in relation to the depth reached. The greater the depth, the greater the overlap would be. These fell into three categories:

1. Intersection of 0.40 m for depths varying up to 50 m
2. Intersection of 0.50 m for depths varying from 50 m to 60 m
3. Intersection of 0.60 m for depths varying from 60 m to 80 m

Bottom Hole Assembly

Proposed Methodology

The methodology proposed to the client had a series of procedures to ensure the overlap of the secant piles. In addition to the increased intersection between piles as the depth increased, the whole operation had to be done with extreme care — from pre-drilling, to the actual drilling, to the filling of the drilled hole. Verticality was the primary concern due to the fact that each shaft was drilled blind. If the hole deviated, a set of procedures had to be conducted to bring the shaft back to verticality to ensure the piles overlapped. The methodology was adopted during construction and consisted of the following steps:



1. *Pre-drilling with a 1.90-m-diameter bucket.* At this stage, a hydraulic rig MAIT HR 180, with up to 18 metric tons of torque, equipped with a Kelly bar and a specially designed bucket, was used to pre-drill the compacted earth fill with bentonite until the fractured rock was reached. The reasoning behind pre-drilling a hole with a hydraulic rig was that once a casing was installed in the ground, it could be slightly tilted as to ensure total verticality. The hydraulic rig was used instead of a crane-attached rotary table, as the precision and the verticality in the drilled hole using the rig has been proven by experience to be much greater.
2. *Installing a 1.85-m-diameter casing in the drilled hole.* A 100-ton crawler crane was used to place the steel casing in the drilled hole. The casings came in sections of up to 25 m and a thickness of 12.7 mm. The verticality of the casing was of paramount importance as it was used as an initial guiding tool for the drilling to follow. Topographic equipment and measurements were used to ensure this verticality. The steel casing did not touch the bottom of the pre-drilled hole and was suspended by a special steel structure. This step was taken to simplify the casing removal once the drilled hole was filled.
3. *Placement of the Wirth Hydraulic Rig on the casing.* Two Wirth Pile Top Rigs model 612 with up to 12 metric tons of torque were used in this project.
4. *Inserting the Bottom Hole Assembly (BHA) and drill pipe.* The bottom hole assembly was specially designed for this project. Weighing approximately 30 tons, the BHA was made by a specially designed drill bit 1.8 m in diameter with tungsten carbide bits and two weight stabilizers separated by three drill pipe counterweights. The heavy weight of the BHA was intended to take advantage of the pendular system that gravity provides. This weight is essential to keep the drill bit from deviating from center line.
5. *Drilling with bentonite using reverse circulation.* Reverse circulation is a process in which cuttings are removed by injecting compressed air into the drill bit. The differential pressure that the injected air creates "air lifts" both the water and the cuttings up inside the drill pipe. In this case, water mixed with bentonite was used due to the unstable characteristics of the fractured rock.
6. *Pouring of coulis into the drilled pile.* Coulis, a mixture of cement, bentonite and water, was chosen to be the appropriate filling of the drilled holes in order to reach permeability rates lower than 10^{-6} cm/s. The project designer developed the technical specification for the mixture, then it was tested and simulated in the laboratory. The coulis was poured through a tremie pipe as is normally done in submerged concreting.
7. *Removal of the 1.85-m-diameter casing.* Four hydraulic cylinders with a capacity of 75 tons each were used to extract the casing.

Measuring Verticality

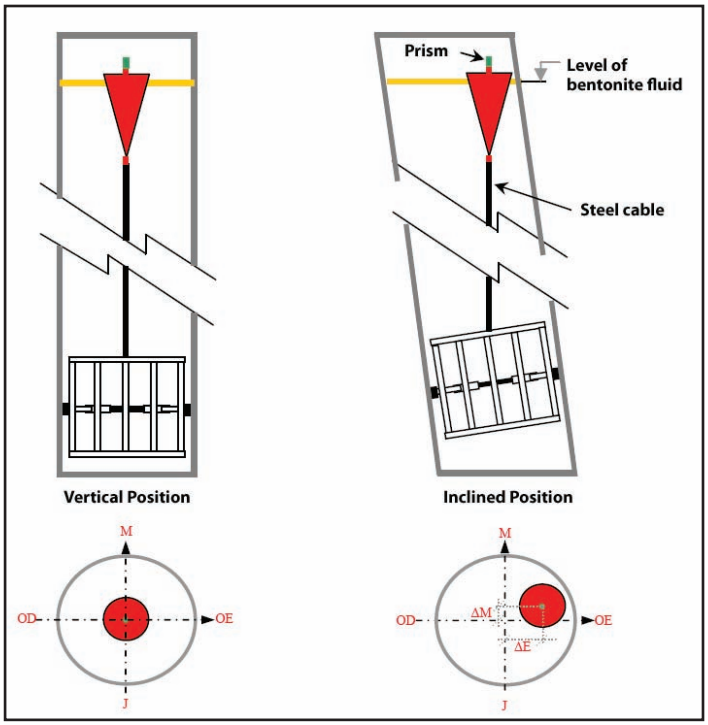
For the cutoff wall to work properly, it was essential that the piles be as vertical as possible, without any gaps between them. Measurements using two methods were taken to ensure this verticality, one mechanical and the other electronic.

Removing the casing

The mechanical measurement was done through equipment based on the principle of an inverted pendulum. The equipment consisted of a cage, shaped like a barrel, equipped with hydraulic cylinders uniformly distributed in its circular section to maintain the cage centered in the drilled hole. This cage was connected — through a steel cable with a diameter equal to 6.35 mm — to a conically shaped buoy. A prism was fixed on the top part of this buoy to enable topographical readings.

The secant cutoff wall construction was simultaneous with filling the dam's reservoir and the three turbines started on time.

Once the cage was lowered into the hole to the depth where the deviation was to be measured, the hydraulic cylinders centered the cage and a reading was taken of the prism in relation to points on the edges of the steel casing. If the drilled hole was vertical, the buoy would be exactly in the center of the casing. If



A prism and buoy system indicated verticality within the casings

inclined, the buoy would not be in the center and the distance of the buoy from the center would show the degree of deviation of the drilled hole.

The electronic measurement was made through an inclinometer, which was inserted through the drill pipe. Even though drilling had to be stopped to insert the inclinometer, readings could be taken at any time and in some cases, if it was necessary, steps could be taken to bring the hole back to vertical.

Readings were taken for all the piles. The maximum deviation measured was 0.4% even though the project allowed for a 1% tolerance.

Conclusion

From mobilization, which started at the end of November 2005, until all equipment was removed from the jobsite, which was in September 2006, 76 piles were placed by two pile-top drilling rigs in less than seven months.

The complexity of the geology was gradually understood during the development of the work, and this complex solution was undertaken for the first time in Brazil. As the construction of the cutoff wall was simultaneous with the filling of the reservoir, the three turbines were started as scheduled, completely satisfying the client with no delays to his project.

The Peixe Angical deep cutoff project was a runner-up in the 2008 DFI annual Outstanding Project Award competition.

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A Secant Cutoff Wall in Brazil: An OPA Special Recognition Award Project