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TUNNELING & UNDERGROUND CONSTRUCTION

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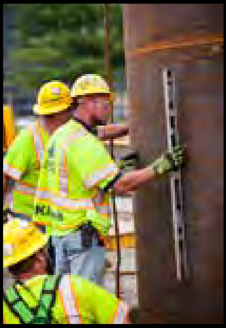
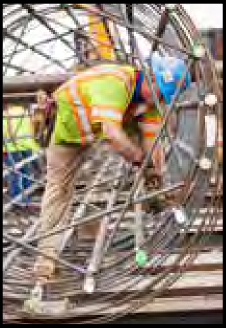
World Tunnel Congress

Risk–based cost estimating

George A. Fox Conference

Special Editorial Section from the publisher of Mining Engineering





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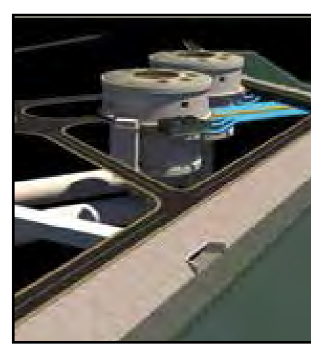
COVER STORY

In this issue — Tunnel and underground space projects are among the most complex projects in the world. It is crucial that cost estimates be considered at all phases of the project. John Reilly, Phillip Sander and A. Moergeli discuss the needs for cost estimating on page 13. Cover photo courtesy of Moergeli + Moergeli Consulting Engineering.

CONTENTS

FEATURE ARTICLES



DEPARTMENTS

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CHAIRMAN'S COLUMN

WTC 2016 will be a spectacular industry event

Since the December 2015 edition of *Tunneling & Underground Construction*, the pipeline of work for all facets of the industry has steadily expanded. Many new studies, conceptual designs, final designs and construction awards have moved forward, and our clients are preparing more opportunities for the engineering, construction and supplier communities. We all look forward to a busy spring, summer and beyond.

The World Tunnel Congress (WTC) 2016, held in San Francisco, CA, April 22-28, promises to be a spectacular event. The technical committee, led by Randy Essex, has selected several hundred papers for both podium and poster presentations. My congratulations go to all of the selectees, along with my thanks to everyone who submitted an entry. I know the committee worked diligently through holidays, nights and weekends to select the best submissions.

The Program/Scientific Committee and the Sponsorship and Exhibit Committee have been tying up details to make this WTC the best one ever, and to raise the bar for future events. My sincere appreciation goes to all of those volunteers.

The UCA of SME Scholarship Committee and Young Professionals Committee have also been very busy over the last few months. We received many more scholarship applications this year than in previous years. The committee, led by Mike Roach, has recommended four $5,000 awards to the most deserving applicants.

The UCA has also made $50,000 available to enable college students to attend WTC 2016. I was delighted to learn that the committee recommended awards to 43 students. I look forward to meeting many of them in San Francisco.

I'd like to remind everyone that we have scheduled Cutting Edge 2016 for November 6-9 in Los Angeles, CA. This year, the conference will focus on Advances in Tunneling Technologies. We expect a large number of attendees, so it's a good idea to register early.

I am grateful to all of our members, UCA staff and sponsors who have worked hard to make WTC 2016 successful. I look forward to

Artie Silber,
UCA of SME Chairman

Hudson tunnel project takes a step forward

Board members of New Jersey Transit voted unanimously to hire consultants to study the environmental impacts of the proposed train tunnel under the Hudson River. The vote is seen as a small step forward for the project.

NorthJersey.com reported that U.S. federal law requires the environmental review to be complete before the project receives any federal money, which must happen before construction can start.

Advocates for the tunnel argue that it is needed to replace the existing tunnels that are more than 100 years old. Some of these tunnels are suffering severe corrosion, exacerbated by salts and chemicals left over from flooding caused by Superstorm Sandy.

Even this small decision comes with its own caveats, however. NJ Transit has not yet chosen a consulting team to handle the work, and the measure passed by the board includes no mention of how much money the review will cost. Amtrak has agreed to pay NJ Transit for the consultant. But spokespeople for both agencies said they did not know the project's cost. NJ Transit expects the review to be complete by winter 2018.

With so much unknown, one rail advocate urged the board to postpone the vote until more details can be fleshed out.

"You're being asked to rubber stamp a blank check," said Joseph Clift, technical director of the Lackawanna Coalition, which pushes for more train service. "I don't understand the rush. There's no barn burning."

Beginning some time in the next 18 years, one of the current tubes must be closed and completely rebuilt, according to leaders of Amtrak, which owns the tunnel. If that happens before the new tunnel opens, officials say, the number of trains that can cross the Hudson during rush hour will drop from 24 trains an hour to six, causing nightmarish traffic delays to radiate across the region.

The prospect that such an

(Continued on page 10)

Bay Tunnel wins ASCE Region 9 Outstanding Water Project award

San Francisco Public Utilities Commission's Bay Tunnel project, was awarded the 2015 Outstanding Water Project in the State of California by the American Society of Civil Engineers (ASCE) Region 9. The award was be presented at the 2015 Region 9 Awards Dinner on March 18, 2016 in Sacramento, CA.

"With their world-renowned knowledge and experience in designing tunnels as well as their in-depth understanding of the operational requirements of the water supply system, McMillen Jacobs Associates continuously engaged the SFPUC and our multiple stakeholders to identify the challenges, facilitate solutions, and maintain focus on the project objectives of designing a lifeline facility that will remain operable after a major earthquake in either San Andreas Fault or the Hayward Fault." wrote Johanna Wong, P.E., M.S., PMP, PgMP, SFPUC's Bay Division regional project manager, Water System Improvement Program.

The presence of environmentally sensitive habitats on the Bay margins precluded using cut-and-cover pipelines, which resulted in the need for an 8-km (5-mile) long tunnel with only launching and receiving shafts and no intermediate construction shafts. These two shafts are located on properties owned by SFPUC in the city of Newark (Newark site) and the city of Menlo Park (Ravenswood site). The tunnel is the first of its kind built under the Bay, utilizing an earth pressure balance tunnel boring machine to effectively counteract the 3.2 bar hydrostatic pressure and sandy/silty soils. Despite numerous challenges, the tunneling was completed eight months ahead of schedule.

The Bay Tunnel was completed on May 20, 2015 within the baseline schedule and well below the baseline project budget. ■


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Britain eyes huge infrastructure investment

Britain's Chancellor, George Osborne, pledged an initial £75 million to fund the 29-km (18-mile) Trans-Pennine tunnel beneath the Peak District to better connect Sheffield and Manchester. It will be one of the longest road tunnels in the world when completed.

Experts have previously warned that road users could suffer "psychological difficulties" because of the length of the tunnel, which will cost around £6 billion, the *Telegraph* reported.

Osborne will also use the budget to give the green light to the Crossrail 2 project and the HS3 railway as part of what is being billed "the largest rail investment program since the Victorian age."

Osborne said: "With the difficulties we see in the global economy, we've got to make Britain fit for the future.

"Now is the time for us to make the bold decisions and the big investments that will help us to lead the world in infrastructure, and create jobs, push up living standards and boost our productivity for the next generation. That's what my budget this week sets out to do."

A report into the feasibility of the tunnel published by the Transport Department in November found "positive" signs for how it could boost the economy and suggested the road would help divert traffic away from Peak District national park.

However, it also warned that the "practical and psychological difficulties of driving in a long tunnel environment should not be underestimated."

Osborne will also announce £60m to take forward HS3 between Leeds and Manchester and develop detailed plans to reduce journey times toward 30 minutes.

Crossrail 2, which would connect

(Continued on page 9)

India plans longest road tunnel along LoC in Held Kashmir

A proposal for the longest road tunnel in India, an 18-km (11-mile) long road tunnel along the Line of Control (LoC) with Pakistan has been submitted to the Ministry of Road Transport and Highways.

If approved, the tunnel will be the longest in the country and almost double the size of Chenani-Nashri tunnel on the Jammu-Srinagar national highway in the disputed region which is expected to be completed later this year.

The Economic Times has reported that at an estimated cost of $1.3 billion, the 18-km (11-mile) long road tunnel will connect Gurez town in the northern part of Indian-held Kashmir with the rest of the valley, the. "We have submitted a proposal to the Ministry of Road Transport and Highways for construction of an 18-kilometre tunnel at Razdhan pass to connect Gurez with the rest of the Valley throughout the year," chief engineer of the Border Road Organisation (BRO), Brigadier AK Das said.

Gurez is a strategically important part of the disputed region both in terms of energy projects and defense. However, the valley remains cut off from the rest of Kashmir during winter season due to heavy snowfall.

India is already working on the construction of a controversial 330-MW hydropower project in the region, which has been disputed by Islamabad at the Permanent Court of Arbitration, The Hague. The estimated construction cost of Kishenganga Hydro Electric Project is $687 million. "A feasibility study has already been conducted for the Gurez tunnel and, if constructed, it will be of huge help not only to defense forces but also the civilian population of the area," Das claimed. "It will improve connectivity leading to development of the area."

Further, according to him, another proposal for the construction of three more "strategically important" tunnels in Indian-held Kashmir has been submitted by the BRO. "These include a 6.5-km (4-mile) tunnel at Sadhna that will improve connectivity with the Tangdhar area (along the LoC) in Kupwara District, another at Furkian (Keran Sector) and a 3.5-km (2.1-mile) tunnel at Zamindar Gali (Macchil Sector)," he said. However, feasibility studies will only be conducted after the projects are approved by the Union Ministry, Das said. ■

Britain: road tunnel

(Continued from page 8)

Surrey and Hertfordshire via new tunnels and stations between Wimbledon, Tottenham Hale and New Southgate, will also be given the go ahead. Supporters say it could support 200,000 new homes and create the same number of jobs.

The Chancellor will also launch a new £1.2-billion fund to release brownfield land to build more than 30,000 starter homes across the country.

The projects have been identified by the National Infrastructure Commission, headed up by former Labor transport secretary Lord Adonis, as worthy of investment. ■

Bertha begins digging more than a year later

After a more than year of sitting idle beneath the streets of Seattle, tunnel boring machine Bertha returned to work in February.

Seattle Tunnel Partners was given conditional permission to restart the drill and resume digging on the $3.1-billion project so long as it adhered to a series of new safety protocol for ground control and worker safety, state transportation officials said.

Reuters reported that Bertha had been ordered by the Washington State Department of Transportation to stop digging underneath downtown Seattle on Jan. 14 after a big sinkhole opened at the construction site.

The stoppage was the latest problem to befall Bertha, the world's largest tunnel-boring machine by diameter, which has become a symbol of failure to critics of the highway replacement project who have argued it was ill-planned and expensive.

About two weeks after its restart, the TBM cleared the roughly 49-m (160-ft) demonstration period the state Department of Transportation had put in place when the machine contractor was allowed to start digging again Feb. 23, WSDOT said in a news release.

The $80-million drill overheated and stalled underneath the city in December 2013, just 10 percent of the way through its work. It took two years to extract and repair the 6.3-kt (7,000-st) machine.

With an initial price tag of $3.1 billion, the project to replace the Alaskan Way Viaduct has cost overruns of at least $143 million, according to lawsuits filed surrounding the project, *Seattle PI* reported.

It's now not expected to be finished until April 2018, according to estimates before the latest suspension.

On March 19, Bertha reached a planned maintenance stop near Yesler Way after successfully mining almost 91 m (300 ft) during a three-week period. According to Seattle Tunnel Partners, the machine functioned within required operating parameters. STP has now mined a total of 475 m (1,560 ft).

STP will spend up to one month inspecting the machine and performing planned maintenance.

When STP has completed its maintenance work, crews will tunnel out of the maintenance stop and beneath the Alaskan Way Viaduct. WSDOT plans to close the viaduct for approximately two weeks to allow the machine to pass beneath the structure. ■

Environmental review

(Continued from page 4)

important piece of infrastructure might fail caused members of the Obama administration to sound alarm bells last spring with federal and state officials.

"We don't have another decade to spend thinking and talking about it," Peter M. Rogoff, an under secretary at the U.S. Department of Transportation, said last May. "We need action by our Congress, we need action in Trenton, we need action in Albany and we need it soon."

The environmental review will study an area parallel to the existing tracks and tunnel, starting near Secaucus Junction train station, continuing under the Palisades and the Hudson River into New York Penn Station. NJ Transit was chosen to lead the effort partly because the agency already led the environmental review and planning stages for a previous tunnel, called ARC, which would have followed a similar route. Gov. Chris Christie canceled the ARC tunnel in 2010, citing the possibility of cost overruns. ■

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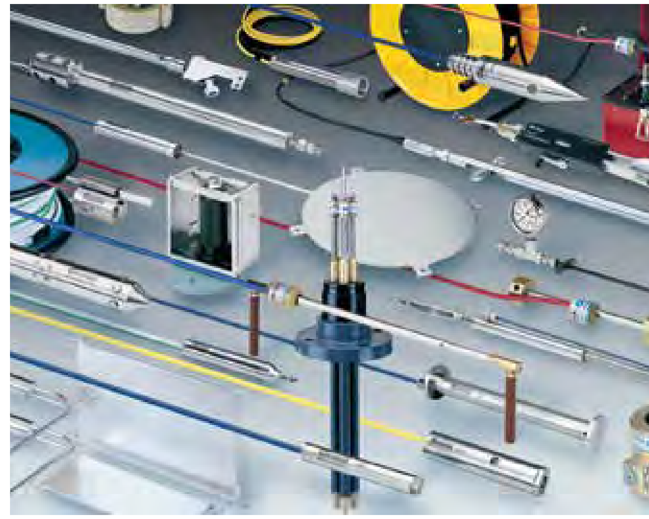

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FEATURE ARTICLE

Only the best of the best will be part of the WTC technical program

From April 22 to 28, the eyes of the tunneling and underground construction world will be on San Francisco, CA, as the world's most influential underground construction industry leaders gather at the Moscone Center for the 2016 World Tunnel Congress.

Recognized as the most important international annual meeting for the industry, the 2016 version comes to the United States for the first time in 20 years and will be hosted by the Underground Construction Association of SME (UCA of SME). The conference will be held in lieu of the UCA's biennial North American Tunneling Conference and will bring the strengths and resources of the UCA of SME and the International Tunnelling and Underground Space Association (ITA). The result will be a conference with unmatched technical programming and a showcase of more than 200 exhibiting companies.

A program committee led by Randy Essex of Mott MacDonald, Lonnie Jacobs of Frontier Kemper Constructors, Michael Mooney, of the Colorado School of Mines, Priscilla Nelson, of the Colorado School of Mines and Amanda Elioff of Parsons Brinkerhoff formed the program committee and worked for more than two years to build the program. The result is four technical sessions with five tracks in each session and 185 oral presentations.

"One challenge was the sheer size of the group that would be assembled, perhaps 2,500 attendees or more, and the large number of abstracts we were likely to receive," said Essex. " We investigated extending the conference a fourth day, but that was not workable with the Moscone Center. We settled on having five concurrent technical tracks – something that has not been attempted in past NAT or RETC conferences to my knowledge. The next step was to develop suggested session titles that would span the breadth of subjects that would interest conference attendees as well as serve the conference theme."

In addition to the program committee, more than 110 professionals assisted with the review of abstracts and manuscripts and each abstract was reviewed by at least two, and sometimes three individuals, with each providing numerical scores against four criteria. The same approach was used for the manuscripts.

"We received 725 abstracts. Based on the reviewers' scores, the top 370 abstracts were approved to advance to manuscript preparation. Though 370 were approved, a number of submissions were withdrawn, and a lesser number of initial manuscripts were rejected due to their poor quality," Essex explained. "With about 10 percent attrition, we had 335 final manuscripts submitted. The session chairs and scientific committee reviewers provided numerical scores and written recommendations to the track chairs. A further review was carried out to ensure that no one author had multiple oral presentations, and that no one project featured multiple presentations in one session."

A thumb drive containing all accepted podium and poster manuscripts will be included with the Congress registration. Delegates will have the option of purchasing a hard copy of the proceedings at the Congress and have the hard copy volumes shipped to them.

In addition to the technical program, attendees will have the opportunity to mingle with colleagues on a robust exhibit floor that will be packed with 222 exhibitors occupying more than 290 booth spaces.

The conference will also include a number of networking events including the welcome reception and the Congress Banquet to close the conference on April 27.

For more information about WTC 2016, visit www.wtc2016.us. ■

T&UC®

FEATURE ARTICLE

Construction — You need risk-based cost estimating

Estimating and managing the costs of complex infrastructure projects – in the planning/design and construction phases, for both owners and contractors – has been a challenge for decades. The more complex and technologically advanced the project, the greater the uncertainty, including potential risks, that are important to owners and contractors, such as:

- Cost risks to owners – meeting budget and schedule, maintaining public credibility.
- Cost risks to contractors – profit, consequences of loss, impacts to reputation/future work.

This concern has been addressed in various ways by the underground construction industry for some time (Reilly, 2001). In particular, while significant advances have been made in cost estimating for the planning and design phases (Reilly et al., 2004), that are important to agencies and political decision-makers, it is not apparent that these advances have been widely adopted for construction cost estimates. The reasons for this may relate to low-bid considerations – any method that tends to increase the contractor's cost estimate, by including risk or likely costs, could lead to an erosion of the contractor's competitive position – if others are not similarly required to include such costs.

Different cost estimating methods produce different levels of information. Specifically, there is a large difference in the character and depth of information if a deterministic (quantities times price plus a contingency) and risk-based cost methods are used. It is this difference in character and depth of information that is the reason that risk-based cost estimating has potential value for owners and contractors. Figure 1 presents hypothetical cost results from deterministic and risk-based methods and illustrates some of these differences.

John J. Reilly, Philip Sander and A. Moergeli

John J. Reilly, member UCA of SME, is president, John Reilly International, **Philip Sander** is general manager, Risk Consult GmbH and **A. Moergeli,** member UCA of SME, is Swiss certified civil engineer, Moergeli and Moergeli Consulting Engineering, email john@johnreilly.us.

Tunnel projects, like the East Side Access project, (pictured) require a high degree of risk management planning. Photo courtesy of Moergeli + Moergeli (m+m) Consulting Engineering.

In Fig. 1, the results for deterministic and risk-based cost estimates are given related to the potential profit or loss for a typical project. As is evident in this example, there is significant potential for costs to be realized that are higher than the proposal/bid value estimated using a deterministic approach, with a 15 percent probability of a loss. There is a 30 percent probability that the project will have a reduced profit. There is a 55 percent probability that the project will return a good profit. Using a risk-based approach, it is possible to better recognize this potential outcome in the bid phase and, as a consequence, develop a strategy to:

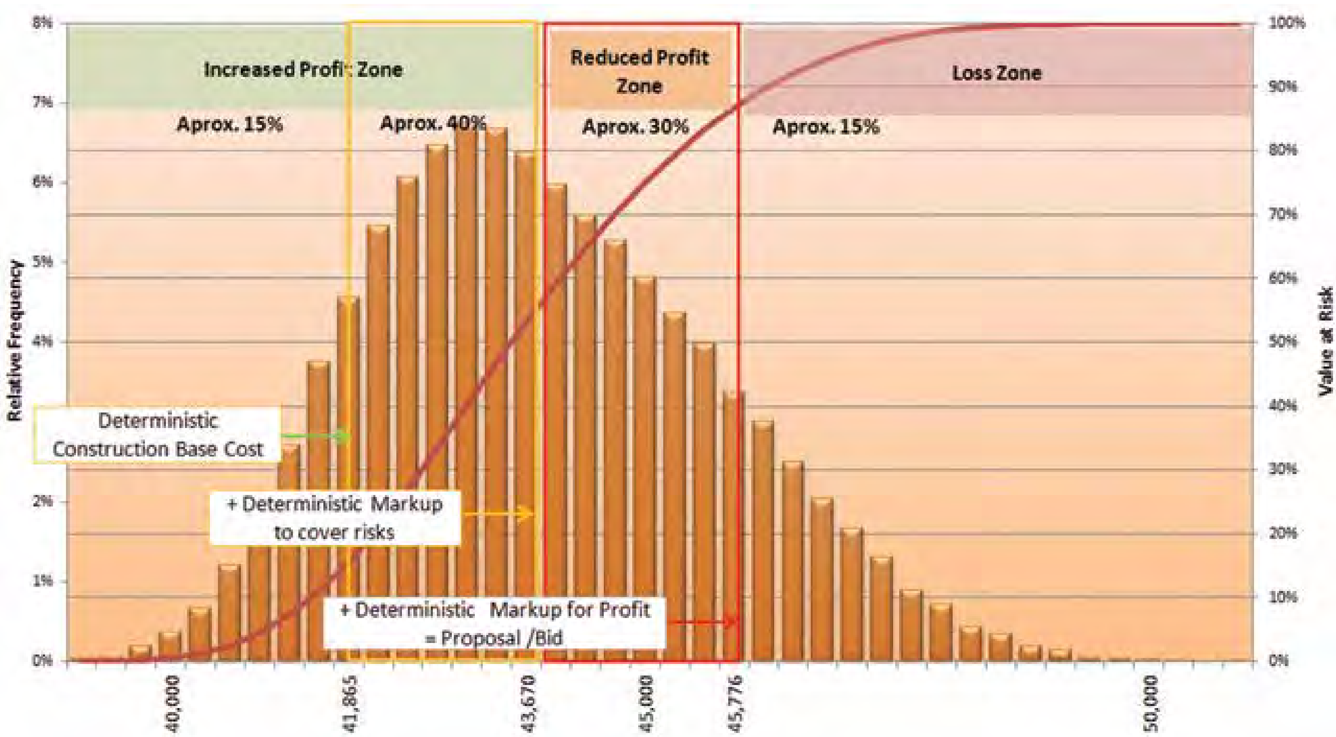
1. Change the proposal/bid amount – if this is consistent with a strategic approach to win the bid, compared to the competition, in order to realize a profit at the end of the job, or
2. To withdraw from the project if a strategy to win the bid but not realize a profit is likely.

Cost estimating - overview

Cost estimating must deal adequately with

FIG. 1

Deterministic cost plus profit–loss curve (Sander, 2014).



uncertainty, especially in the very early stages of projects where:

- Quantities and prices are not well known.
- Quantities and prices can only be addressed by reference to basic elements plus a large contingency.
- A detailed analysis is not yet available due to a lack of sufficiently precise information.

With a deterministic approach, information about uncertainties and their characteristics – such as higher or lower values, ranges of quantities and potential costs – cannot be easily taken into consideration for cost estimating. A risk-based approach can more reasonably deal with this type of uncertainty.

Types of cost estimates

There are several different methods of cost estimating, depending on the purpose, level of planning, and/or design as well as project type, size, complexity, circumstances, schedule and location. These methods can fall into categories such as parametric, historical bid-based, unit cost/quantity based, range and risk-based estimates. For a detailed discussion of cost estimating, see Reilly, 2010. References for best cost estimating practices include "Project Management Body of Knowledge" Chapter 7, "Project Cost Management" (PMI, 2004), State Agency guideline documents such as Washington State Department of Transportation's (WSDOT) "Cost Estimating Manual for WSDOT Projects" (WSDOT, 2009) and the Association for the Advancement of Cost Engineering International (AACEI) Guidelines (AACEI, 2003 et seq.).

Components of cost estimates – Base cost, risks and other uncertainties

The components of cost that need to be correctly addressed in the estimate include:

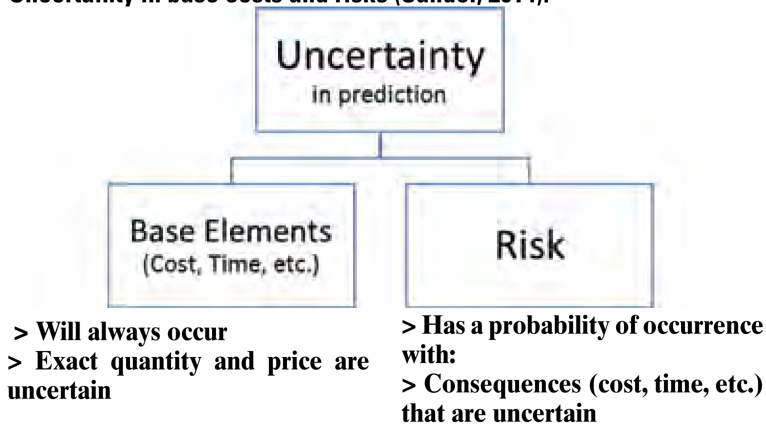
- Base cost – the cost that will result if "all goes according to plan" (Reilly, 2004).
- Risk costs – the result of threat and opportunity events, if they should occur.
- Escalation costs – costs resulting from normally expected inflation with variability.
- Other uncertain costs – costs that result from other events, normally external to the project team's control, which may include unanticipated events, politically related changes and "black swan" events (Talib, 2007).

In order to identify and address risk factors, an individual uncertainty factor should be associated with each cost category. In particular, for larger projects, individual budgets should be created for all cost components to enable tracking of deviations and management of changes as the estimate and the project evolves.

The method by which these cost components are evaluated, quantified, modeled and combined is critical to a valid result. Different methods treat each component differently, which can lead to differences in the reliability and usefulness of the results. Additionally, uncertainty always plays a major role in estimates – for example, while basic cost elements may be reasonably well known, the quantities and prices associated with them are uncertain leading to variability in these base costs.

FIG. 2

Uncertainty in base costs and risks (Sander, 2014).



Representative cost estimating methods addressed in this paper

1. Deterministic: Aggregated unit quantities multiplied by unit prices – usually with some degree of conservatism built in – plus an added reserve or contingency.
2. Risk-based: A range approach that combines base costs with some variability, plus risk and opportunity costs, combined probabilistically to produce a “range of probable cost.”

The deterministic cost estimating method. The deterministic base cost approach process is commonly used by contractors to create a bid price. This involves estimating known quantities (from bid plans) and unit prices (from the contractor or suppliers) to get “line item costs” and adding an overall contingency to the base costs to account for the incomplete nature of the design, project uncertainties and the consequence of future events.

A risk-based deterministic approach adds line-item risk to the deterministic base cost elements and assigns a probability of occurrence and impact to each line item. The result is the expected value of risk impacts. If multiple risks are to be accounted for, the total risk is often computed as the mathematical sum of all single risks.

However, such a simple summation of risks delivers no information about any probability and best and worst case scenarios. It is also necessary to add an overall contingency to account for other unknowns. An overall contingency is subject to bias since there may be no rational basis for how unknowns are aggregated or estimated.

Contingency. The uncertainty (and associated contingency) at various project phases can be classified by such techniques as “estimate class levels” (AACEI, 2003), used in deterministic cost estimates, in which the inherent uncertainty is reduced as the project advances through the phases of planning, design, bidding and into construction. The uncertainty is represented by “contingency factors” that are related to these phases. Contingency in the AACEI table can range from 5 to 75 percent depending on phase and circumstance. Alternatively, cost-risk estimating recognizes that base costs and risk events have uncertainty in both probability and impact (positive or negative). This method is more detailed and analytically more complete.

Contingency is a very broad approach, not very useful for identifying and developing a strategic management of risk or achieving a profit in construction. The contingency applied in the deterministic standard method is often based solely on the cost estimator’s judgment or experience with a history of similar projects, if available – but this is problematic for at least the following reasons:

- Estimators and project staff are generally optimistic in their approach to cost.
- The history of similar projects varies with each contractor’s experience.
- The history of similar projects is likely to be inadequate to apply to the current project.

The contingency approach does not give useful information on the probability and impact of uncertain events. This means that strategies such as risk avoidance, risk mitigation or risk transfer cannot be sufficiently evaluated in the bidding phase – which is very important

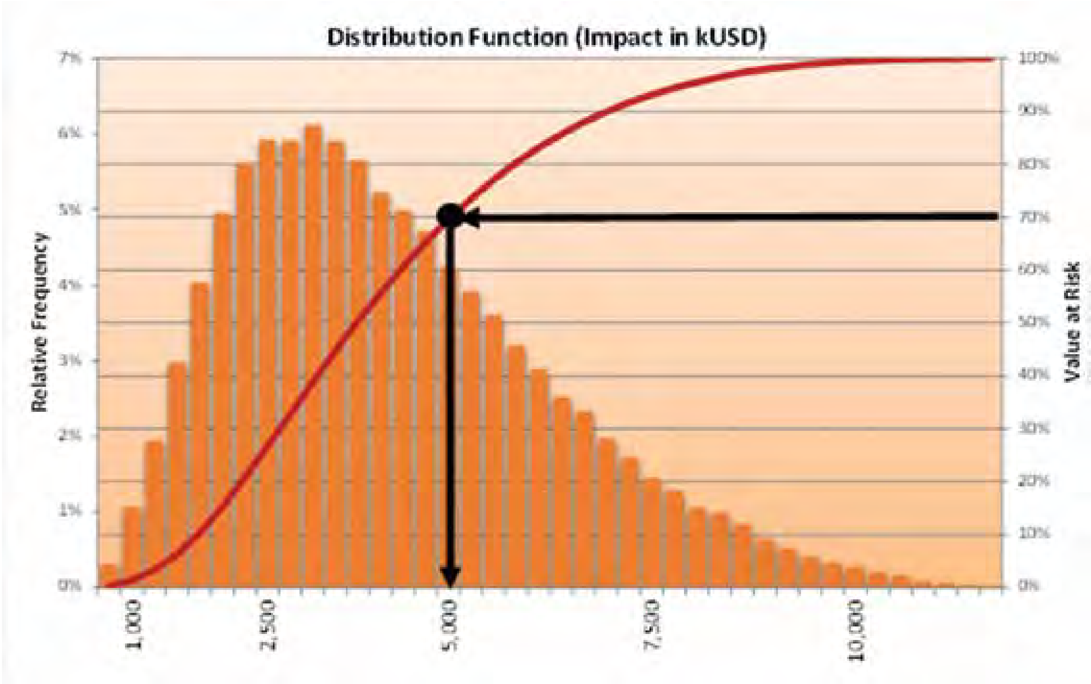
FIG. 3

Equation for deterministic aggregation of risks.

$$R_{total} = \sum p_i * I_i$$

FIG. 4

Probability density distribution function showing probable project cost with Value at Risk information.



for the contractor in order to:

1. Determine a competitive bid price, while understanding relevant risks.
2. Implement strategies to maintain a profit margin in the construction phase.

The risk-based cost estimating method. In the risk-based method, the total cost is made up of base costs (quantities times unit prices, both with some variability) plus risk events including risks of delay with associated liquidated damages, risks of escalation and the cost impact of other higher-level (e.g., political) risks. Risk impacts are determined by estimating the probability of occurrence and the impact of specific risk events (normally in a workshop with project staff and subject matter experts). Dependencies and correlations between specific risks are also elicited and used in modeling.

Since empirical/historical data as input to the risk analysis is often not available, the risk probabilities can be difficult or complex to estimate. The risk-based method characterizes each risk, with individual and specific distributions, such as a large range for large uncertainties or a narrower range for smaller uncertainties. Using this approach, the uncertainty contributing to a particular cost estimate can be modeled more specifically and in greater detail than by use of a single-point deterministic estimate (Sander et al., 2009).

Single risks can be evaluated using distributions, and those distributions can be aggregated using simulation methods (e.g., Monte Carlo Simulation or Latin Hypercube Sampling) to determine a probability distribution that represents the overall risk environment.

Value at risk (VaR) defines a value (e.g., USD) that will not be exceeded at the corresponding probability (risk). In the example above, VaR 70 means that a $5-million cost would not be exceeded in 70 percent of all simulated scenarios. However, even with such coverage, there remains a 30-percent probability that the $5 million cost will be exceeded (Sander, 2012).

Comparison of cost estimation methods

Key considerations – deterministic versus risk-based cost estimates.

Cost estimating using the deterministic process can significantly misestimate potential costs by:

- Misapplication of "contingency factors."
- Neglect of variability in prices and quantities.
- Lack of appreciation of the impacts and probabilities of potential risk events.
- Including additional (non-explicit) contingency in base cost and the overall contingency.
- Overestimating the total cost of upper levels of ranges in the range-estimating approach.

A risk-based cost estimating process inherently identifies more detail regarding risks and opportunities

TABLE 1

Comparison of deterministic versus risk-based probabilistic cost estimation methods.

Element	Deterministic base + risk cost	Risk-based (probabilistic)
Input	A single value for probability and a single value for impact of each risk.	One figure for the probability of occurrence and several values for the impact (e.g., minimum, most likely, and maximum) to define "fuzzy" risk.
Result	A single value from a mathematical addition of base cost and the expected cost of risks (probability multiplied by impact).	A "range of probable cost" with all project risks shown as a probability density function based on thousands of coincidental but realistic scenarios.
Qualification	Results are displayed as a single, sharp figure, which, in itself, does not have a probability.	Results are displayed using distribution densities.
Treatment of risk	Risk and uncertainty are added as a lumped "contingency" based on the estimator's historical experience and industry guidelines (e.g., AACEI 2003).	Risk and uncertainty are explicitly and quantitatively identified, characterized, modeled, and aggregated probabilistically. Risks are added probabilistically.
Risk management/response	Risk management is usually based on a separate risk register, using historical experience.	Risk management can be focused on the higher level risks that are identified and quantified by this method.
Other high level risks	Financial, schedule, and other risks are identified, characterized, and quantified "approximately." Significant high-level risks may not be included or addressed.	Financial, schedule, and other risks can be explicitly identified, quantified, and prioritized for risk response

and can generate more useful information of the characteristics of uncertain events. Risk-based methods can better quantify the range of potential costs by more detailed characterization of risk and opportunity and the inclusion of conditional, dependent and inter-related risk cost results. This can lead to better strategies in the bidding phase (to secure the project) and in the construction phase (to preserve profit).

Risk-based methods are more sophisticated than deterministic methods, which are often based on a normal spreadsheet approach. The main reasons why a risk-based approach is recommended can be summarized as follows (Tecklenburg, 2003):

- A deterministic method can give equal weight to risks that have a low probability of occurrence and high impact and risks that have a high probability of occurrence and low impact if using a simple multiplication of probability and impact. This approach is incorrect.
- By multiplying the two elements of probability and impact, these values are no longer independent. Therefore, this method is not adequate for aggregation of risks where

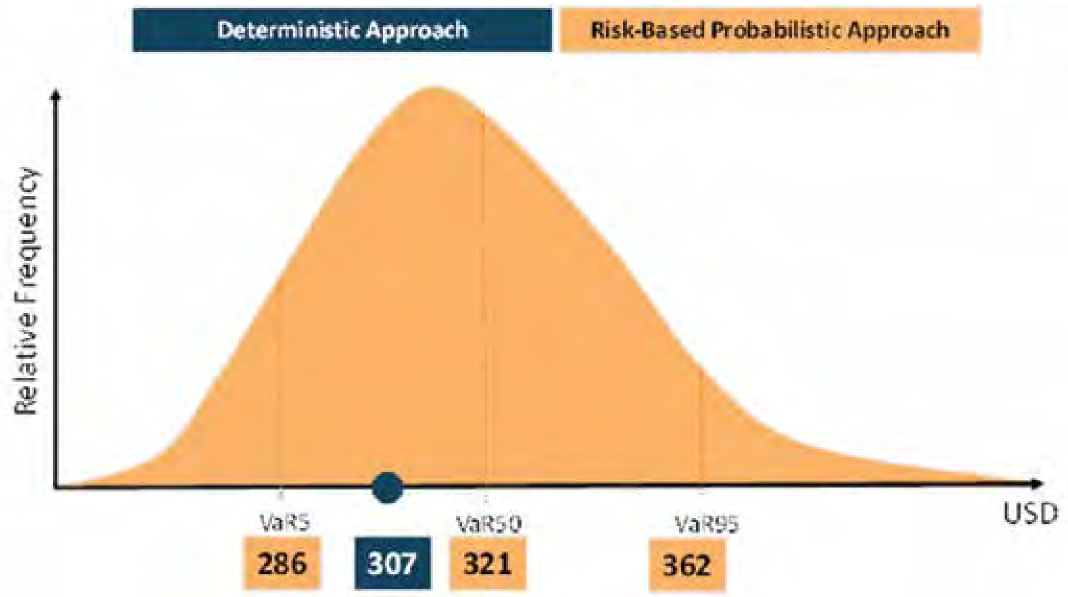
TABLE 2

Deterministic base cost of an excavation and support category with triangle distributions.

	Quantity				Unit price (US$)			Deterministic cost/ meter of tunnel (ml)
Cost item	min	ml	max	unit	min	ml	max	
Shotcrete 10 cm, top heading	13.8	15.4	17.7	m^2	9.7	12.1	15.8	186.3
Steel mesh AQ50	13.8	15.4	16.9	m^2	1	1.2	1.6	18.8
Swellex 3 m, top heading	1.7	1.8	2	pc	20.7	25.9	33.7	47.1
Shotcrete 5 cm - bench	5.2	5.8	6.6	m^2	6	7.5	9.7	43.1
Swellex 3 m, bench	0.4	0.5	0.5	pc	20.7	25.9	33.7	11.7
ml= most likely value								307

FIG. 5

Visualized result - comparison of estimating methods.



probability and impact information need to remain available. Due to multiplication the only information that remains is the mean value.

- The actual impact will definitely deviate from the deterministic value (i.e., the mean).
- Without the value at risk information, there is no way to determine how reliable the mean value is and how likely it is to be exceeded.

Bier summarizes the opportunities for probabilistic risk assessment as follows (Bier, 1997):

- Probabilistic risk analysis allows reasonable modeling of deviations from normal (expected) values for complex projects and systems.
- Probabilistic risk analysis can characterize any element or system performance, including the performance of subsystems and their interactions.
- As a consequence, specific impacts from different interacting systems can be identified and differentiated.
- Probabilistic risk analysis delivers a quantitative risk estimation, which can lead to better decision-making and risk response/mitigation.
- Probabilistic risk analysis takes uncertainties into consideration. This is especially valuable if statistical data about potential impacts are sparsely available and large uncertainties dominate.

Comparing cost estimating methods – example

In order to compare these estimating methods, the same input parameters are used in Table 2, which shows inputs used for estimating the base cost of a simplified tunnel excavation and support element in order to compare the previously mentioned estimating methods by means of a practical example. Quantities are used with a triangle distribution using a "minimum (min), most likely (ml), and maximum (max)" expectable value for each cost item.

Deterministic approach. The deterministic approach delivers a single figure (US$307) as the sum of all products of most likely quantity multiplied by the most likely price.

Risk-based probabilistic approach. The probabilistic approach combines base cost plus risk costs in a simulation. The result is a "probability density function," showing the probability that the out-turn cost will be a particular value (or between a range of values).

Figure 5 shows results of the above methods for the example given. It is apparent that the risk-based method gives much more useful information about the potential cost.

Assessment of the estimating methods. Table 3 compares pros and cons for the deterministic and probabilistic methods.

Recommendation. Contractors and owners can benefit strategically and operationally from sufficiently complete risk-based information, including potential cost ranges and risk characterization. The more complex

TABLE 2

Assesment of estimating methods from an owner's or contractor's perspective.

Estimating method	Pro	Con
Deterministic	One single figure. Well-known and accepted. Quick. Can be performed "manually."	No probability information of single value. No VaR information. More often than not on the unsafe side (high, unknown probability of cost overruns).
Risk-based (probabilistic)	Full probability information.	Needs probabilistic thinking and understanding. Needs software support.

and risky a project is, the more information is needed, and this information is critical to success. If a contractor does not identify and characterize risks early, they will not be able to manage their project sufficiently or to protect against adverse events and loss of profit. Risk management procedures have been sufficiently defined, and sufficient information technology is available in a variety of software products that are not difficult to understand and use.

Advantages of using a risk-based (probabilistic) method

How a better cost-risk assessment helps in a "low-bid" environment. Previous papers (Reilly, 2008) have noted that, in a low-bid environment, each party enters a contract at its own risk and the contractual environment is characterized by the ability of each party to treat the other party as an adversary – for their gain, at the potential expense of the other. To be the low bidder, the contractor must do at least two things:

1. Determine the lowest cost to deliver the work specified at an acceptable quality level.
2. Determine a strategy to bid that cost – or lower – to secure the work, with the expectation that any deficiencies in price can be made up in changes caused by new agency requirements, changed site or environmental conditions, defects in the design documents, or other strategies that will accrue to their advantage.

The risk assessment used in the probabilistic method results in an improved understanding of who owns each potential risk according to the requirements of the contract documents, industry and legal precedent. The contractor can therefore better prepare a bidding and construction strategy to achieve a profit even in a very competitive bidding environment. The better risk assessment also allows better construction change management since the strategy related to those changes can be better understood and quantified early in the bidding and construction process.

Contractor's advantage using risk-based estimating. Risk-based estimating produces information that allows a better understanding of the risks that might occur, as well as their characteristics and probabilities. Several benefits flow from this:

- The deterministic contingency approach, adding a percentage on top of the base cost, may give an estimate that is greater than that obtained using risk-based cost (because not all risks will occur). This could mean that, if using a cost-risk process, a reduced bid price is possible, leading to a competitive edge for that contractor.
- The potential contractor will have a more realistic understanding of base cost, risk cost and the level of risk that they are willing to undertake in order to bid the job.
- Because the risks are defined (characterized) in detail, it is possible to understand who should own those risks – i.e., which risks are clearly the responsibility of the contractor, which are clearly the responsibility of the owner and which risks are clearly the responsibility of other (external) third parties.

In particular, if the owner has included a sufficiently comprehensive risk register in the bid documents, and the potential contractor prepares their own detailed risk register, they will better understand the risk environment and can also judge if the owner's risk register is accurate. There are several possibilities in this regard:

- If the potential contractor thinks that the owner has estimated the consequence or probability of some risks too high, they may see a bidding advantage compared to other bidders.
- If the owner has estimated the consequence or probability of some risks too low, it may mean that the potential contractor, using a reasonable assessment of risk, is likely to submit too high a bid and may not win the project compared to other bidders who have a lower appreciation of risk.

A concern has been expressed that if an improved risk identification process is used the contractor's estimate will include higher potential costs, which will mean that their bid will be higher and they are likely not to be successful in so many bids. This is a valid concern, however, the authors would argue that more detailed and realistic information about potential risk events is an advantage if an appropriate bidding and construction management strategy is used by the owner and contractor and these strategies are compatible and consistent. (See also the contractor's advantage section.)

Owner's strategy for budgeting and bidding. The owner is interested in fostering conditions for a reasonable and responsible low-bid. Better (more complete, detailed, specific) information can inform all bidders about issues and risks that may be realized. This means that all bidders will have more complete information as they prepare their bids. If the owner uses a more detailed probabilistic cost-risk estimating process in the planning and design phases, and includes a reasonably complete risk register in the specifications, two benefits are possible:

- The owner's budget for the project will be more likely to reflect a more realistic project cost, leading to a more realistic establishment of an appropriate budget (Fig. 4). This permits sufficient resources to be committed to deal with issues in construction. If an inadequate budget is the case, a lack of public trust can develop if major problems and cost increases occur in the construction phase, requiring additional funding.
- All bidders will have a consistent basis for their cost estimate and to establish their bid price. This will help to reduce the probability of the low-bidder submitting an unrealistically low bid, which can lead to issues in construction and an increased probability of disputes, claims and litigation.

Owner's strategy in the construction phase. Using the more detailed cost-risk estimating process, the associated risk register can show which risks are the responsibility of the owner, the contractor and third parties. This means that those risks that are the responsibility of the contractor or the owner can be made explicit and their respective risk management plans can reflect this. Additionally, the probability of unforeseen risks – those that the contractor may claim as unforeseeable – is reduced if such risks are explicit in the owner's risk register.

Contractor's strategy in the construction phase. Likewise, the contractor can better analyze the risks that may occur and determine, during the bidding phase, which risks are they responsible for and which are the responsibility of the owner or third parties. A strong rationale for risks that are not the contractor's will help defend the contractor in the construction phase, if they occur. A correspondingly robust risk-management plan will help to reduce exposure to such risks in construction (Grayson et al., 2015).

Summary

Traditional deterministic cost-estimating methods, while well accepted, can overestimate or underestimate costs and provide very limited information regarding risks that may occur. Risk-based cost-estimating methods build on a deterministic cost base and add consideration of variability and potential risk events to give information that is relevant to risk identification, characterization, and management. They also give more information to manage to budget (owners) and to secure a project in a competitive bidding environment (contractors), as well as inform strategies to manage disputes and claims in construction (owners and contractors).

More relevant information gives more options to manage risk. The earlier such information is available, the sooner that strategies and management actions can be implemented to avoid problems and achieve good results.

In particular, such information helps owners by highlighting budget issues early, allowing good decisions to be made regarding expected bid results, and helps contractors to decide if they can be competitive given the owner's budget and in competition with other contractors. Subsequent to winning a bid, strategies for cost and claims management are informed by better cost and risk information. ■

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FEATURE ARTICLE

Evolution of a mega project: Update on the Bay Delta Tunnels

Water drawn from the Sacramento-San Joaquin Delta provides water supply to 66 percent of California's population and supports the state's agriculture industry. The existing through-Delta water system is outdated and unreliable with environmental risk to some fish and wildlife species. The Bay-Delta Conservation Plan (BDCP) has been established to environmentally retrofit and modernize California's water delivery system through the Delta by restoring habitats, constructing new diversion points in the north Delta and providing a means to transport water supplies under the Delta, rather than through sensitive natural channels.

Under BDCP, the Delta Habitat Conservation and Conveyance Program (DHCCP) has developed several alternatives to convey water from the Sacramento River in the north to the existing pumping facilities in the south Delta through an isolated conveyance system. The new conveyance system would become an integral part of the State Water Project (SWP) and the federal Central Valley Project (CVP) by transporting water to the export pumping plants for each of these projects. The DHCCP is managed by the California Department of Water Resources (DWR), while state and federal water contractors provide technical support to the program.

The initial conceptual study efforts on the overall program commenced in 2007 and examined various options for the proposed conveyance system. Several conveyance alternatives were analyzed at that time. The Conceptual Engineering Report published on Oct. 1, 2013 identified the modified pipeline/tunnel option (MPTO) as the preferred alternative to be included in the BDCP environmental documents. MPTO includes three river intakes and pump stations along the Sacramento River, various sizes of pipelines and tunnels, junction structures and two forebays that are capable of delivering up to 4 million gpm (9,000 cfs) from the Sacramento River to the SWP and CVP. The river intakes are located near Hood in Sacramento County approximately 64 km (40 miles) from Clifton Court Forebay (CCF) in Contra Costa County. This route would cross portions of Sacramento, San Joaquin and Contra Costa counties. Figure 1 depicts the configuration of the MPTO alternative.

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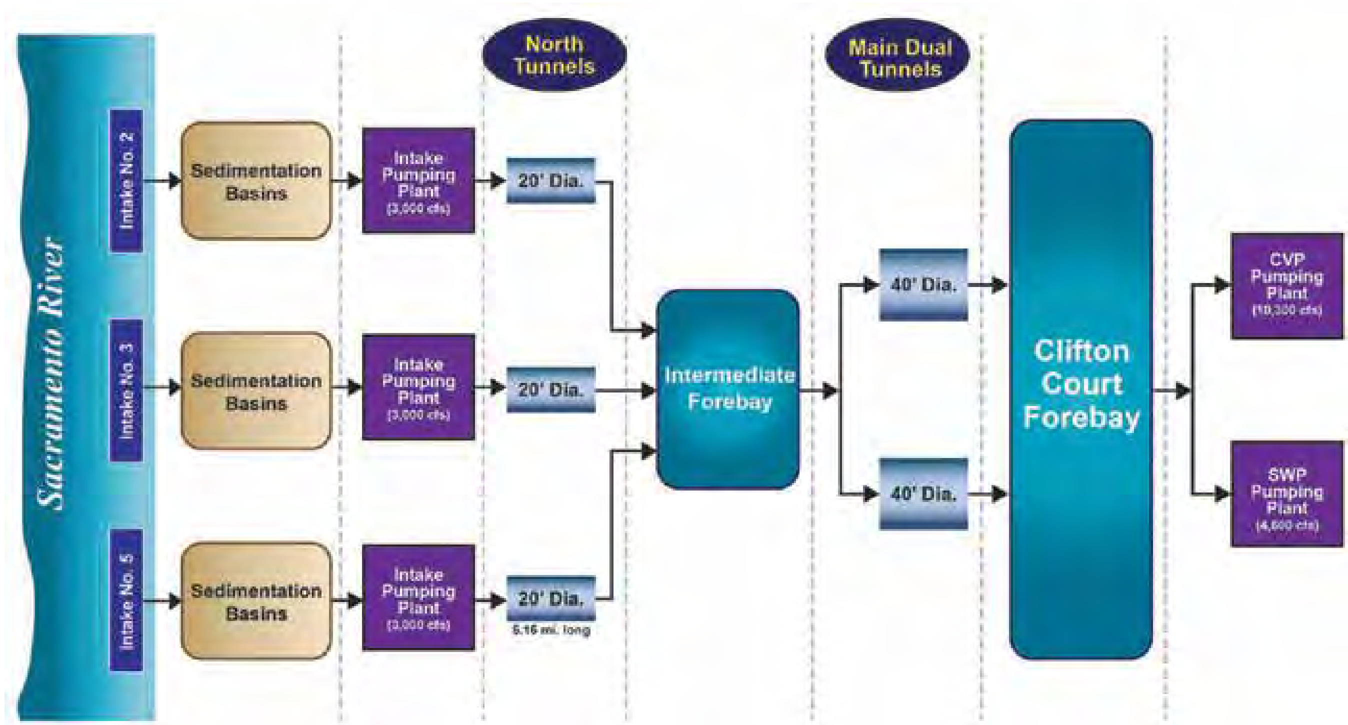
DWR, managing the design and construction of the conveyance facilities, initiated further optimization of the MPTO configuration. The primary goals of the optimization effort included (1) reducing environmental impacts of the proposed facilities along the Sacramento River and (2) identifying a project configuration that would place the concrete segmental tunnel liner systems into compression during system operations instead of the MPTO case, which caused the liner system to be in tension during operations. Clifton Court Option (CCO) was structured to address both of these issues. The CCO alternative retains the project's major design criterion of: maximum velocity of 0.06 m/s (0.2 ft/sec) at each intake fish screen two maximum total flow take of 4 million gpm (9,000 cfs) from the Sacramento River (1.3 million gpm or 3,000 cfs per each intake). Figure 2 depicts the CCO configuration with the main project pumps facilities located at Clifton Court Forebay, the extreme south terminus of the project. Figure 3 depicts the anticipated differences in the hydraulic profiles between the MPTO and the CCO in a simplified side-by-side comparison. Project designers found that the MPTO hydraulic configuration led to the tunnel lining systems being subjected to internal tension due to high hydraulic grade lines. Conversely, the CCO configuration places the tunnel lining systems in compression due to the lower anticipated hydraulic grade lines.

The significant components for the MPTO that are revised under CCO modifications include the following:

- Combining and relocating the three individual pump stations from the Sacramento River to the terminus of the project at Clifton Court Forebay.
- Modifying the intermediate forebay (IF) to work in conjunction with the new pump configuration.
- Revising piping, gates and controls at each of the three river intakes.
- Revising tunnel diameters for the three north tunnels.
- Modifying tunnel segmental lining systems to

FIG. 1

MPTO configuration with intake pump plant on the Sacramento River.



take advantage of reduced hydraulic grade conditions.

The engineering technical efforts that were conducted to support the development of the CCO represent a refined "proof of concept" analysis, and are considered to be conceptual in nature. This work effort was not intended to be an in-depth review of all the technical aspects of the CCO. The more detailed analysis of the remaining technical aspects of the concept will be further developed in preliminary design.

CCO tunnels

North tunnels. The CCO alternative relies on gravity flow from the Sacramento River to the IF, and then down to the CCF pumps stations. As such, hydraulic losses into the north tunnels must be reduced from those that are experienced in the MPTO alternative in order to successfully implement the CCO alternative. Consequently, north tunnel sizes under the CCO were increased from the MPTO as shown in Fig. 4. The diameters are approximate and should be further refined in preliminary design.

Main tunnels. Under the CCO alternative the size of the twin main tunnels remains unchanged from the 12-m (40-ft) inside diameter that is utilized in the MPTO.

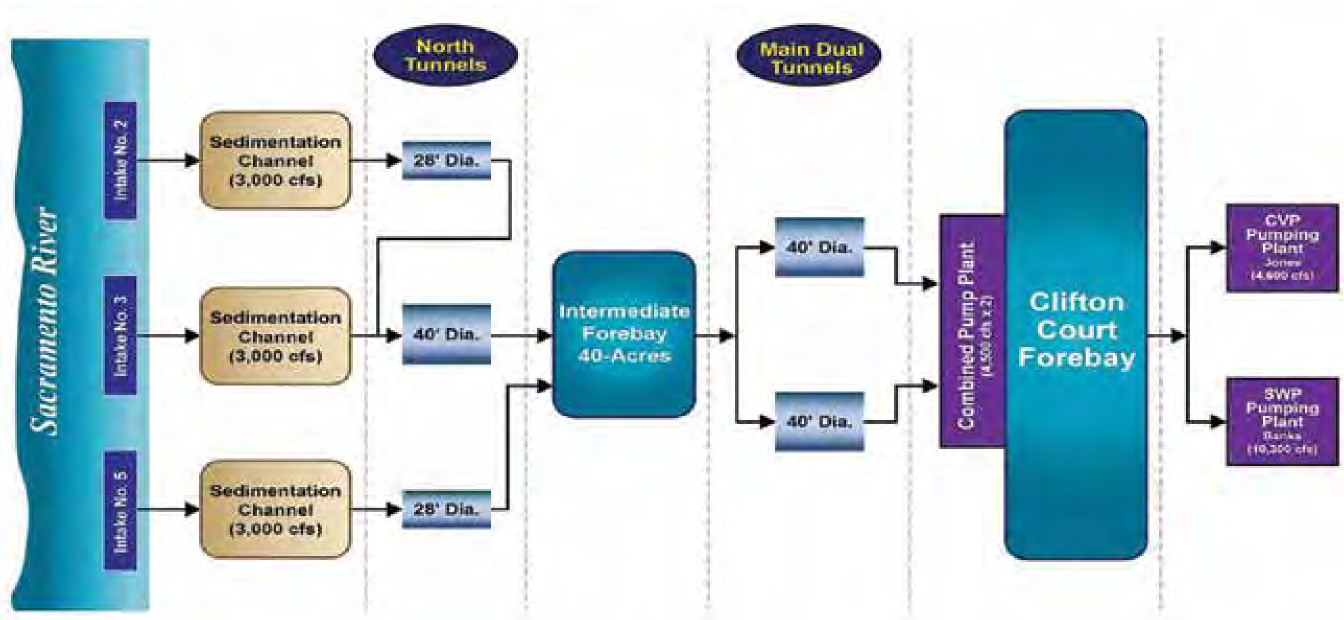
Tunnel segmental liner criteria. For the purposes of designing the segmental liner for the tunnels, the overall tunnel system can be divided into two regions, namely the north tunnels section and the main tunnels section. North tunnels deliver water from the three river intakes to the IF, and the main tunnels convey water from IF to the Clifton Court Forebay (CCF). The inside diameters of the north tunnels vary for each proposed option (MPTO or CCO), while the inside diameter of the main tunnels remains constant at 12 m (40 ft) under both alternatives.

Early in the planning process for the overall tunnel system, it was determined that a single-pass tunnel liner system could be utilized as a cost effective lining system. The tunnel liner system consists of precast concrete segmental liner with bolted-gasketed joints, and there is no steel second-pass liner in the tunnels. For the main tunnels, it is anticipated that a nine-piece ring configuration would be used with segment thickness of approximately 508 mm (20 in.). The segments (up to 7,000 psi strength) will be cast and steam-cured in concrete segment plants under strict quality control measures. Reinforcement will consist of traditional steel reinforcement and steel fiber as required to increase durability and provide crack control.

Under the single-pass liner design, a typical joint between segments will include a gasket to seal against water seepage and alignment bolts for tunnels subject to compression load only. If the segment ring is subjected to internal tension load, as was anticipated under the

FIG. 2

CCO configuration with intake pump plant at Clifton Court.



MPTO arrangement, special positive connection across the joint and tension reinforcement are necessary to transfer the tensile force throughout the segments. Historically, it is uncommon that a bolted-gasketed tunnel liner system is subject to net tension in soft ground conditions. However, under the MPTO, this is the case. Therefore, substantial research and analysis were conducted during the study phase to ensure feasibility and constructability.

In addition to strength requirements, leakage control through the liner is essential to ensure liner performance. Excessive leakage through the liner would lead to potential soil erosion, hydraulic fracturing and loss of liner support. In the long run, deterioration of the tunnel liner could occur. In addition, water leakage from the tunnel to the surrounding soil translates to economic loss.

The performance criteria for the tunnel liner system dictated that the liner be designed for all the following load cases to ensure reliable performance during the minimum 100-year design life of the system:

- Full external ground load and external ground water pressure.
- Net internal pressure (difference between internal hydraulic pressure and external ground water pressure).
- Ground strain associated with seismic design.
- Segment handling loads such as lifting, hosting and TBM pushing.
- Crack and leakage control performance criteria.

For the net internal pressure design of the liner, the external ground water pressure can be assumed to be at elevation 0.0 (MSL) along the majority of the alignment. Occasionally, lower ground water elevation may occur, and the lowest probable elevation is less than 3 m (10 ft) at isolated locations. Currently, the tunnels are planned to be constructed with an invert depth of approximately -42 to -45 m (-140 to -150 ft). Further geotechnical exploration will identify and confirm the ground water elevation along the alignment. Additionally, ground overburden to counteract the internal hydraulic pressure was ignored at this time as a measure of additional conservatism due to the concept-level work underway and the lack of geotechnical data to justify the overburden.

Using the same tunnel design criteria stated above for each option (MPTO or CCO), the following areas were evaluated:

- Loads on tunnel using results of preliminary hydraulic analysis.
- Modifications to tunnel design for each option.
- Advantages and disadvantages of MPTO and CCO.

Tunnel liner design of the MPTO

Under the MPTO option, each river intake facility consists of a pumping plant that pumps water from the river and conveys it throughout the system. Based on the pumping scenarios at the intake, a summary of the hydraulic grade line (HGL) is shown in Fig. 5. The MPTO HGL is called out on the figure, and the CCO HGLs are shown below the MPTO HGLs. Given

FIG. 3

Simplified hydraulic configuration comparison MPTO vs. CCO.

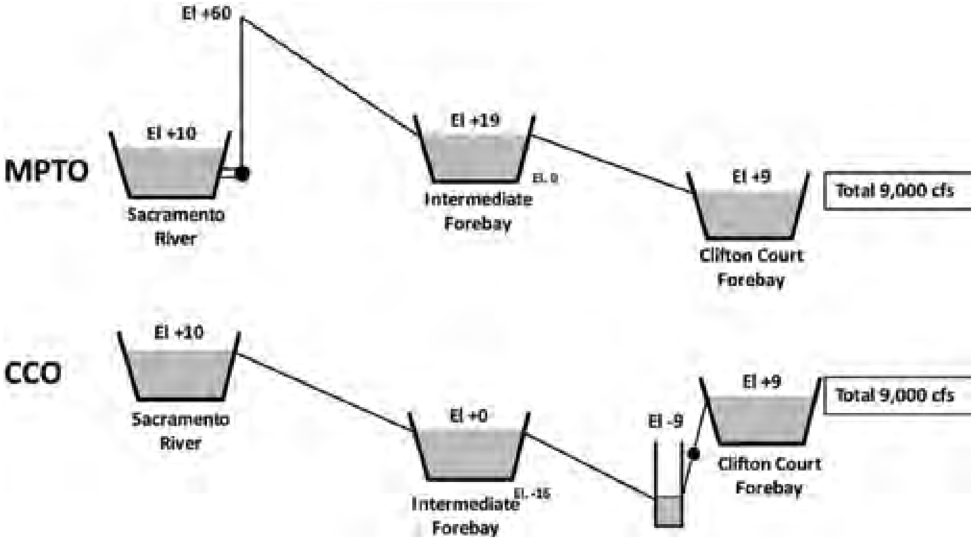
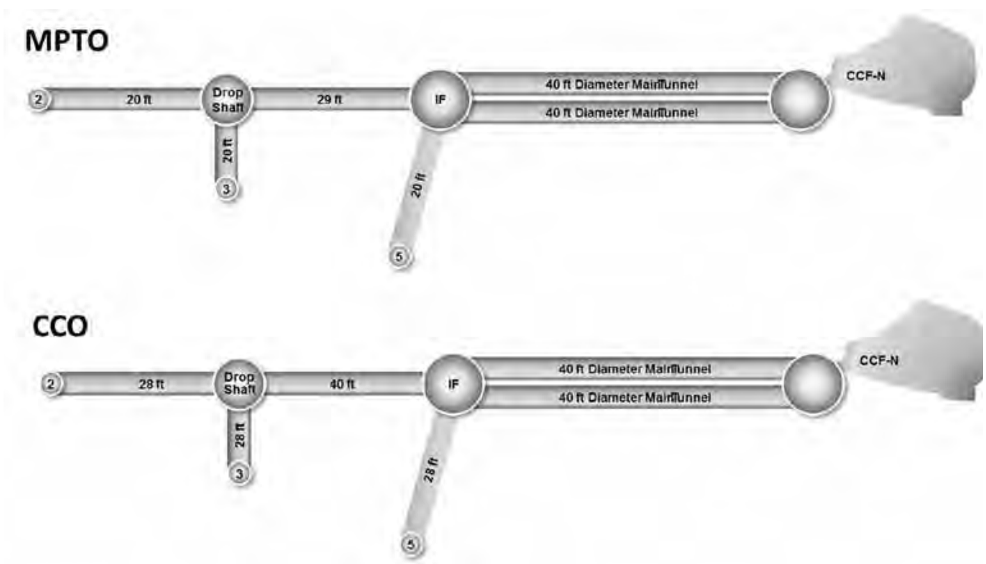


FIG. 4

Tunnel diameters: MPTO vs. CCO.



that the HGL for the MPTO is always higher than the external ground water elevation. Both the north tunnels and the main tunnels are always in tension during normal operation. Figure 5 shows the HGL for both the MPTO and CCO along the tunnel alignment from the river intake to CCF. Since the flows and hydraulic grades of CCO are dependent on the river elevations, both the normal high +3 m (+10 ft) and normal low +0.3 m (+1 ft) elevations are shown with the respective hydraulic grades. The mean ground water elevation is assumed to be at 0.0 (MSL).

One solution to this structural design challenge in order to provide tension capacity for the liner is to use a bolted connection similar to the San Diego South Bay Outfall project. Figure 6 shows the schematic design, and Fig. 7 shows an in-fabrication photo of the segment for the South Bay project. The South Bay project had similar hydraulic design parameters as the MPTO tunnels. However, the South Bay tunnels were only 3.3-m (11-ft) ID.

Given the high tensile loads associated with MPTO, the tensile reinforcement consists of high-strength hoop bars up to #11 and bolts up to 42 mm (1.625 in.) in diameter. The use of hoop reinforcement provides a positive connection across the segments with sufficient ductility to handle the high-tension force. However, the special connection increases ring-build time, complicates segment alignment, increases segment manufacturing cost, increases tunneling cost and leads to longer construction schedule. Additionally, it is anticipated that a PVC T-lock liner may have to be installed in the tunnel to further reduce the risk of leakage from the tunnels.

Tunnel liner design of the CCO

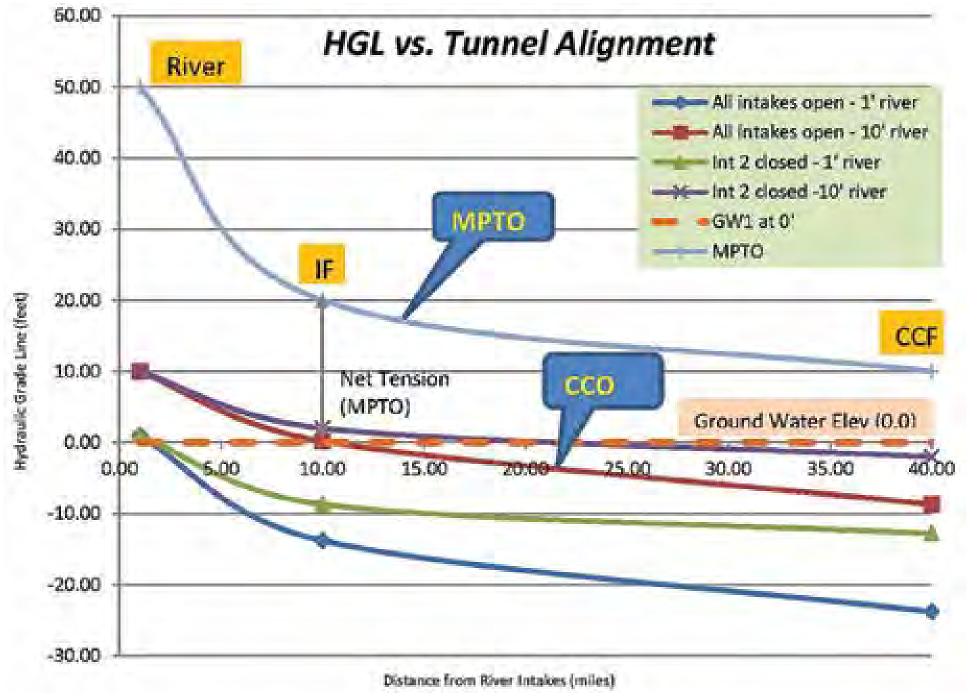
Under the CCO, a combined pumping plant is located at CCF with control gates at each river intake. Using results from preliminary hydraulics study, the HGL elevations of the CCO alternative that were previously shown in Fig. 5 are now summarized in Table 1 at a flow rate of 4 million gpm (9,000 cfs). As this table and the figure show, under the CCO alternative, the HGL inside the tunnels is greatly reduced from the MPTO alternative. Under the MPTO option, with the smaller north tunnels, the river intake pumps had to lift the water to elevations more than 15 m (50 ft) in order to ensure that the water would flow by gravity to Clifton Court forebay. Under the CCO option, with the larger northern tunnels, it is possible to flow 4 million gpm (9,000 cfs) all the way to the CCO pump plant under a variety of river elevations as shown in Table 1.

In fact, under the CCO alternative, Table1 shows that the main twin 12-m (40-ft) tunnels will most likely have HGLs that are equal to or less than the ground water elevation. For tunnel locations with HGL at or below the ground water table, the tunnel liner will be in compression only, which is the design condition for the majority of concrete segmental liner constructed today. No special tension bolts or hoop reinforcement will be required for a compression-only liner. It is anticipated that the compression-only segment design will yield significant cost savings and schedule improvements compared to a tension-compression system.

For regions where the HGL is higher than the ground water elevation for the north tunnels, net tension will develop in the liner, but the corresponding hoop tension force is 55 percent to 80 percent less than the original MPTO design under normal pumping operation. For extreme flood river elevations of 6 to 7.5 m (20 to 25 ft) under CCO, design considerations on ground overburden, backfill grout, ground permeability, concrete tensile strength will be considered during preliminary and final design to ensure the liner will provide strength and leakage control.

FIG. 5

HGL vs. tunnel alignment under various operational conditions.



Comparison of the MPTO and CCO tunnels

Under the CCO pumping scenario, the net internal hoop tension on the segmental liner can be substantially reduced or eliminated. This will significantly reduce overall tunnel costs, and reduce leakage risks.

Advantages of CCO for tunnel design can be summarized as follows:

- 12-m (40-ft) main tunnels 48 km x 2 = 96 km (30 miles × 2 = 60 miles) are subject to compression-only loading for the majority of the tunnel alignment between IF and CCF. The elimination of tension on the liner implies that special high-strength tension bolts are not required at the joint and additional hoop reinforcement is not necessary in the segment. Additionally, the T-lock liner inside the tunnels will not be required. Under this situation, liner construction utilizes conventional proven tunneling methods for better production and lower costs than presently planned under the MPTO.
- Leakage from the tunnel to the surrounding soil is eliminated if the tunnel is always under compression. The absence of net tension minimizes crack formation and propagation in the concrete segments, which will provide a durable and reliable conveyance liner system. This reduces the probability of soil erosion behind the liner, ground support loss and minimizes economic loss.
- For the north tunnels (between river and IF), net

TABLE 1

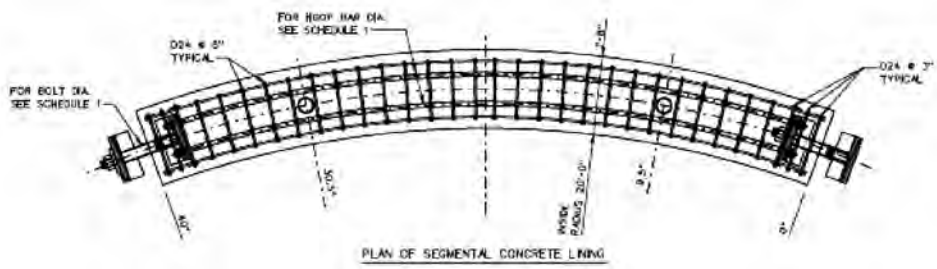
HGL elevations for each option.

Option	Intakes	River Elev (ft)	IF Elev (ft)	CC Elev (ft)
MPTO	—	+50*	+20	+10
CCO	All intakes open (9,000 cfs)	+10	+0.2	-8.7
		+1	-13.8	-23.8

*Pumping at river intakes.

FIG. 6

Preliminary reinforcement for Bay Delta Tunnels (MPTO).



tension will likely remain given the variable river elevations. However, the tensile force magnitude is substantially reduced for CCO because the HGL was reduced. Maximum probable high water HGL is 3 m (10 ft), which is only 20 percent of the net internal pressure of MPTO 15 m (50 ft). Hoop stress is also reduced as some of the north tunnel diameters are smaller than the main tunnels. Because the tension force is reduced, joint bolting and hoop reinforcement will be reduced. In addition, other tension-resisting devices (e.g., shear cones) may become viable because the tensile load is decreased. The T-lock liner will most probably not be needed on the north tunnels for leakage control.

- Eliminating net tension along the majority (or all) of the main tunnels and decreasing tension in the north tunnels will benefit DHCCP. The CCO alternative optimizes liner design, reduces construction costs, increases tunneling production rates, shortens construction schedule and eliminates some of the long-term potential risks associated with tension design of the large-diameter, high-pressure segmental liner.

Combined pumping plant at Clifton Court

General site layout and configuration. In the CCO approach, the northeast corner of Clifton Court Forebay serves both as the terminus of the 12-m (40-ft) tunnels, and location of the new combined pumping plant. At this location, there is a small island within DWR's property holdings that is suitable for constructing the needed facilities.

The facilities arrangement at this location consists of the main tunnels, surge shafts and twin deep-shaft pump plants. The proposed facilities are shown in Figs. 8 and 9. The surge shafts provide a point of interconnection between the 12-m (40-ft) tunnels and this provides for increased operational reliability and flexibility. Further south of the surge shafts are the deep-shaft pump plants that house the pumping equipment. The diameters of the pump shafts are larger than the surge shafts so the pumps and other equipment could be adequately arranged. The distance between the surge shafts and the pumping shafts was set at a minimum of 137 m (450 ft) to provide working separation for the tunneling contractors and the pump station contractors.

Surge shafts. Each 12-m (40-ft) tunnel connects to a 46-m (150-ft) diameter surge shaft. The surge shaft is divided into three sections for reliability and operational flexibility. The surge shaft has the following operational functions:

- **Surge protection:** In the event of a hydraulic surge in the tunnel system, this shaft is configured with an unrestricted opening above each weir gate that will allow water to spill over into Clifton Court during a surge event. Surge discharge channel is shown in Fig. 8.
- **System isolation:** A platform wall at the center of the shaft is used to divert water flow vertically up the shaft where six isolation drop gates are located. During tunnel maintenance and dewatering activities, these gates can be closed to isolate one of the twin tunnels from the rest of the system.
- **Flow diversion:** The two surge shafts are located side-by-side. Four drop gates between the two shafts are used to divert

FIG. 7

San Diego Bay outfall segment reinforcement.

water flow from one shaft to the other allowing the use of both pumping shafts interchangeably. This operation flexibility allows the use of either pump shaft during maintenance and repairs.
- **Gravity flow operations:** Under certain river stage conditions and water levels in CCF, it may be possible to convey water from the river to CCF entirely by gravity. Under such conditions, water will rise in the surge shaft and spill into CCF in the same manner that water would spill from the shaft in a surge event. Water will not flow through the pump shaft in the gravity operation mode.

FIG. 8

Cross section of CCO surge shaft and pump shaft.

Pump shafts. Downstream of the surge shaft, water flows into the pumping plant shaft via short 12-m (40-ft) tunnels. Two pump shafts have a capacity of 2 million gpm (4,500 cfs) each, for a total of 4 million gpm (9,000 cfs). The pump suction receives water flow from the center of the shaft. The configuration allows for an even hydraulic flow split among all the six pumps (five duty and one spare). Each pump is sized for 4 million gpm (9,000 cfs) for a max flow capacity of 2 million gpm (4,500 cfs) per pump station shaft. Two low-capacity pumps, 135,000 gpm (300 cfs) each, will be used during low flow conditions to avoid running the rpm on the large pumps down to a speed that may cause thrust bearing issues, and for draining the pump wet well during pump inspection and repairs.

The water level in the Sacramento River elevation varies from elevation 0.15 m to elevation 7.3 m (0.5 ft to 24 ft) above sea level, and the Clifton Court Forebay elevation varies from elevation -0.6 to 1.8 m (–2 ft to 6 ft). Hence the pump stations must be able to operate over a wide operational range. In order to select appropriate pumps the discharge side at Clifton Court Forebay will be fixed to elevation 3 m (9 ft). Three system curves and operating conditions were determined using the fluctuation in elevation of the river and the fixed discharge elevation at the Clifton Court Forebay. The three system curves consist of (1) a high head curve, (2) a low head curve, and (3) a design condition curve. The design condition curve was interpreted as being a typical river elevation of 1 m (3 ft), which will be the typical operating condition.

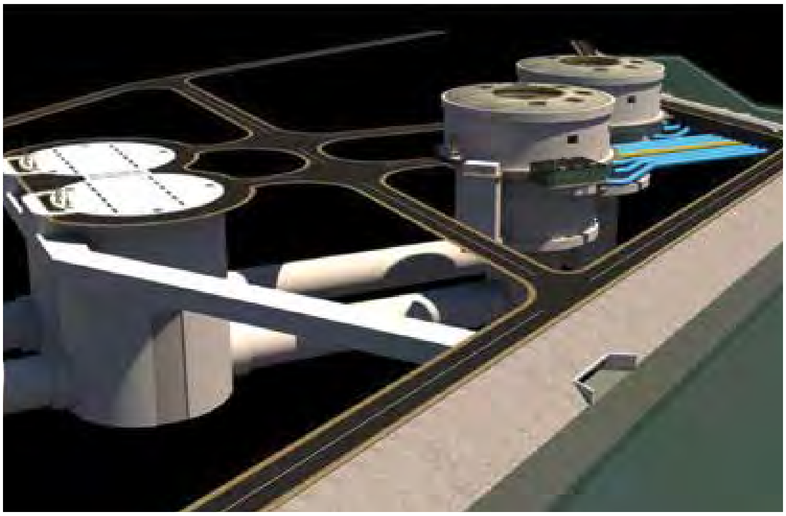
At the design operating condition of 4 million gpm (9,000 cfs), the total dynamic head of 10 m (30.3 ft) is required to pump into Clifton Court. The projected total dynamic head from the river to the pump shaft has a head loss of 5.8 m (19.3 ft) based on the hydraulic model that was completed for this study. The total horsepower for the CCO arrangement under design head conditions is approximately 25,000 kW (34,000 hp), compared to the MPTO system which has an installed horsepower requirement of 42,500 kW (57,000 hp). The difference between the two options is 17,200 kW (23,000 hp). It is believed that the CCO arrangement will provide an opportunity to run the system in a "full gravity mode" under some flow ranges conditions. The MPTO does not provide a gravity flow option pumping is required for all the flow ranges.

System hydraulics – real-time modeling

Due to the innovative nature of the CCO, it was determined that a real-time model was needed to evaluate system response and hydraulic performance based on demand patterns in the river and the proposed intake deliveries. The model was used to help identify any fatal flaws in the hydraulic and operation aspects of the CCO alternative. Some of the key points of interest included in this dynamic model analysis were the following items: (1) river intake flow control, (2) intermediate forebay fluctuations, (3) pump operation, (4) overall flow delivery capabilities and (5) upset/stress condition analysis. The real time model was not intended to provide surge/transient analysis. The system surge analysis will be conducted in the future (i.e., preliminary design). As previously discussed, the CCO system layout provides a large surge shaft/chamber immediately upstream of the pumps and any pump "trips" will discharge water from the surge chamber back into Clifton Court Forebay. Therefore, on a conceptual basis, it is believed that the overall system is adequately

FIG. 9

3D rendering of surge and pump shafts with tunnels (view to east).



protected from hydraulic surge events by these surge shafts.

Hydraulic model analysis. The hydraulic model was used to evaluate extreme operating conditions and determine the effects on the overall CCO conveyance system. The flow data used for the analysis consisted of data supplied by DWR from previous BDCP-related hydraulic studies. The main analysis included ramping up of the pumps to achieve a range of flow conditions and durations up to a maximum total system flow of 4 million gpm (9,000 cfs) from intakes 2, 3, and 5 consisting of 1.3 million gpm (3,000 cfs each) and then transitioning to an emergency shutdown of intake 2, to a new steady state system flow of 2.6 million gpm (6,000 cfs). These conditions were analyzed to determine the fluctuations in the Intermediate Forebay elevations and if the following two criteria were exceeded: (1) fish screen velocities not to exceed 0.2 fps at any time, and (2) flow per intake not to exceed 1.3 million gpm (3,000 cfs) at any time.

Some of the key conclusions that were obtained from the real-time hydraulic modeling include:

- The CCO alternative can deliver the desired flows to CCF under all operational scenarios set forth in the project criteria.
- Overall, under both normal operating conditions and extreme stressed conditions, the system performances are unaffected by relocating the pump stations from the intakes to Clifton Court Forebay.
- At steady-state flow from each intake, some gate throttling at the exit from the sedimentation basins at the river intake structures will be required to balance the flows equally. Alternatively, the flows can be balanced without throttling gates by further refining the size of the northern conveyance tunnels to each intake accordingly. This analysis will be conducted in preliminary design.

Conclusions

The CCO configuration for the DHCCP was developed to address several different challenges related to the design, construction and operation of the new conveyance facilities. The existing concept, referred to as the MPTO, presented significant technical challenges related to the design of the segmental tunnel liner due to the high pressures that were anticipated inside the tunnel during operations. Additionally, the MPTO configuration placed large industrial-type pumping and support facilities in close proximity to environmentally sensitive features along the Sacramento River. The CCO alternative combines and moves the pump stations from the river intake facilities and places them near the terminus of the project at the Clifton Court Forebay. Under this configuration, water will flow by gravity from the river to the pump station, from which point it is lifted into Clifton Court by two identically sized pump stations. By utilizing gravity flow through the north and main tunnels, operating pressures in the tunnels are reduced, thereby simplifying the design of the tunnel's segmental liner system. Relocation of the main pumping plants from the river intakes reduces the amount of construction required in an environmentally sensitive area, and eliminates the need for permanent high voltage transmission lines, and long-term operational activities in these areas. ■

FEATURE ARTICLE

George A. Fox Conference focuses on the future of the industry

During his presentation at the 2016 George A. Fox Conference about the history of public-private-partnerships (PPP) in the tunneling and underground construction industries in New York, Vincent Tirolo, Jr., told a story about how, as a young engineer in the late 1960s, he and others pooled money to purchase a calculator for $75 that had the ability to perform sine and cosine functions. That was a big deal in those days and would make their job much easier. Oh how far things have come. Tunnel and underground construction engineers can now virtually map out and plan entire projects before the first shovel ever breaks ground. And the machines that are used to build the tunnels have advanced in ways that could not have been imagined 50 years ago.

The calculator is just one example of innovation in the industry and on Jan. 26, more than 400 industry professionals attended the George A. Fox Conference at the Graduate Center of New York (CUNY) to learn more about the next innovations, new tunneling technologies and what the future might hold for the industry. The conference included sessions on contracting models, rescue and fire life safety and new technological developments as well as an international project spotlight presentation from Nasri Munfah about the Eurasia Tunnel, connecting the European and Asian sides of Istanbul, Turkey.

The project, also known as the Istanbul Strait Road Tube Crossing project, was named the 2015 Major Tunneling Project of the Year by the International Tunneling and Underground Space Association.

The tunnel boring work for the 3,344-m (11,000 ft) long tunnel under the Istanbul Bosphorus Strait was completed in August, heralding a new era in tunneling.

Tunnel boring work was launched in April 2014 with a ceremony with then Prime Minister Recep Tayyip Erdogan in attendance. The work was completed on Aug. 22, 2015 with Prime Minister Ahmet Davutoglu participating in the ceremony.

While the bulk of the Fox Conference was about where the industry is headed, there was significant time spent on the history of the industry as well. It's been said that those who ignore history are doomed to repeat it. Keeping this in mind, Randy Essex teed up the conference with a keynote address linking the fascinating history of tunneling in the Northeast and beyond to the exciting, future of the industry. It is a future that is filled with advances in safety, efficiency, innovation and challenges that, in some cases, are just now starting to be considered.

One of the most pressing challenges is finding ways to fund the massive projects that will improve or repair infrastructure in cities around the world.

"It all starts with financing," Essex said. "We see more and more that there is fewer publicly available funds, whether it is tax dollars or bonds. Given the political dynamics of the way things are, there is insufficient funding to build what needs to be built. The projects we work on are growing in expense and in time duration. We used to have projects in the millions of dollars and now they are in the billions of dollars over much longer durations and there is a recognition that, if we don't get smarter about what we are doing, we may not be able to afford the things we need."

In his keynote address, Essex said one of the greatest challenges the industry has faced over the years is a lack of innovation. According to Essex, the industry in the United States was handcuffed by an overly legislative environment, forcing the U.S. to import much of its innovation from Europe. This includes technical as well as business process innovation.

As with any challenge, there is also opportunity and according to Essex, the challenge to find ways to fund mega projects like the SR-99 project in Seattle, WA or New York's East Side Access project has forced the industry to find innovative solutions to the contract delivery challenge. One of the solutions that has come to the forefront recently is private financing in the form of public-private partnerships (PPP).

"The light is getting brighter. Historically in the United States we have been restrained by legal precedent, but with the advent of a number of evolving dynamics in our business relating to contracting practices and different forms of contract delivery and involvement from interests overseas, contractors are bringing their own approaches and ideas for innovation. This is driving a much more fertile environment for innovations to be discussed, considered and in some cases, implemented and to the great benefit to the cost of schedule to all the stakeholders," Essex said.

PPPs have opened new avenues for the industry as they spread the risks, and reward, among multiple partners. And, while there are detractors to the PPP method, it would seem that

William Gleason, Senior Editor

Eurasia Tunnel, connecting the European and Asian sides of Istanbul, Turkey, is an example of success through innovation.

PPP is here to stay.

Tirolo noted that often the public is lery of PPP because of its distrust of the elected officials involved with the PPP, a distrust that has been earned.

During the contracting sessions, Robert Goodfellow spoke about risk management on projects, urging the crowds to read the contract carefully as they vary from project to project. Goodfellow noted that these projects are complicated matters on every level, not just technically. All parties need to be aware of what they are stepping in to.

Rescue and life safety

As with any heavy construction industry, there are inherent risks to workers in tunnel and underground construction. But just as with contracting and technical challenges, there are innovative solutions that can minimize and even eliminate some of those risks. During the 2016 Fox Conference three papers focused on safety in in the industry. Bill Connell of Parsons Brinkerhoff spoke about fire protection as it applies to design and construction considerations and Henry Russel of Parsons Brinkerhoff spoke about tunnel fire proofing in a paper that compared state-of-the-art boards to spray fireproofing.

Shay Burrows of the Federal Highway Administration spoke about that administration's new tunnel inspection requirements.

New technical developments

The conference concluded with a focus on specific technological developments. Mike King and Anthony Harding of CH2M spoke about international innovations in pre-cast segmental lining. Phil Sheridan of Clark Construction Group and Jan Cermak of Mueser Ruthledge Consulting Engineers provided a presentation about the instrumentation of CSX Virginia Ave. Tunnel and Jim Nickerson of Vegas Tunnel Constructors provide an updated about the Lake Mead project and tunneling in high water pressure.

The 2017 George A. Fox Conference will return to CUNY on Jan. 31. ■

COMPILED BY JONATHAN KLUG, DAVID R. KLUG & ASSOCIATES

TUNNEL NAME	OWNER	LOCATION	STATE	TUNNEL USE	LENGTH (FEET)	WIDTH (FEET)	BID YEAR	STATUS
Gateway Tunnel	Amtrak	Newark	NJ	Subway	14,600	24.5	2018	Under study
2nd Ave. Phase 2-4	NYC-MTA	New York	NY	Subway	105,600	20	2017-22	Under study
Water Tunnel #3 bypass tunnel	NYC-DEP	New York	NY	Water	20,000	22	2015	Kiewit - Shea JV awarded
Water Tunnel #3 Stage 3 Kensico	NYC-DEP	New York	NY	Water	84,000	20	2017	Under study
Cross Harbor Freight Tunnel	NYC Reg. Develop. Authority	New York	NY	Highway	25,000	30	2018	Under study
South Conveyance Tunnel	City of Hartford	Hartford	CT	CSO	16,000	26	2016	Kenny/Obayashi low bid
Amtrak B& P Tunnel	Amtrak	Baltimore	MD	Rail	10,000	30	2018	Under design
Purple Line - Plymouth Tunnel	MD Transit Administration	Baltimore	MD	Subway	1,000	30x40	2016	P.L. Transit Const. low bid
Thimble Shoal Parallel Tunnel	Chesapeake Bay Bridge and Tunnel Dist.	Chesapeake	VA	Highway	5,700	45	2016	Proposal stage
Northeast Boundary Tunnel	DC Water and Sewer Authority	Washington	DC	CSO	17,500	23	2018	Under design
US Highway 17 drainage tunnel	City of Charleston	Charleston	SC	CSO	8,420	12	2016	Bid date 3/17/16
Bellwood Tunnel Phase 2	City of Atlanta	Atlanta	GA	Water	21,000	12	2016	Under design
Olentangy Relief Sewer Tunnel	City of Columbus	Columbus	OH	Sewer	58,000	14	2016	Under design
Blacklick Creek San. Interceptor Tunnel	City of Columbus	Columbus	OH	Sewer	24,000	10	2015	Michels/Jay Dee low bid
Alum Creek Relief Tunnel Phase 1 Phase 2	City of Columbus	Columbus	OH	Sewer	30,000 21,000	18 14	2016 2017	Under design Under design
Doan Valley Storage Tunnel	NEORSD	Cleveland	OH	CSO	9,700	17	2017	Under design
Westerly Main Storage Tunnel	NEORSD	Cleveland	OH	CSO	12,300	24	2020	Under design
Shoreline Storage Tunnel	NEORSD	Cleveland	OH	CSO	16,100	21	2021	Under design
Southerly Storage Tunnel	NEORSD	Cleveland	OH	CSO	17,600	23	2024	Under design
ALCOSAN Ohio River Tunnel Allegheny River Tunnel Monongahela Tunnel	Allegheny Co. Sanitary Authority	Pittsburgh	PA	CSO	 10,000 41,700 53,900	 14 14 14	 2019 2020 2021	 Under design Under design Under design
Lower Pogues Run	Indianapolis DPW	Indianapolis	IN	CSO	9,000	18	2016	Under design
Fall Creek	Indianapolis DPW	Indianapolis	IN	CSO	19,600	18	2016	Under design
White River Tunnel	Indianapolis DPW	Indianapolis	IN	CSO	28,000	18	2016	Under design
Three Rivers Protection/Overflow	City of Fort Wayne	Fort Wayne	IN	CSO	26,400	12	2017	Under design
Pleasant Run Deep Tunnel	Citizens Energy	Indianapolis	IN	CSO	38,000	18	2020	Under design

TUNNEL NAME	OWNER	LOCATION	STATE	TUNNEL USE	LENGTH (FEET)	WIDTH (FEET)	BID YEAR	STATUS
St. Louis CSO Expansion	St. Louis MSD	St. Louis	MO	CSO	47,500	30	2016+	Under design
KCMO Overflow Control Program	City of Kansas City, MO	Kansas City	MO	CSO	62,000	14	2016	Under design
Mill Creek Peaks Branch Tunnel	City of Dallas	Dallas	TX	CSO	5,500	26	2014	Odebrecht low bid
Bellevue Tunnel - E330	Sound Transit	Seattle	WA	Transit	2,000	40x30	2015	Atkinson awarded
Ballard to Wallingford	Seattle Public Utilites	Seattle	WA	CSO	14,250	14	2018	Under design
L.A. Metro Regional Connector	Los Angeles MTA	Los Angeles	CA	Subway	20,000	20	2014	Skanska-Traylor JV Awarded
L.A. Metro Westside Extension Phase 1 Phase 2 Phase 3	Los Angeles MTA	Los Angeles	CA	Subway	42,000 26,500 26,500	20 20 20	2014 2015 2017	Skanska/Traylor, Shea awarded Prequals complete Under design
Speulvada Pass Corridor	Los Angeles MTA	Los Angeles	CA	High/Trans.	55,500	60	2017	Under study
Northeast Interceptor Sewer 2A	LA Dept. of Water and Power	Los Angeles	CA	Sewer	18,500	18	2016	RFQ under way
River Supply Conduit - Unit 7	LA Dept. of Water and Power	Los Angeles	CA	Water	13,500	18	2016	Under design
JWPCP Effluent Outfall Tunnel project	Sanitation Districts of LA	Los Angeles	CA	Sewer	37,000	18	2015	Under design
Freeway 710 Tunnel	CALTRANS	Long Beach	CA	Highway	26,400	38	2016	Under design
BDCP Tunnel #1 BDCP Tunnel # 2	Bay Delta Conservation Plan	Sacramento	CA	Water	26,000 369,600	29 35	2017 2018	Under design Under design
Iowa Hill Pumped Storage Project	Sacramento Muni. Utilities District	Sacramento	CA	Water	3,500	20	2018	Under design
SVRT BART	Santa Clara Valley Trans Authority	San Jose	CA	Subway	22,700	20	2016	Under design/ Delayed
Coxwell Bypass Tunnel program	City of Toronto	Toronto	ON	CSO	35,000	12	2015	Under design
Stormwater Management Program	City of Toronto	Toronto	ON	CSO	72,000	20	2017+	Under design
Keswick Effluent Outfall Tunnel	City of Toronto	Toronto	ON	CSO	11,600	23	2018	Under design
Yonge St. Extension	Toronto Transit Commission	Toronto	ON	Subway	15,000	18	2016	Under study
Scarborough Rapid Transit Extension	Toronto Transit Commission	Toronto	ON	Subway	25,000	18	2017	Under design
CSS - East-West	City of Ottawa	Ottawa	ON	CSO	14,400	10	2015	Under design
Second Narrows Tunnel	City of Vancouver	Vancouver	BC	CSO	3,600	14	2013	Under design
UBC Line project	Trans Link	Vancouver	BC	Subway	12,000	18	2015	Under design
Annacis Island Outfall Tunnel	City of Vancouver	Vancouver	BC	Water	8,000	10	2017	Under design
Northern Gateway Clore Tunnel Hoult Tunnel	Enbridge Northern	Kitimat	BC	Oil Oil	23,000 23,000	20 20	2014 2014	Under design Under design

AWARDS

New Irvington Tunnel wins APWA 2016 Environment Project of the Year

McMillen Jacobs Associates played a critical role in the San Francisco Public Utilities Commission New Irvington Tunnel project, which recently received the 2016 Project of the Year Award in the Environment Category for projects over $75 million from the American Public Works Association. The award was presented at its awards luncheon on Feb. 25 in Berkeley, CA.

McMillen Jacobs Associates was the lead designer for the tunnel, shafts and portals, and provided engineering services during construction. Facilities include the new tunnel with initial and final linings, overflow shaft, tunnel portals, a manifold and pipelines to facilitate the connection of Bay Division Pipelines 1, 2, 3, 4, the new Pipeline 5 and related ancillary appurtenances.

The tunnel was excavated by conventional means from four headings: two from the Vargas Shaft (adjacent to Interstate I-680), one from the Alameda West Portal and one from the Irvington Portal.

The project, estimated to cost $250 million, broke ground in the fall of 2010. The first tunneling began from the Alameda West Portal in March 2011, and hole-through occurred in October 2013. The project completed in November 2015. ■

SHORT COURSES

CSM offers short courses in grouting and shotcrete

The Colorado School of Mines (CSM) Center for Underground Construction and Tunneling announced the dates of two annual short courses to be held on the Golden, CO campus under the direction of Raymond Henn, rhenn@mines.edu, and Rennie Kaunda, rkaunda@mines.edu. Underground Grouting & Ground Improvement will be held May 16-20, 2016 and Underground Shotcrete will be held Sept. 7-8, 2016.

Underground Grouting & Ground Improvement is a five-day course that covers grouting and ground modification used for underground construction, tunneling and mining projects. It includes topics in engineering, equipment, materials and methods for grouting and ground modifications used on various types of underground projects. The course consists of classroom presentations by internationally recognized experts, a day of off-campus field demonstrations, as well as some on-campus laboratory demonstrations and testing of grouts and grouting methods.

Topics to be covered include: grouting methods (jet, compaction, fracture, permeation, consolidation, backfill and contract); ground freezing for shafts, tunnels and cross passageways and construction dewatering systems.

CSM will award 3.5 continuing education credits to participants who complete this course. For more information, visit http://csmspace.com/events/groundimprovement.

Underground Shotcrete is a comprehensive three-day course on the effective and sustainable uses of shotcrete, increasingly used for support of excavation, geotechnical retaining walls, soil nails, underground construction and tunneling, new structural wall and wall repair and mining.

Industry experts will instruct attendees on how to specify, design and provide quality assurance of reinforced concrete construction using shotcrete complemented with ACI specifications, guide and underground guide specification and Nozzleman certification documents. This course provides an excellent opportunity for meeting and networking with shotcrete industry professionals.

CSM will award 1.4 continuing education credits to participants who complete this course. For more information, visit http://csmspace.com/events/shotcrete. ■

PERSONAL NEWS

AXEL NITSCHKE (SME) is Shannon & Wilson's new director of operations for underground services. He will assist the company's underground services portfolio and provide full-service underground consulting and engineering to transportation, utility and other infrastructure clients. He has a 20-year career working on road, rail and utility tunnel projects for infrastructure and mining clients in North America, South America and Europe. He is a contributing author to tunneling and shotcrete publications, including the 2016 World Tunnel Congress. With the addition of Nitschke, **RED ROBINSON** (SME) will shift his role to director of marketing for underground services. He has been with Shannon & Wilson since 1974, and he has more than 40

PERSONAL NEWS

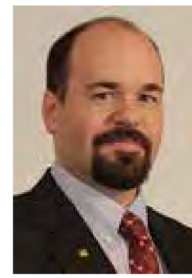

NITSCHKE

years of underground experience consulting on more than 300 tunnel projects worldwide.

PEGGY GANSE (SME), PE, PG, Shannon & Wilson's senior tunneling services project manager, recently obtained National Certified Tunnel Inspector certification to perform safety inspections of tunnels nationwide. Ganse attended training provided by the National Highway Institute of the Federal Highway Administration. She is a geologist and geological engineer with 23 years of experience designing, managing and performing geotechnical services for tunneling projects across North America.


GANSE

DAVID C. WARD (SME), PE, PG, has been promoted to senior associate in Shannon & Wilson's Seattle, WA office. He works primarily on tunnel and underground projects in soil and rock. Other promotions in the Seattle, WA office include **HISHAM J. SARIEDDINE** to vice president, **ROB CLARK** to senior associate and **WENDY L. MATHIESON** to senior associate. The company also promoted **DAN McMAHON, ELLIOTT C. MECHAM, BRIAN S. REZNICK** and **SCOTT R. WALKER** to associates. ■


WARD

OBITUARIES

BRADFORD F. TOWNSEND

Bradford Field Townsend, 60, of Bridgewater, NH, died at his home on Dec. 24, 2015. Townsend was born in Beverly, MA on June 22, 1955. He obtained a B.S. in natural/environmental science at Johnson State College in 1979 and an M.S. in civil engineering from the University of New Hampshire in 1985. His work as a civil engineer in the United States and internationally included the design and construction of tunnels, mines and bridges, and highway and rail transportation systems.


TOWNSEND

Townsend's engineering career began at Haley and Aldrich in 1986. There, he worked on projects in the New England area that included foundations for buildings and bridges, soil and rock excavation, and water, pedestrian, subway and highway tunnels. He later worked on projects in Cairo and Bangkok.

In 1994, he joined Louis Berger International and worked in Asia on the BTSC Mass Transportation project in Bangkok, which involved the design of elevated, heavy-rail mass transport and 25 stations. He also worked on the Hai Van Pass Tunnel Project in Vietnam, which included the design of tunnels and bridge work. From 2000 to 2005, he was the deputy chief director of engineering for the Taiwan High Speed Rail project working for Parsons Brinckerhoff. The high speed rail project required the design and construction of mined and cut-and-cover tunnels, viaduct structures and cut-and-fill embankment.

Upon returning to the United States, Townsend joined Hatch Mott MacDonald working on the San Francisco Downtown Rail Extension, a multimodal transportation facility accommodating busses, commuter rail and future high-speed rail operations. To care for his parents, he moved back to New Hampshire in 2012 and joined Parsons Transportation as a vice president, overseeing large transportation bridge and tunnel projects. He later joined Dr. Sauer and Partners in early 2015.

Throughout his career, Townsend assumed a prominent role in the civil engineering and tunneling community. He published several articles in *North American Tunneling* and American Society of Civil Engineers (ASCE) journals and, for more than 20 years, presented at a variety of global engineering conferences. His projects won an American Council of Engineering Companies' Engineering Excellence Award and ASCE national and regional excellence awards.

Although highly accomplished as a civil engineer, Townsend considered his own construction company his pride and joy. In 1979, after graduating from Johnson State College, he became the owner and manager of Lone Pine Construction, concentrating on residential and light commercial projects, general site civil development and waterfront work. After becoming an engineer, he continued to operate Lone Pine as a construction and engineering company until his death.

Townsend is survived by his wife Sandie Kuo Townsend, his mother Helyn Acosta Townsend, his sister Lisabeth Carol Townsend, two aunts and many cousins. He was preceded in death by his father, John Burnett Townsend. ■

OBITUARIES

WILLIAM LEECH

William (Bill) Leech, 70, long-time member of the underground construction, tunnel and mining industries, died Jan. 14, 2016 in Tucson, AZ.

Leech was raised in Northern California and earned a B.S. degree in mining and metallurgy from the University of Nevada, Reno.

Following graduation, he was accepted into the U.S. Navy's officer candidate school in Newport, RI and, upon his Naval Reserve Officer Training Corps commission, served as a damage control officer aboard the USS Canberra and the USS Belknap during the Vietnam War. During his career of more than 40 years, Leech worked for many major contracting, engineering and construction management firms.


LEECH

Leech's career path took him and his wife Peggy to many locations overseas. They spent extended stays in Peru, where their son was born, Iceland, Saudi Arabia, Lebanon, Canada and Taiwan. Upon retirement, he and Peggy moved to Tubac, AZ, where they enjoyed the relaxed life and friendships of that small artist community. He and Peggy loved adventurous travel and finally realized a life-long dream by taking a safari in Africa just prior to the illness that took his life.

Leech is survived by his wife, Peggy; his daughter, Sarah Leech; his son, Thomas Leech; a granddaughter, Isobell Leech and a sister, Karen Mansene. He was a devoted family man, a true professional in his career, and superior friend to many. He will be missed. ■

NEW PRODUCTS

Brokk unveils compact diesel robot

The Brokk 120 diesel is a compact diesel-powered demoliton robot for tunneling and mining. The multipurpose, medium-sized demolition robot weighs 1.1 t (1.2 st) with a lifting capacity more than 300 kg (661 lbs) and fills gap in the market between inspection robots and heavy machines. Its primary advantages are its compact size, its flexibility and reach with a three-part arm and its ability to accept attachments for drills, crushers, grapples and hammers. Weighing less than one-fourth of the Brokk 400 diesel, the 120 has a 22.7 L (6-gal) fuel tank and will run more than eight hours before refueling.

The Brokk 120 D was developed to fulfill the need for a very compact machine that was independent from a fixed power source. Only 78.7 cm (31 in.) wide, 203 cm (80 in.) long and 124 cm (49 in.) high, it can pass through any standard door opening and maneuver in tight spaces. Its light weight allows it to drive over weight-restricted floors and helps make it easy to transport to and from sites.

Powered by a compact and efficient diesel engine, the Brokk 120 D can run a full shift independent from any power source. This flexibility comes without sacrificing any of the power and performance of its similar-sized, electric-powered sibling, the Brokk 100. Plus, the Brokk 120 D uses the same attachments and generates the same hydraulic power as the Brokk 100, increasing its versatility.

The 120D has a Kubota D1105-E4 B, EPA tier 4, EU stage 4 motor.

Akkerman drill head adapter debuts in Australia

The concept of a steering head adapter to accommodate horizontal directional drilling tools for pilot tube systems has been years in the making.The new Akkerman drill head adapter assembly was used on its inaugural drive on a project in Darwin, Australia for a steel casing installation.

The contractor, Queensland Infrastructure Services (QIS), used a GBM 240A and guidance system to install pilot tubes to achieve line and grade accuracy and later upsized to the steel casing diameter with their American Augers auger boring rig. QIS coupled the adapter with a TriHawk I Drill Bit from Hammerhead which chewed its way along the 25-m (82-ft) bore path as a bentonite pump helped to flush the cuttings away.

After following along its course through rock, the tooling emerged into a manhole at the exact target. QIS and the owner were thrilled with its success and plan to use it for four more drives on the same project, one that will be significantly longer. Crew members dubbed it "the animal" for the way that it attacked the rock. ■

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