Use of Electric Power and Controls for Erecting Precast Segmental Bridges
Case Study- Lee Roy Selmon Crosstown Expressway

Guy Dickes, Constellation Group LLC
guy@cgllc.us
www.cgllc.us

ABSTRACT: Electric power is underutilized in the bridge construction and precast industry. Hydraulic power is generally the preferred mode. By understanding how easily electric motors can be controlled; how efficient electric motors are and how safe electric power is; the bridge construction and related industries should reexamine its choice of power mechanisms.

Three major advantages of electric power are controllability, environmental safety and available torque. Full torque or more is available from as low as 1-2% of full speed to full speed of an electric motor. This cannot be said of hydraulic, diesel or gas power. An examination of torque and horsepower curves will demonstrate this fact. Electric speed control is easily available in step increments of 1/600th of full speed. This is 0.10% per hertz to 60 hertz.

Utilizing Variable Frequency Drive (VFD) technology, electric motors can be controlled with a touch of a button or turn of a switch. Predetermined acceleration/deceleration rates of motor speed can be programmed into the most basic VFDs. Feedback systems can be employed for absolute rock-solid speed control, if necessary. The use of programmable VFDs gives the designer/engineer a multitude of controllable parameters not available in other power systems**.**

The Lee Roy Selmon Crosstown Expressway project was designed to be constructed with span-by-span bridge erection techniques. On this project two electric-powered chain drive systems were used to set approximately 3400 eighty ton precast bridge segments for this elevated roadway. The large twin-girdered gantries (each pair of girders was called a heading) were placed on pier brackets for precast segment erection. **See Photo 1.** Extremely tight job site conditions dictated lifting the precast segments onto one end of gantry and then pulling the segments along the gantry into position. Accurate speed and positioning controls were required. Each segment had to be placed within inches of each other prior to bonding epoxy application, and then set into final position.

Two fifteen horsepower, VFD controlled, electric motors provided all the necessary power for moving the 80 ton segments into position. Clean, quiet, effective, easy to use and maintain electric power built the elevated Lee Roy Selmon Crosstown Expressway with no delays due to the segment setting equipment.

Photo 1: Pier Bracket and Erection Girders

Major Players:

Owner:	Tampa Hillsborough Expressway Authority
Engineer:	Figg Engineering, Tampa, FL
General Contractor:	PCL Civil Constructors, Tampa, FL

Background: The Lee Roy Selmon Crosstown Expressway needed to be expanded due to increased commuter traffic into and out of Tampa, FL. Designed by Figg Engineers, Tampa FL this new roadway extends approximately 7 miles east of downtown Tampa and joins with other highways in the area. The innovative design is elevated above the highway's median for most of its length, saving a substantial amount of money in land acquisition for the owner, the Tampa Hillsborough Expressway Authority. Construction was, in general, span-by-span, using precast/post-tensioned segments. Considering that three lanes of highway were added, there was minimal disruption of commuter traffic. Much can be read about the project- it has won several major industry awards for excellence in design and execution and written about in numerous magazine and trade journals.

The general contractor selected for construction was PCL Civil Constructors, based locally in Tampa. Constellation Group LLC was initially asked to visit PCL to discuss the design and construction of an automated silo for use with the approximately 8 million pounds of post-tensioned grout to be used on this project. Although an excellent time and money- saving idea, this silo was eventually not permitted by Florida Department of Transportation on this project as project specifications required 50 pound prebagged grout. At that meeting CGLLC was asked about designing the drive systems used on the project for setting the precast segments.

At the next meeting, John Karpinski, PE, LRS project manager for PCL at that time, provided the necessary technical requirements for the design. In that one day meeting, Karpinski and CGLLC discussed all the parameters around which the system would be designed. This coordination is critical in all such projects; expectations are put on the table; anticipated schedule; costs; limitations of equipment; requirements of all parties involved are expressed.

The basic engineering requirement was the ability to move 80 ton precast segments along the parallel erection girders. The pull load was determined by PCL not to exceed 12,000 pounds laterally. Karpinski's requirements included a maximum segment speed of fifteen (15) feet per minute along the girders and the ability to 'creep' the segments into place. Initial erection schedule allowed for the complete placement of one 160 foot span every three days. To minimize any impact on traffic, segments would be lifted into place during the night shift. This added a measure of complexity to the project.

The first planned heading design factors included a 'place and return' to start position of the system speed of 20 feet per minute. Once the segment was set into position, the drive system would be disconnected from the segment and returned to the start (or loading) position to receive the next segment.

Constellation Group LLC's solution was to use a parallel chain drive system.

Photo 2: First Segment Up

The Basic Engineering Requirements: Heading One

Load or Pulling Requirement:	12,000 pounds -worst case scenario, allowing for horizontal and maximum uphill loads
Forward Speed:	15 feet per minute
Return Speed:	20 feet per minute
Safety Factor:	1.5
Creep*:	3/8" per second Forward and Reverse

* Creep- the ability to adjust the final position of each segment using very slow speeds (3/8" per second). Forward and reverse controls were available for either side of the heading, independent of each other.

Recognized early was the requirement that electric power (or any other power system) could not be engaged at full speed. It was necessary for the segments to be accelerated up to the 15 foot per minute speed, and decelerated back to zero, as well. These precast segments were being erected over live traffic, as high as 50 feet above the existing roadway. Electric power was selected as the safest, most-controllable power system.

Control System:
The control system was designed with one major factor in mind- SAFETY. The system had to be easy to operate and protect the workers and public as well. Numerous interlocks were built into the control panel, avoiding the possibility of accidently operating conflicting controls simultaneously. One example of conflicting controls would be full speed forward on one side, with full speed reverse on the other- a potential catastrophic combination. Full speed forward was designed into one control; full speed reverse into another. The majority of expense and complexity of the control panel involved the installation of system shut-off controls between functions. In order to change from any function to another the system went through the off position. The VFD was programmed to return to zero speed before restarting in another mode. Additional interlocks included a deadman foot switch on each control panel. If the operator left the control panel, it would shut down.

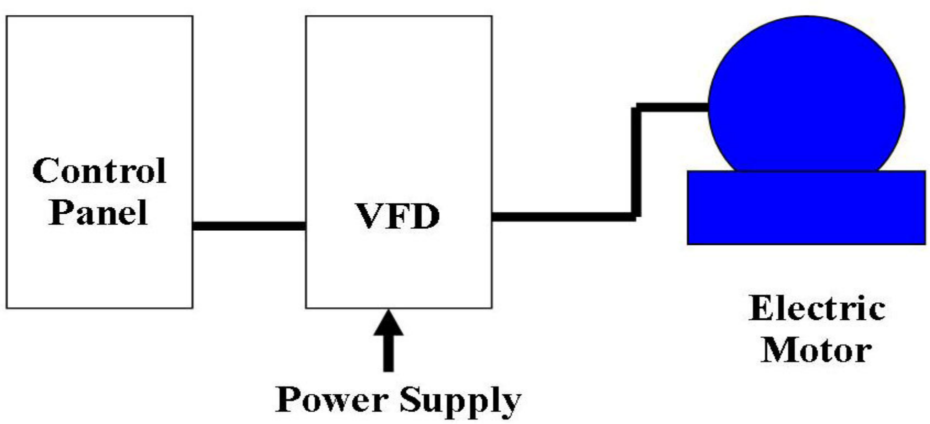

Fig 1. The Simplicity of Control Set-up

Photo 3: Control Panel, Heading One, VFDs Behind

The Mechanical System:

The entire design of this system was predicated upon the maximum design loads of 12,000 pounds of pull. After applying the Safety Factor of 1.5, the design load was now 18,000 pounds. From this point, hardware and equipment selection commenced. It was determined a chain drive system would work best in this application. Positive connection between the motor drive system and the segments was necessary. This resulted in the use of chain drive.

The chain selected needed to be ANSI 200, rated at a working load of 18,000 pounds. Discussions with numerous vendors allowed CGLLC and PCL Purchasing to select the best possible chain, at the best possible price. Selected was the Hitachi ANSI 200 HS (high strength) chain, rated at 20,000 pounds working load, adding to our Safety Factor. It must be noted that the quantity of chain purchased overall for this project was over 500 linear feet, and required the supplier to search the country in order to fulfill the order.

The ANSI 200 chain dictated much of the rest of the hardware. ANSI 200 chain requires the use of ANSI 200 drive gears and appropriate sized bearing pillow blocks. Support from Dodge Power Systems assisted in parts selection.

Photo 4: ANSI 200 Chain

Numerous power train manufacturers were contacted for their input on the gear box design and sizing. Given the load and pull speed requirements, a torque value was determined and several gear box designs were made available. Selected was a 238:1 turndown unit by Emerson Power Transmission (EPT) for several reasons- it was built in the USA, available within a few weeks of order, the price was the best, and it had a dual output shaft. This last feature perhaps was most important. It allowed the overall system to have one universal gearbox, instead of a left and right unit.

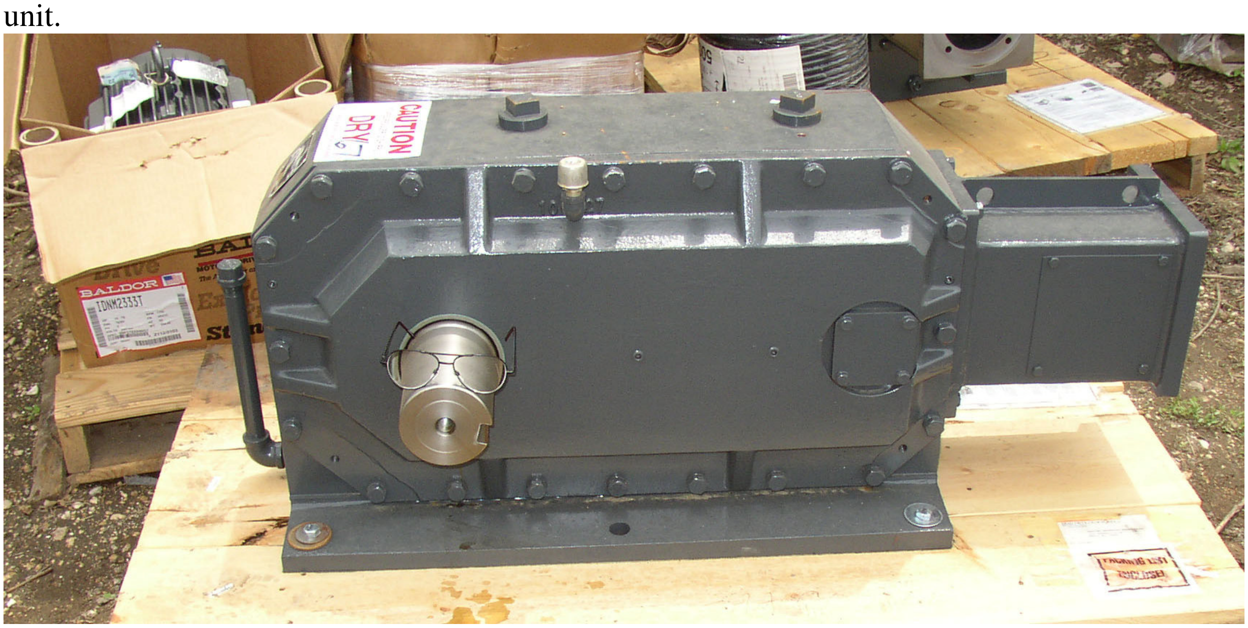

Photo 5: The Work Horse- Gearbox
Note Eyeglasses- 5.25" Output Shaft

Back-up:

CGLLC was designing a system that had to be up and running 100% of the time. Downtime for any reason would be a costly set-back. Constellation Group LLC and PCL decided the controlling factor for replacement availability for any given part was 24 hours. As nearly all parts were from US manufacturers and suppliers, not much was required for standby parts. A gearbox, however, was the only long lead time/ non-stock item and one extra gearbox was purchased. It was never used.

Power Supply:

Used throughout the project, a commercially available 480 volt 3 phase generator provided power. These generators provided power not only for the chain drive systems, but for the heading lighting systems. Each motor requires about 20 amps (full load). Although larger generators were used, a 25KW generator would have sufficed for the chain drives.

The Headings:

Each erection assembly gantry system was referred to a heading. Heading One started at the east Lee Roy Selmon toll booth area and worked westward towards Tampa. Heading One chain drive system used chain for the drive section and a wire rope system to return the chain back to its starting position for its next segment. In Heading One, the control panel was hardwired to the variable frequency drives. The control panel was located at the midpoint of the gantry system.

Heading Two was built at a later date and initially worked the areas east of the toll booth towards the east to connect with the local highways. This chain drive used a continuous chain and proved even more efficient. The chain would not have to be returned to its start position; a segment could be attached at any point on the chain. Furthermore, the heading was reversible, allowing segments to be loaded from either end of the heading. Additional improvements were incorporated into the control system. The PCL erection superintendents wanted the control panel to be located on the top deck, primarily for better visibility and communication. Control parameters were changed to accommodate the change in design.

Support:

One thing about designing specialized equipment such as this- it is necessary and advantageous to use the best resources available. By asking major vendors for their input and technical advice, CGLLC was able to utilize the minds of the best engineers in their respective fields and design a system that worked perfectly from day one. All this support was at no cost to PCL or CGLLC.

Variable Frequency Drives (VFDs):

Variable Frequency Drives (VFDs) are the brains of the system. In simplistic terms, the variable frequency drive does just that. By changing the baseline frequency of standard electric alternating current (60 hertz in the US) to something else, i.e. 30 hertz, the electric motor is now rotating at a speed proportional to the frequency (?/60hz). The electric motor is still providing full torque. Using the computer board on the VFD, and controllable speed and other parameters are at the designer's needs. In the case of Lee Roy Selmon, 41 hertz provided the 15 foot per minute forward speed, and used an acceleration of zero to full speed over 20 seconds. Deceleration was programmed as well. Due to the accuracy of the variable frequency drives, it was not necessary to provide feedback from the electric motors. The two sides of the chain drive system worked in unison.

VFDs should be selected based on their intended usage and not by price alone. There are numerous ways these controls work- varying frequency (hertz); amplitude and voltage. This paper will not delve into each of these functions, but refer you to 'Support'- ask the experts. Most VFDs are rated by horsepower- use the correct sized VFD for its application. A higher horsepower VFD can be used on a lower horsepower electric motor, but not the reverse (i.e. 20 HP VFD used with a 15 horsepower motor, but not a 15HP VFD with a 20 HP motor). VFDs come in a multitude of horsepower ratings and voltages, for almost any electric motor application. More sophisticated VFDs can accept inputs from sensors and even computers, for even greater control. CGLLC has designed electric power systems using ½ horsepower VFDs up to 35 horsepower VFD controlled pumps.

Variable Frequency Drives can often have multiple or different input controls. Nearly all VFDs have on-board input panels. External controls, such as those used on this project, are easily wired into the unit's connector block. See Figure 1 for a typical installation. Many VFDs can be electronically locked-out so unauthorized access to the program is prevented.

For the Lee Roy Selmon Crosstown Expressway project, the TB Woods WFC series AC inverter was selected because of its high torque rating at very low frequency. Less expensive units were available, but not accepted primarily for not having a full torque rating at very low rpm. A major design criteria was the ability to move the 80 ton precast segments at very slow speeds. TB Woods was so surprised that their equipment was being used on a construction project instead of in the usual industrial setting, they used the Lee Roy Selmon Crosstown Expressway as an example of new markets for their equipment in an internal marketing magazine (Woods @ Work, January 2004)

TB Woods has since divested itself of this line of equipment and is currently built by Vacon, Inc.

Personnel and Training:

These systems were designed to be simple to learn and operate. Training required less than one shift for the erection crew to learn how to handle the systems and 80 tons of rolling precast segments. Numerous crew members became proficient on the systems. Night shift required everyone to watch their fingers and toes. Not one injury was reported to CGLLC due to erection procedures or equipment. This a testament to the skill of the crews and the reliability of the equipment.

Photo 6: VFD at Load, 41 HZ or 15 feet per minute
Note Load at 23% Plenty of Reserve Power

Control Panels:

The control panels were built at the CGLLC facility in Baltimore, MD. In keeping with the 24 hour replacement rule, all hardware used was supplied by US manufacturers or stocking suppliers. Industrial switches and relays were used. Relays were used instead of PLCs (programmable logic controllers) for ease of replacement. The cost associated with PLCs was not justified for this application. An auxiliary 24 volt power supply was installed to provide additional low voltage power to the relays and indicator lights. LED output meters were installed to monitor chain speed.

On Heading One, the control panel was situated halfway from either end of the girder system. On Heading Two, the control panel station was designed to be movable, using a multi-conductor control cable for connection. The 100 foot long control cables were built by CGLLC to accomplish this goal. A spare cable was supplied to support the 24 hour replacement rule. Thirty conductors were used for all the necessary interconnects.

Control Parameters:

The VFDs can be programmed such that specific settings can be locked in and to prevent tampering.

VFD Programming Functions and Settings as of 5/17/03 (Heading One)

Main Run Forward:	Preset Speed #1 (Par 33) 41 HZ or approximately 15 FPM	
Main Run Reverse:	Preset Speed #2 (Par 34) 60 HZ or approximately 21 FPM	
Creep Fwd/Rev:	Preset Speed #3 (Par 36) 5 HZ or approximately 1.75 FPM	
Acceleration: Main	Par 42:	20 seconds allows for 15 sec ramp up of Main
Deceleration: Main	Par 43	20 seconds allows for 15 sec ramp down of Main

Acceleration: ART	Par 44:	5 seconds allows for ramp up for Reverse
Deceleration: ART	Par 45:	5 seconds allows for ramp down for Reverse
Mode 21	Set for Function 14- disables VFD Keypad except for Stop	

It was not necessary to set up the VFDs and motors for high torque/ low rpm operation, although this function was available.

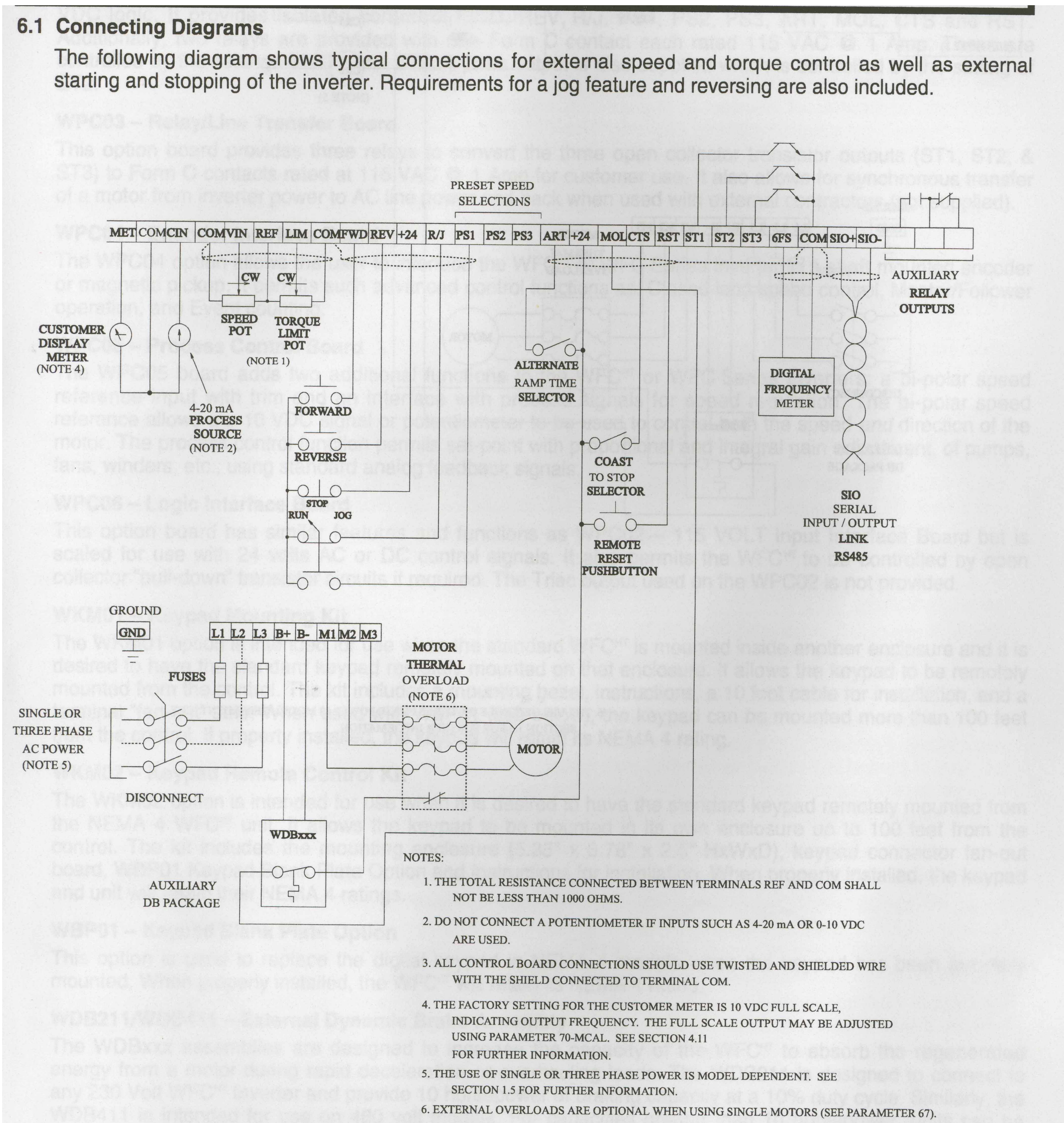

Fig 2. Typical Variable Frequency Drive Hook-up
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Other Advantages of Electric Power:

Some other advantages of electric power include efficiency, noise level, safety, fewer environmental hazards, ease of use, low maintenance costs and ready availability. There are no hydraulic lines to leak or rupture. There was only one major part replacement (a cracked pillow block) during the entire construction project. This occurred during the foundation collapse and not due to wear.

Safety is always a concern. Safe handling of power cables is of utmost importance. 480 volt 3 phase power packs a powerful punch. Persons working near, on or around should be properly trained on high power electric equipment. The only exposed power cables were from the generator up to the connectors on the headings.

Torque:

Perhaps the major advantage of electric power is available torque at all speeds. By using the VFD, the torque curve for an electric motor is virtually flat from near zero to full speed. Below is a typical diesel torque versus rpm power curve:

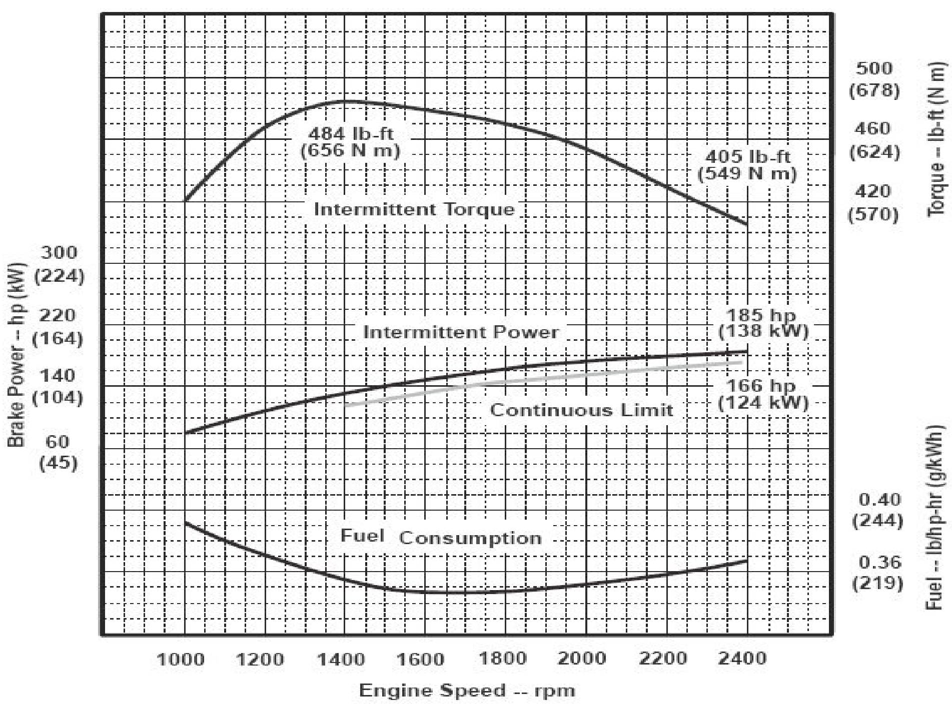

Fig 1. Typical diesel engine torque curve
(reprinted with permission of Frontier Power)

Note the torque curve in Figure One. The torque starts to build at 1000 rpm, and goes up to peak at 1400 rpm and then falls off. Imagine maximum torque at 35 rpm (2% of 1750 maximum rpm of an electric motor) and remains flat up to 100% (1750 rpm). The advantage of electric power is the nearly flat power curve from near zero to full speed. The next advantage is being able to control the speed in roughly 3 rpm increments. This cannot be accomplished with a hydraulic motor or diesel or gas engine.

The following is copied verbatim, with permission, from the Vacon Electronic Drives Catalog (formerly TB Woods) about constant torque:

Constant Torque:

"Constant torque applications are the most common type of load. The basic characteristic is that load demands are the same throughout the designed speed range of the machine. The drive system, consisting of the AC drive and motor, can supply constant torque because the motor can deliver the
required horsepower proportional to the speed across the operating range. Matching drive and motor performance is essential to making sure you have enough power for the application. Constant torque loads are found in most industrial environments. Applications such as conveyers, positive displacement pumps, extruders, and hoists are good examples of this loading characteristic. Overloads, shock loading and high-inertia loads are also potential loading issues that are found in constant torque applications. This is where the issue of Normal Duty versus Heavy Duty comes into play. Three basic characteristics are true for constant torque applications:

1. The same amount of torque is needed to move the load regardless of the operating speed.

2. The load usually requires more torque to break the load loose and start the load moving than to keep it moving.

3. The load has the potential to exceed the motor power rating during operation."

Items One and Two were the issues at Lee Roy Selmon.

Conclusion:

Electric motor power is safe, predictable and very easily controlled. By understanding the capability of electric motors and using variable frequency drive technology, an untapped source of motion control is available to the bridge constructor or precaster. Ease and flexibility of set-up and use, reliability and low maintenance costs add to the bottom line.

References/Acknowledgements

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