Concrete Vibration and Consolidation

Concrete Vibration can take some time ans sometimes it just seems to take longer than it should to pour and consolidate a precast product, such as concrete pipe or a manhole section. Frustrated by sluggish procedures, The Cretex Companies' Rapid City, South Dakota, plant determined to improve on the half hour it took to pour zero-slump concrete, consolidate it, and get the top ring in place on their 48-inch span arches (8-feet long). Cretex developed a method to cycle the vibrators in a specific direction. The span arch had two vibrators mounted at the top of the form and two more opposing toward the bottom. By sequencing the vibrators and reversing opposite alternate units they were able to cut their pour time in half. Clearly, these new *concrete vibration* measures were a boon to their productivity.

Indeed, proper fresh concrete vibration of important to ensure optimum strength, durability, and appearance of quality precast products. Accepted practices in the precast industry are unique in some respects because of the industry's production environment.

Quality, precision, and efficiency can be maximized during consolidation of precast concrete products. A controlled environment allows consistent quality day after day. Precasters can test and refine many production practices, especially consolidation.

The What and Why of Concrete Vibration
Because finishing of quality precast concrete products depends upon consolidation and compaction, it is important to understand these two terms. Consolidation is the even distribution of all ingredients throughout the mix, while compaction refers to the packing of concrete and removal of entrapped air.

Consolidation by vibration is necessary for some very good reasons:

- Newly placed concrete must be worked to eliminate voids, honeycombs, entrapped air, and to fully encase all rebars and other embedments.
- Entrapped air, which can be as high as 20 percent in freshly placed, wet-cast concrete, needs to be released.
- Vibration generates pressure waves that separate aggregate particles and reduce friction between them. This action releases entrapped air and increases density.
- Increasing concrete density improves bond, increases concrete strength, and makes the concrete less permeable.

Fresh concrete must be properly vibrated so that, once hardened, its strength and durability potential are maximized. Ultimate compressive, tensile, and flexural strength is lower in concrete with inadequate concrete vibration. Under-consolidation reduces density, which can result in

increased permeability and consequently less resistance to deterioration. Other important characteristics such as rebar-bond capacity, as well as appearance, are likewise affected.

Excessive Vibration
Over-vibrated concrete has a very wet surface and a layer of mortar without coarse aggregate. When over-vibration is evident, the slump (rather than the amount of vibration) should be reduced. Over-consolidation, however, is normally not a significant concern and rarely occurs in the precast industry. In fact, in cases in which the appearance of the concrete surface is important, it is common to double the normal vibration time to ensure a smooth, defect-free finished surface. This depends upon the type of vibration system, so check with the vibrator supplier.

How Do Vibrators Work?
Vibrators impart a vibratory force into the concrete through a combination of frequency and amplitude. Frequency is the number of vibration cycles per minute, and is expressed as "rpm" or "vpm." It is noisier than amplitude and more effective with lighter mass. It moves the sand and slurry around the rock, and governs liquefaction.

Vibration of fresh concrete reduces its internal shear strength and enables the concrete to temporarily liquefy, facilitating the consolidation process. Once the vibration stops, its liquid flow subsides.

Amplitude is more effective with a heavier mass of concrete. It moves the rocks and determines the radius of action. It may be simpler to think of frequency as the number of times that the vibratory forces occur, while amplitude is the distance that the force is "thrown." A light, thin section, for example, would be vibrated at a high frequency and low amplitude, because high amplitude would throw the concrete out of the form. Heavier, thicker sections, on the other hand, are more effectively vibrated with higher amplitude and lower frequency.

Consolidation Methods
Consolidation of precast concrete products can be accomplished using a variety of vibration methods. An optimal vibration system depends upon the concrete mix design and whether the concrete to be consolidated is wet-cast or dry-cast. External vibration can be accomplished with forms and tables, while stingers (spuds, pencils, sticks, pokers) are used for internal vibration. Dry-cast concrete can be vibrated with vibrators mounted on external and/or internal forms, while some systems utilize a vibrating table that imparts vertical vibratory forces to the concrete.

Stinger Vibration
Internal vibration is very effective for wet-cast concrete. Surface finishes, however, can often be enhanced by utilizing both stingers and form-mounted vibrators. The following recommendations will help ensure effective stinger vibration.

- Concrete vibration time depends on frequency – the higher the frequency, the less vibration time needed.
- Frequency will be reduced by about 20-25 percent, when the stinger is immersed in the concrete.

- The diameter of the stick should be the wall thickness of the product being poured, divided by four.
- Overlap the "field of action" (vibrating radius) throughout the pour. Doing this will bond the batches and lifts of concrete together into a monolithic pour.
- Completely immerse the stinger into the concrete.
- Immerse vertically and quickly (about one foot per second), but withdraw slowly (about three seconds per foot).
- Put the stinger into each area of concrete, only once.
- When concrete is poured in layers, place the stinger about six inches into the previous layer.
- Start concrete vibration when the stinger is completely submerged into the concrete.
- Stop vibration when the surface becomes shiny and there are no more breaking air bubbles. . These vibrators use eccentric (unbalanced) weights to generate the vibratory forces. Generally, they can be adjusted for both amplitude and frequency. Form vibration is faster than stinger vibration, but the forms usually need to be stronger. Some tips for form vibration:
    - Don't fasten the vibrators directly onto the form. Mounting brackets should be welded onto a form stiffener with the vibrator attached to the mounting bracket.
    - Vibrator location is critical. They must be mounted on the form at locations where their potential will be maximized (confirm with vibration supplier).
    - Check with your vibrator supplier to determine the size of vibrator required for your product. The vibratory force required can vary from the total weight of the form and concrete divided by two; for walls, to as much as two or three times the total form and concrete weight to achieve zero-slump concrete.
    - Start vibration when the concrete is about six inches above the vibrator.
    - Stop vibration when the concrete has a level, glossy surface and there are no more breaking air bubbles.
    - Fully tie rebar cages to ensure that their positions are maintained during the consolidation effort and to reduce the potential for adverse vibrations that could compromise the concrete-rebar bond.

Table Vibration

Vibration tables, external-form vibrators, drop tables, and other specialized equipment is unique to the precast industry and are commonly used. Vibration tables are rigid decks mounted on flexible supports which operate at 3,000 to 6,000 vibrations per minute (vpm). Specialized equipment can offer product-specific benefits, offering more uniform control and greater overall economy.

External-form vibrators should be mounted just below poured concrete surfaces and have frequencies ranging from 2,000 to 6,000 vpm. All consolidation equipment should be adequately secured, and the formwork should be sufficiently sturdy to resist the repeated vibration and/or shock loads. Locking mechanisms are recommended on connectors (i.e., bolts), as needed.

Table vibrators vary from eccentric shaft to shaker tables for wet-cast concrete to tables that utilize rotary or linear vibrators. The vibrators used for table

vibration of dry-cast concrete impart what is referred to as unidirectional vibration forces. That is, all of the vibration forces are vertical (up and down), while the horizontal vibration is zero.

Unidirectional concrete vibration is effective for tall products such as manholes, catch basins, vaults, septic tanks, and box culverts, as well as for smaller products such as meter boxes and grade rings. The vibratory forces required for the larger products would be generated by using high amplitude and low frequency, where the smaller products would be vibrated with lower amplitude and higher frequency settings.

As a general rule, for dry-cast concrete, the vibrator should be sized with an impact force that is 1.5-2 times larger than the total weight of the concrete and the form, but specific supplier recommendations should be followed. If you correctly inform your vibrating table supplier about the weight and dimensions of the product, they will size a system to meet your requirement, for wet- or dry-cast concrete.

Types of Vibrators
Several different types of vibrators are used in the precast concrete industry. Each has its advantages for a given application.

A variety of features are offered with each type of vibrator. These features include adjustable speed and force (frequency and amplitude), remote converters, and various types of mounting brackets. Vibrator types are:

- electric (115 volt / 220 volt)
- pneumatic
- operating pressure
- turbine models
- hydraulic
- compaction tables
- foot pedal, on-off switch

Some high-end features can result in great benefits for a precaster. For example, a producer of box culverts installed radio control of an inverter-driven vibrator, with great benefits. The casting process included a vibrating system with a variable-speed drive. The inverter was usually moved away from the product to allow for more room during casting.

However, this set-up usually required a worker to be assigned to running the inverter. Radio control of the variable-speed drive was installed. This has saved lots of footsteps (25-30 each way) for workers and often completely freed up a worker. The crew likes it because they can run the vibrators without leaving the product during casting. An additional feature is that they can vary the frequency with the radio controller, as needed.

Quality Control
Surface imperfections can be caused by either under-vibration or over-vibration. Under-vibration generally results in honeycombing, excessive entrapped air, and sand streaks. The results of over-vibration can be segregation, form deflection, form damage, and sand streaks. It may take a

few trial runs to determine which combination of frequency and amplitude, as well as vibration time, are correct for a given product.

It is important to recognize that the vibration of dry-cast products is very different from wet-cast vibration. Suppliers of dry-cast systems design their forms to work with their specific vibration system. It is not, therefore, a good idea to "mix and match" forms that were designed for one system with a vibration system supplied by another manufacturer.

Dry-cast forms are specially designed to withstand the high vibratory forces that are required for zero-slump concrete. As a result, they are generally more expensive than wet-cast forms.

Service and Use
Cretex decided to add core vibrators to their pipe forms at their Elk River plant. Initially, they installed hydraulic vibrators and found that they were big and delivered more performance. However, it was later found that maintenance and capital costs were significantly higher. They changed the vibrators to small (but still substantial) internal/core electric vibrators with excellent results. In side-by-side comparisons, Cretex was able to reduce the time to place head rings from 5-10 minutes to less than two.

A comprehensive, preventive maintenance program is urged for all consolidation equipment. Equipment should be frequently cleaned, inspected, and serviced, including in-service verifications to ensure continued reliable performance. Because adequate consolidation is important, you should stock reserve vibrators and spare parts.

Forty years ago, the use of vibration to consolidate concrete had been cited as the greatest advance in the art of concrete placement since the invention of the mixer. That advance and continued improvements of consolidation equipment has made the use of stiffer mixes possible, resulting in an
appreciably higher quality concrete.

Effective utilization of concrete vibration will improve your product and may increase production efficiency. The proper consolidation and compaction of concrete will increase concrete density to make your product stronger and less permeable.

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