Choosing a concrete vibrator

Frequency, amplitude, power source and other factors to consider

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When we dump low to moderate slump concrete into a form, it is in a honeycombed condition—consisting of mortar-coated coarse aggregate particles and trapped air voids of varying sizes. The amount of entrapped air depends on the mix design, aggregate grading, size and shape of the form, amount of reinforcing steel and the method of depositing the concrete. It is usually in the range of 5 to 25 percent. (This is of course in addition to any intentionally entrained air—the much smaller bubbles resulting from the use of an admixture.)

What if we were to allow the concrete to harden in this condition? It would be weak, porous and poorly bonded to the reinforcement. It would lack durability, and the appearance would be unsatisfactory. In order to realize its full potential as a structural and architectural material, concrete must be consolidated (compacted) by removing the entrapped air.

Today most concrete is consolidated by vibration. Vibration subjects the fresh concrete to very rapid impulses which temporarily liquefy the mixture (Figure 1) and cause the concrete level to subside. The entrapped air, being the lightest ingredient in the mix, rises to the surface where it escapes.

EXTERNAL VIBRATION

Concrete may be vibrated externally by attaching a vibrator to the formwork, by means of vibrating screeds, and by vibrating tables. External vibration is beyond the scope of this article, but much useful information can be found in References 1 and 2. A description of vibrating screeds appears on page 729 of this issue.

INTERNAL VIBRATION

Internal or immersion vibrators are most commonly used in general construction. They are often called spuds or stingers. Europeans call them pokers. They are generally of the rotary type. A casing or head containing an unbalanced weight called the eccentric is immersed in the concrete. The eccentric is turned at high speed, causing the casing to revolve in a small orbit which subjects the concrete to vibratory impulses. Internal vibrators generally have the eccentric turned by electric motors, but they may also be powered by gasoline engines, compressed air or a hydraulic pump.

Figure 1. Internal vibrator liquefying low slump concrete.

Motor-in-head vibrators

Of the electrically driven vibrators, the motor-in-head (MIH) type is probably the most common. It has the motor inside the vibrator head (Figure 2). Most MIH vibrators are high-cycle, which means that 180-cycle current is required for their operation. They use induction motors and operate in the concrete at a speed of about 10,000 revolutions per minute, which is only 5 to 10 percent less than the speed in air. High-cycle current may be obtained by passing commercial power through a frequency converter. Generally, however, a small portable generator is used, and the frequency can be varied by adjusting the throttle on the engine. MIH vibrators operating on commercial (60-cycle) power are also now available. They are convenient to operate, but are weak and not very effective in low slump concrete.

Flexible shaft vibrators

In the flexible shaft type, an electric motor outside the vibrator is plugged into commercial current. A flexible shaft leads into the vibrator head where it turns the eccentric weight. The motor is of the universal (ungoverned) type, and the speed when operating in air is

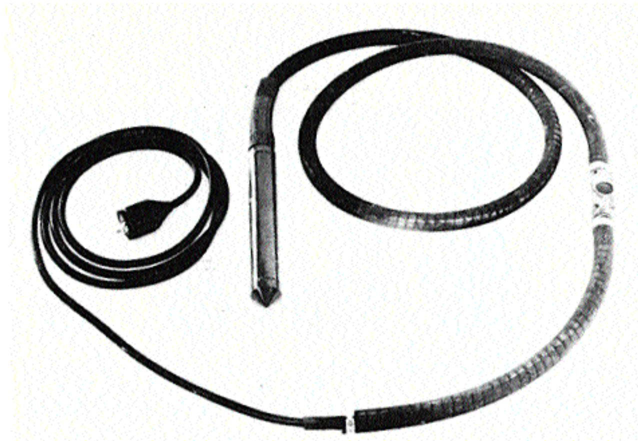

Figure 2. Motor-in-head immersion (internal) vibrator, powered electrically. Usually MIH vibrators require 180-cycle current.

very high—of the order of 12,000 to 15,000 revolutions per minute. When the vibrator operates in concrete, however, the motor is under load and the speed is generally down in the 8000 to 12,000 revolutions per minute range. Flexible shaft vibrators (Figures 3 and 4) can also be driven by gasoline engines, an advantage where commercial power is not available.

Pneumatic and hydraulic power

For vibrators operated by compressed air, there is generally an air motor inside the vibrator head. These vibrators are particularly useful in mass concrete. The frequency varies with the air pressure, which is often a drawback.

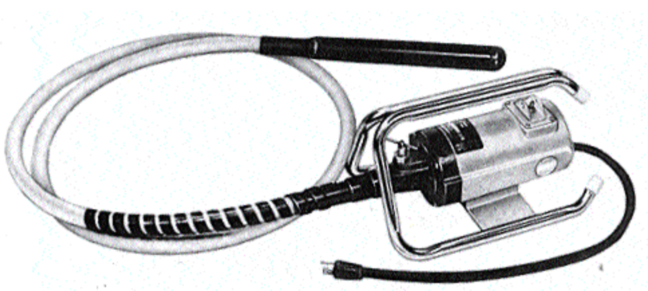

Figure 3. Flexible shaft vibrator with electric motor which plugs into commercial current. Gasoline powered vibrators of this type are also available.

Hydraulic vibrators are coming into widespread use for pavement construction because they are more trouble free in operation than electric vibrators. Hydraulic motors are used. The frequency can be varied by changing the pressure setting on the hydraulic pump. Each vibrator can be individually adjusted.

CHOOSING AN INTERNAL VIBRATOR

The vibrator must effectively consolidate the concrete mixes used on the job. It should have an adequate radius of action (distance from the vibrator head over which the concrete is fully consolidated), and it should be capable of "melting down" and deaerating the concrete quickly. Insofar as possible the vibrator should be reliable in operation, light in weight, easy to handle and manipulate, and resistant to wear. Some of these requirements are conflicting, so compromises are necessary.

Figure 4. Backpack gasoline engine drive for this flexible shaft vibrator allows complete freedom of movement for most vibrating operations. The backpack power unit weighs 21½ pounds.

The effectiveness of a vibrator depends mainly on three things—the head diameter, frequency, and amplitude or "kick."

The larger heads engage more concrete during vibration, and are more effective with large size aggregates, with low slump, and where a large radius of action is desired.

The frequency and amplitude together establish the vibration cycle which largely determines the nature and effectiveness of the vibration. The frequency largely governs the liquefaction of the concrete, and the amplitude determines the radius of action (which governs the insertion spacing). Frequencies and amplitudes are generally of the order of 10,000 revolutions per minute and 0.03 inch, respectively. Higher frequencies and lower amplitudes are preferred for plastic mixes in thin sec-

FREQUENCY AND AMPLITUDE

The two factors most critical in establishing effectiveness of a vibrator are defined this way:

Frequency: number of vibration cycles per minute.

Amplitude: maximum distance a point on the vibrator head moves from its position of rest. The author follows the ACI practice of using this term to mean peak amplitude, which is half the peak-to-peak amplitude or displacement used by some in describing vibrations.

tions, while lower frequencies and higher amplitudes are more suitable for the stiffer mixes used in heavy sections.

Other characteristics are sometimes used as rough indicators of the performance of a vibrator:

- Centrifugal force. This equals the weight of the eccentric times its acceleration, and is a rough indicator of the force output of a vibrator.
- Horsepower rating of the motor. This gives the power consumption of a vibrator.

Satisfactory values for centrifugal force horsepower do not guarantee an effective vibrator, mainly because they do not assure that the frequency and amplitude are in the proper range.

Guidance for selecting vibrators for general building construction is given in the table. The head diameter, frequency and amplitude are shown. Approximate values are also given for the radius of action of the vibrator and the rate of concrete placement. If frequencies are near the lower end of their acceptable range, it is advisable that amplitudes be near the upper end of their range, and vice versa.

Equally good results can usually be obtained by using a vibrator from the next larger size group, provided suitable adjustments are made in the spacing and time of insertion.

MEASURING VIBRATOR ACTION

The vibrator manufacturer should provide information on the frequency and amplitude of the vibrators. As a check on those values, and to determine whether the vibrators are working properly, some field measurements should be made.

Check of vibrator frequency

The frequency of internal vibrators should be checked by a suitable tachometer. The vibrating reed type is most commonly used. The resonant reed type is more expensive, but it is more rugged and gives more accurate values. These tachometers are available from testing equipment suppliers and from some vibrator manufacturers.

The frequency should occasionally be determined while the vibrator is operating in air, but it is the fre-

CHARACTERISTICS, PERFORMANCE, AND APPLICATIONS OF INTERNAL VIBRATORS

Group	Diameter of head, inches	Recommended frequency, vibrations per minute, while vibrator is in concrete	Recommended amplitude, inches*	Approximate radius of action inches**†	Approximate rate of placement, cubic yards per hour per vibrator‡	Use of vibrator
1	¾—1½	10,000—15,000	0.015—0.03	3—6	1—5	Plastic and flowing concrete in very thin members and confined places. May be used to supplement larger vibrators, especially in prestressed work where cables and ducts cause congestion in forms. Also used for fabricating laboratory test specimens.
2	1¼ —2½	9,000—13,500	0.02—0.04	5—10	3—10	Plastic concrete in thin walls, columns, beams, precast piles, thin slabs, and along construction joints. May be used to supplement larger vibrators in confined areas.
3	2—3½	8,000—12,000	0.025—0.05	7—14	6—20	Stiff plastic concrete (less than 3-inch slump) in general construction such as walls, columns, beams, prestressed piles, and heavy slabs. Auxiliary vibration adjacent to forms of mass concrete and pavements. May be gang mounted to provide full width internal vibration of pavement slabs.

* Measured or computed as described in Reference 1. This is the average of the values at the tip and back end, with the vibrator operating in air.

** Distance from vibrator over which concrete is fully consolidated.

† Assumes insertion spacing is 1½ times the radius of action, and vibrator operates two-thirds of time concrete is being placed.

‡ These ranges reflect not only the capability of the vibrator but also differences in workability of the mix, degree of deaeration desired, and other conditions experienced in construction.

quency in concrete which is most important. It should be regularly checked. The frequency may be determined by holding the tachometer against the back end of the operating vibrator while it is almost submerged in the concrete. For an air vibrator, holding the device against the hose is equally satisfactory. The measurement should be taken just before the vibrator is withdrawn, and is always the fastest speed while it is operating in concrete.

Check of vibrator amplitude

The amplitude or kick may also be determined by measurement, by using a visual effect scale (Figure 5) called an optical wedge. The wedge must be carefully drawn and printed on a heat- and moisture-resistant paper. Paper with an adhesive backing will simplify attachment to the vibrator at any point where the amplitude is desired. Normally one measurement is made near the tip and another near the back end, and the average is considered as the amplitude of the vibrator. Measurements are made with the vibrator operating in air. Research has shown that the amplitude is reduced about 25 percent when operating in concrete. The wedge is available from some vibrator manufacturers and other sources. The amplitude may also be computed. Methods of measuring and computing amplitude including the vibrograph used for external vibrators are described in Reference 1 in more detail.

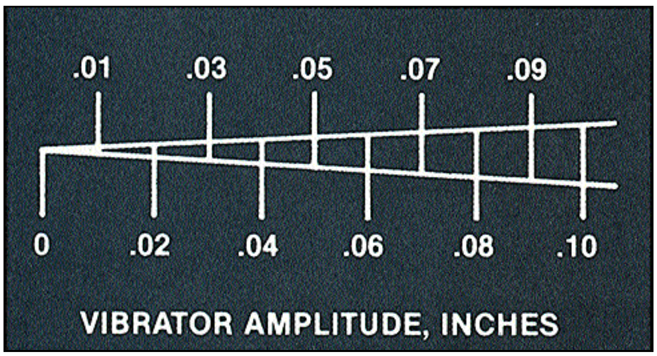

Figure 5. This optical wedge, accurately drawn and printed on heat-resistant paper, is adhered to the vibrator in one method of checking vibrator amplitude. How-to-use-it details are given in Reference 2.

It is important to agree on the definition of amplitude. Textbooks, ACI, and many vibrator manufacturers define it as peak amplitude. Unfortunately some U.S. manufacturers still speak in terms of peak-to-peak amplitude or total throw, which is twice the peak amplitude.

FIELD EXPERIENCE WITH VIBRATOR MEASUREMENTS

A few years ago a study was made of 27 concrete vibrators on 9 construction jobs, varying from the 1 3/8-inch-diameter pencil size to 6-inch mass concrete vibrators, to determine their compliance with the new job specifications patterned after the ACI recommendations. Head diameter, frequency and amplitude were measured, and the effectiveness of the vibrators in the concrete was observed.

We had expected that field personnel might have some difficulty in using the optical wedge to determine amplitude. We were therefore pleased to find that the reported amplitude results generally appeared to be reasonable. Values for the same model of vibrator were fairly consistent on any given job and for different jobs. These results also checked the manufacturers' data fairly well where such were available.

We were surprised to find that the frequency values, usually determined by a vibrating reed tachometer, showed as much variation as the amplitudes. For the air vibrators the low frequencies may result from low air pressures on the job.

It was found that low amplitude and low frequency were the most frequent causes of failure to comply with the specifications. The 60-cycle motor-in-head type and some of the air vibrators were particularly prone to low amplitude. We remember that field personnel had complained that these vibrators "did not move the head."

In some cases the vibrator selected for the job was too small or too large for the concrete mix. Using an undersized vibrator makes it very difficult or impossible for the operator to get good consolidation. Using a grossly oversized vibrator (such as a 6-inch-diameter size in a plastic 3/4-inch-aggregate mix) is also unsatisfactory. Although it will eliminate honeycomb, it will likely cause segregation and result in rather poor surfaces because of generally low frequencies and wide spacing of vibrator insertions.

References

1. ACI Committee 309, "Recommended Practice for Consolidation of Concrete (ACI 309-72; Reaffirmed 1978)," American Concrete Institute, Detroit, 1978.

2. ACI Committee 309 Report, "Behavior of Fresh Concrete During Vibration (ACI 309.1R-81)" American Concrete Institute, Detroit, 1981; originally published in ACI Journal, Janu-