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Effects of Vibration on Concrete Mixtures

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Effects of Vibration on Concrete Mixtures

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Introduction

Vibration is used to help fresh concrete flow around reinforcement and to fill forms, as well as to remove entrapped air bubbles. While vibration is important for proper consolidation, care must be taken to avoid segregating mixtures or removing entrained air. In addition, there is a growing body of evidence indicating that improper vibration frequency moves water away from the vibrator toward form walls, resulting in bug holes and voids on the external faces of the forms for structural elements.

A typical vibrator consists of an off-center weight on a rotating shaft that generates waves of energy that move away from the vibrator shaft. Factors that govern the effects of a vibrator on a mixture include:

- Amplitude—linear displacement governed by the geometry of the weight
- Frequency of rotation
- Energy—governed by the mass and offset of the rotating weight as well as by amplitude and frequency. Energy is normally reported in terms of the acceleration imparted to the mixture, which reduces with increasing distance from the vibrator.
- Spacing—measurement between vibrator insertion points
- Duration of vibration—time per cubic foot of concrete

The greatest effect of vibration is to fluidize the mixture, effectively overcoming the yield stress needed to initiate flow. This fluidization also allows air bubbles to float out of the system, with larger bubbles moving faster than smaller bubbles. However, the amount of vibration energy (acceleration) required to fluidize a mixture the right amount has not been experimentally quantified. Likewise, the negative side effects of overvibration such as water movement, air reduction, and aggregate displacement are currently not well understood or controlled.

The variability of concrete materials adds further complexity when attempting to ensure that a given mixture will perform as desired under vibration. Fresh concrete is a complex (and changing) mixture of liquids and solids of various sizes. The rheological properties (i.e., yield stress, viscosity, and thixotropy) of a given mixture are influenced by several variables including water content, aggregate shape, aggregate type, dosage of chemical admixtures, and age. This means that one mixture may perform satisfactorily under a given vibration effort while another may segregate under the same conditions. Therefore, there is great value in understanding the relationships between mixture properties and a given vibration system.

Normally, rheology is the study of liquids. However, low slump concrete, such as that typically used for slipform concrete paving, is not a liquid unless the mixture is under vibration. Initial yield stress is the effort required to start a mixture moving, which for concrete is generally associated with slump. Once movement starts, a certain amount of effort is required to keep the mixture moving, and the difference between initial yield stress and this dynamic yield stress is related to a property known as thixotropy.

Ketchup is the classic example of a thixotropic material: hit the bottle too hard to get it out and your food is drowned. Slipform paving concrete has a desirably thixotropic nature, which allows the form to shape the concrete while it is in the paving machine, yet it stands without edge slump behind the machine. Pumped concrete, however, should exhibit low thixotropy to avoid plugging the pump's pipes. Viscosity is a measure of how fast movement occurs under a given mechanical effort. The V-Kelly test and the Box test have been developed in order to evaluate these properties in fresh, low slump concrete. More information on these tests is available at the following link: https://cptechcenter.org/performance-engineered-mixtures-pem/.

Conventional approaches to specifying vibration parameters have been rules of thumb based on experience. It is common for contractors to increase vibrator frequency to facilitate the placement of mixtures with poor workability, which sometimes results in negative side effects such as vibrator trails in pavements, poor surface finishes, and compromised mixture durability.

As increasingly complex mixtures that contain multiple supplementary cementitious materials and innovative admixtures are used in practice, there is a growing need to understand how a given mixture should be vibrated and to deliver a suitably controlled vibration system.

The purpose of this MAP Brief, therefore, is to summarize a recent investigation by the CP Tech Center to understand the nature of vibration, identify the mechanical properties that cause material separation, and identify concrete load relationships under dynamic conditions.

Experimental Work

Materials and Mixture Proportions

A single set of materials was used, including Type I portland cement, 1-inch crushed limestone coarse aggregate, river sand, air-entraining admixture (AEA), and water-reducing admixture (WRA).

The matrix of variables presented in Table 1 was adopted to assess the effects of air content, water content, the presence of WRA, and vibration frequency, with Mixture 1 acting as the control.

Test Methods

The fresh mixtures were tested for slump and air content using standard methods. Other nonstandardized tests used are discussed as follows.

Vibration Energy Test

The vibrator used for this investigation was a commercial controlled-frequency vibrator that is programmed to run at a selected frequency regardless of the load imposed by the concrete. The vibrator's electronic control system is able to report the voltage drawn over the time of the test to maintain this selected frequency. The curve that it reports may be considered an indication of the energy required to achieve that frequency over time for the mixture being tested.

The configuration of the vibration energy test is shown in Figure 1. The vibrator was fitted with a 1" diameter head that was mounted vertically on the left side of the box which was 4" wide, 15" long and 17" high. The vibrator head was mounted 2" above the bottom of box. The vibration time for all tests was 20 seconds to show both the initial yield stress and dynamic stress curves.

Three steel rods were placed horizontally inside the box with their tips 3", 6", and 9" from the vibrator, and their other ends outside the box. The rods' purpose was to transfer vibration energy to the accelerometer sensors, that were in turn connected to a device that reported vibration energy expressed as acceleration (G).

After vibration, the rods and vibrator were extracted, and the sample was allowed to harden for 24 hours before it was demolded and stored at 72°F and 50% relative humidity for 28 days. Three 4" diameter × 9" long cores were drilled vertically from the sample. Vertical slices were extracted from the center of each core and used in drop absorption tests and hardened air evaluations to investigate the movement of air and water in the mixture. After cutting, the samples were conditioned for one day in the same conditions as described above. See Figure 2.

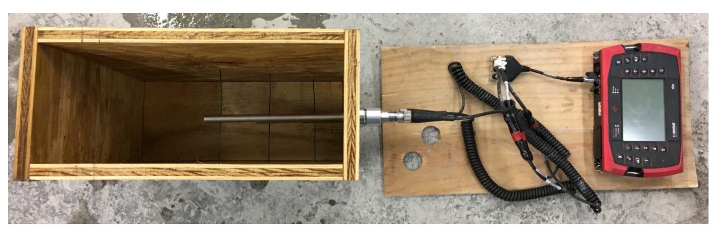

Figure 1. Vibration energy test system

Table 1. Mixture variables

Mixture	Air, %	Slump, in.	Water-cement ratio (w/c)	WRA	Frequency, vibrations per minute (VPM)
1	3.7	4	0.4	No	8,000 12,500
2	7.2	4	0.4	No	8,000
3	3.0	1	0.25	No	8,000
4	3.1	4	0.29	Yes	8,000

*** Highlights indicate the parameters varied in each mixture**

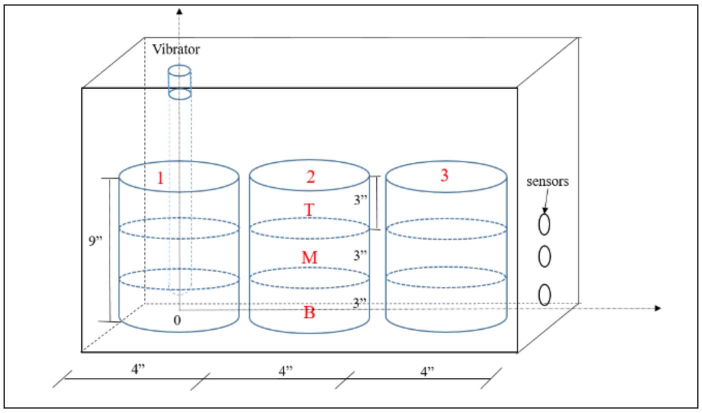

Figure 2. Sample locations

Drop Test

A 10-µL drop of water was placed on an exposed paste area of the sample being tested. The time taken for the water to be absorbed into the paste was then recorded. Up to 8 tests were conducted in each selected area of a sample, and their data were averaged. Although crude, this test enables comparison of surface permeability over small zones of the same sample, thereby identifying variability throughout a section. The longer the time required for water to be absorbed, the lower the permeability of the paste. Variations in permeability were assumed to be due to changes in water/cement ratio (w/c). Each sample had two cut surfaces to test for drop absorption.

Hardened Air Evaluation

The same samples used for the drop absorption test were next evaluated using an automated optical scanning method to determine the quality of the air void system.

Results and Discussion

The following trends were noted:

- The vibration energy transferred through a mixture generally displayed a linear rise in voltage demand and transferred energy, then a slight drop (thixotropy), and finally a slight stable change in the energy transfer of the mixture. Time to stability in all mixtures was generally less than 4 seconds. See Figure 3.
- For all samples tested, the permeability (w/c) increased with increasing distance from the vibrator tip, implying water movement away from the vibrator during vibration. The effect was more marked with increasing slump of the mixture. See Figure 4.
- There is clear indication of air movement in all tested samples. Some air was observed to move toward the surface of the concrete. The mixtures with higher slump, containing WRA, or vibrated at the higher frequency exhibited more air movement. See Figure 5.
- The controlled output vibration energy and the energy transfer (G) were compared to assess the effects of frequency on a controlled mixture. Nearly double the energy input was required to maintain the frequency of the vibrator at 12,500 VPM compared to 8,000 VPM. More than double the energy was transmitted at the higher frequency to the nearest sensor; however, the rate of attenuation with increasing distance from the vibrator was also greater at the higher frequency. See Figures 6 and 7. The results of this study are summarized in Table 2.

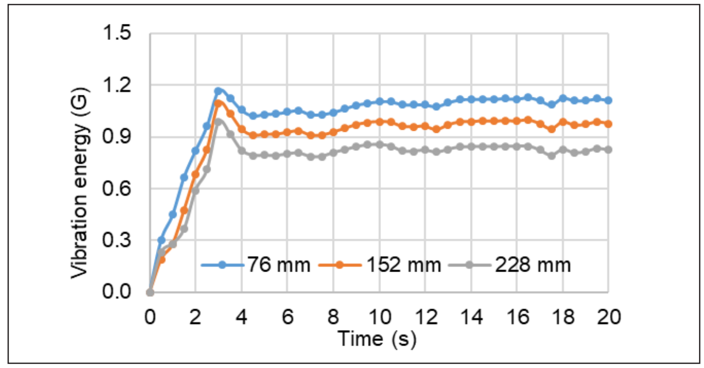

Figure 3. Vibration energy detected using the sensing device at three different distances from the vibrator (Mixture 1 at 8,000 VPM)

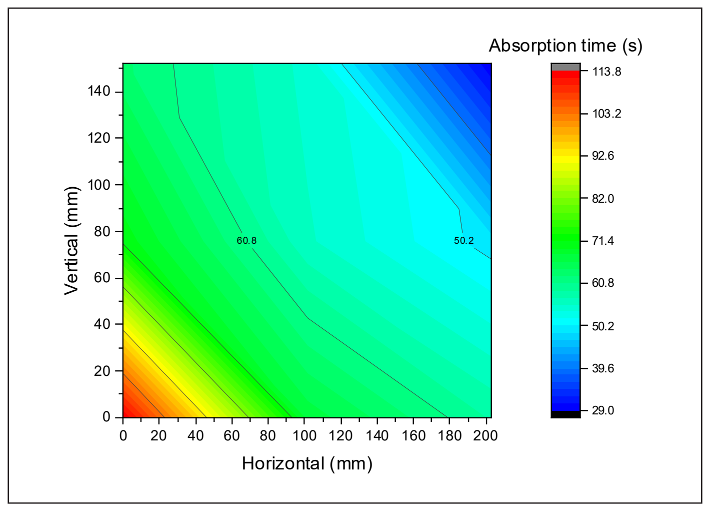

Figure 4. Time required to absorb a 10-µL drop of water decreased the greater the distance (in both directions) from the vibrator tip (See bottom left of this graphic for Mixture 1 at 8,000 VPM)

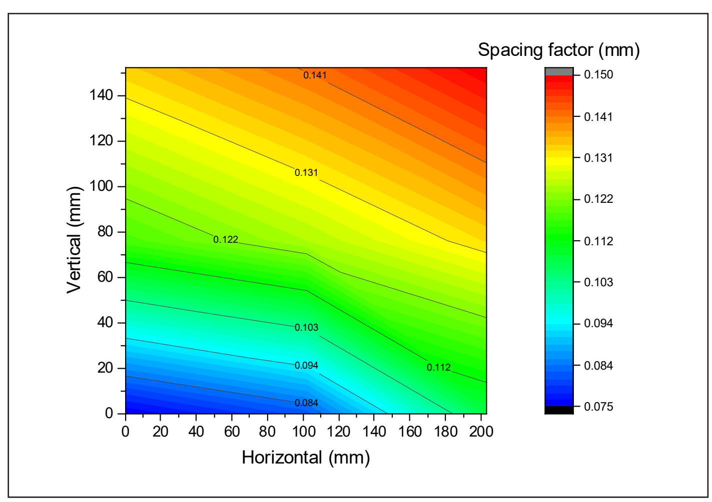

Figure 5. Air void spacing factor characteristically increased the greater the distance (predominantly vertically) from the vibrator tip (Mixture 2 at 8,000 VPM)

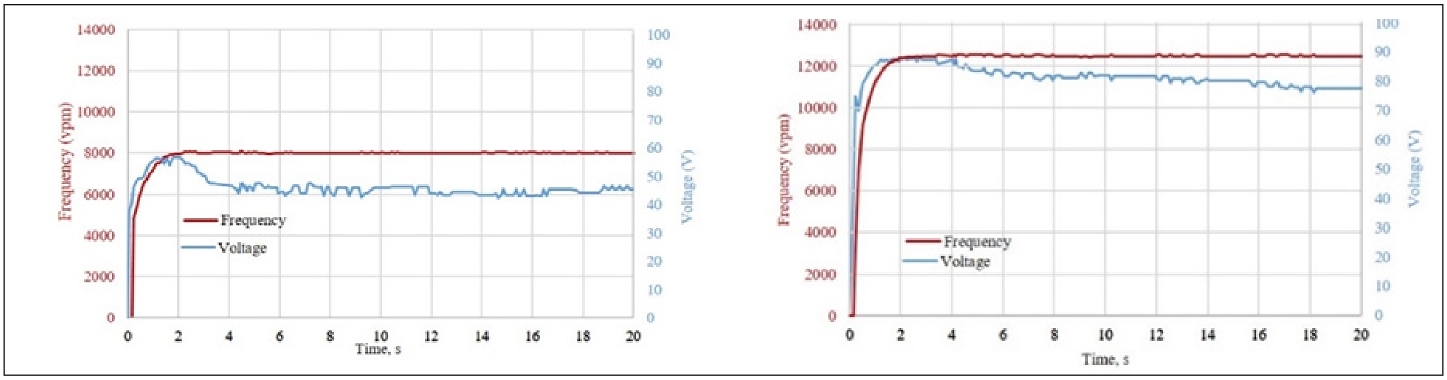

Figure 6. Energy demand plots to maintain vibrator frequency at 8,000 VPM (left) vs. 12,500 VPM (right)

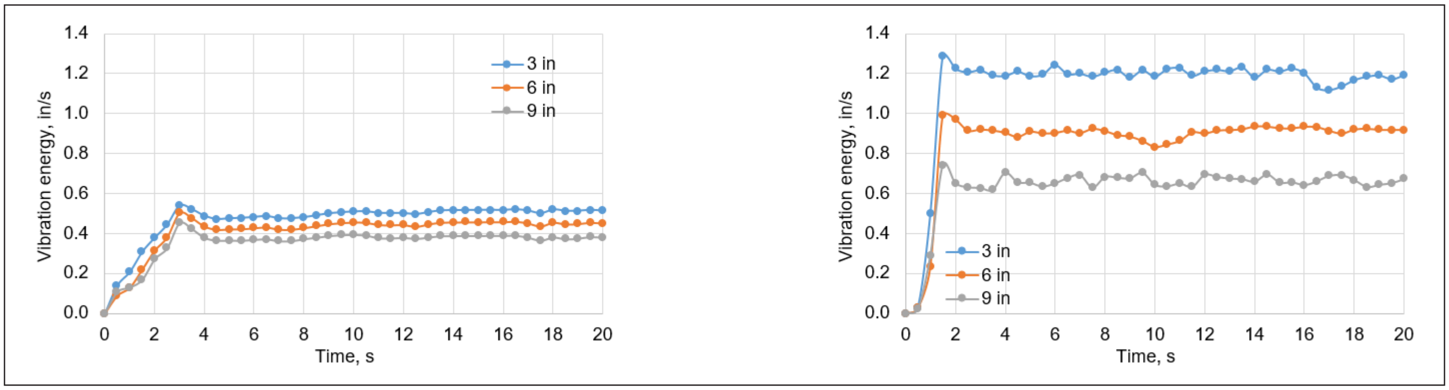

Figure 7. Energy transfer plot to maintain vibrator frequency at 8,000 VPM (left) vs. 12,500 VPM (right)

Table 2. Summary of text results

Variable	Mixtures compared	Voltage demand	Energy transfer	Energy loss with distance	Thixotropy	Water movement	Air movement
Air content	1, 2	Slightly higher with more air	Similar	Similar loss	Similar and low thixotropy	Less water movement with more air	Movement toward the surface
Water content	1, 3	Higher with less water	Decreased with less water	Similar loss	Similar	Improved permeability with less water	Movement toward the surface
Presence of water reducer	1, 4	Similar	Increased with WRA	Similar loss	Similar	Improved permeability with WRA (and less water)	More air loss with WRA
Vibration frequency	1, 1	Increased with increased frequency, reduced over time	Increased with increased frequency	Increased with increased frequency	Similar	Similar	More air movement with increased frequency

The data support the hypothesis that vibration moves air and water, and the effects significantly increase with increasing vibration speed. The data lay the foundation for future work needed to refine our understanding of the relationships between mixture variables and vibration variables.

Deliberate mix proportioning along with controlled process variability along with controlled vibration practices in the field will represent a significant step toward limiting potential durability issues and reducing poor formed-finish aesthetics in vertical structures.

Closing

Future research is needed to confirm these initial findings regarding the impact of vibration parameters on concrete mixture performance and to develop predictive tools that correlate mixture properties and construction practices with pavement and structure performance.

For more information

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