

# INTERNAL VIBRATION AND VISCOUS CONCRETE: APPLICATION AND PREDICTION OF THE RADIUS OF ACTION

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## ABSTRACT

*The vibration applied to the fresh concrete has function to improve the filling of the formwork, to enable the bond strength between reinforcing steel bars and concrete and to increase the density of the material. However, many cases were reported recently where the applied vibration characteristics (frequency and amplitude) did not seem to be compatible with the casting of modern concretes with low Water/Cement ratio and strongly adjuvanted. In a first part, we empirically measure the radius of action of poker vibrators inside cementitious materials. Then, we validate a simple analytical model to predict the range of internal poker according to their mechanical properties and rheological properties of materials. These results validate the technological rules of engineers and show a maximum optimization of vibration with the equipment used in practice with viscous concretes. In aim to maintain the same performance, a technological modification seems necessary.*

**Keywords:** internal vibrating poker; ordinary concrete; viscous concrete; radius of action

## INTRODUCTION

Internal vibrating pokers are traditionally used to compact fresh concrete and enable the steel bars/concrete composite to reach its maximal efficiency (Ref 1). Effects of vibration on properties of reinforced concrete have been extensively studied in the fifties. Around 1930, along with the development of reinforced concrete, vibration was introduced in order to improve both the filling of the forms and the bond between concrete and steel bars. However, in the last two decades, modern concrete mix design has gone through major changes with the industrial production of e.g. high strength or high fluidity concretes. In parallel, the number of components entering mix design of concrete has increased along with the use of organic admixtures. Many cases were reported recently where the applied vibration characteristics (frequency and amplitude) did not seem to be compatible with castings of these modern concretes. Nowadays national (Ref. 2) or international (Ref. 3) technical recommendations, mostly concern vibration duration as a function of concrete workability. These recommendations are based on empirical and experimental approaches from the first half of the 20th century, in which concrete was considered as a material dominated by direct frictional contacts between the coarsest aggregates. For these materials, vibration is said to be able to break the contact network between these coarse grains. However, in the case of modern fluid concretes containing higher amounts of fine particles, it was shown recently that consistency is strongly affected by the rheology of the constitutive cement paste.

The pervibration or internal vibration has become the method of vibration on the most common on building site, see Ref.3. It is characterized by a poker vibrating at a frequency of 200 Hz with amplitude of about 2 to 3 mm and a radius varying traditionally between 40 and 50 mm. In these configurations, current guidelines consider the radius of action of a vibrating poker is about ten times its physical size.

Our study presents a simple equilibrium of forces between the surface of the vibrating poker and the non-vibrated concrete which identifies the radius of action of a vibrator according to the rheological properties of the test material and vibration applied. In aim to explore a wide variety of configurations vibration /fluidity, we use a vibrating poker with a variable frequency on various cementitious materials. Finally, in the case of modern concretes with strong vibration, we have the emergence of singularities.

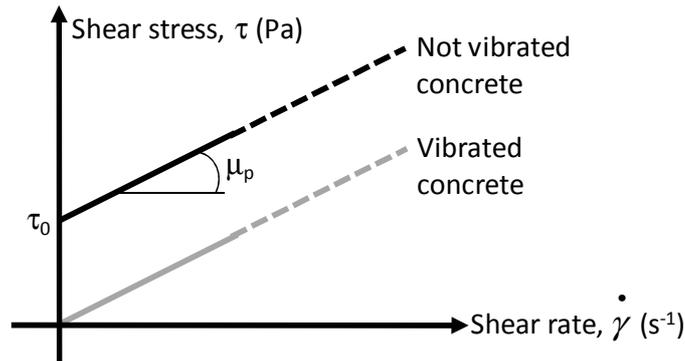
## MATERIALS AND METHODS

The behavior of concretes is well known. The behavior of concrete is well known. In fact, there are yield stress viscous fluids, e.g. they flow above the action of a minimum yield stress. In rheological point of view, they are traditionally represented by a

Bingham model, cf equation (1), see Ref. 4 and Ref. 5. The internal vibration break this yield stress by liquefying the material in an area whose size depends on the rheological material and the vibrating poker, see Ref. 6 and Ref. 7 as shown in Fig. 1

$$\tau = \tau_0 + \mu_p \dot{\gamma} \quad (1)$$

Figure 1. Rheological model of concrete.



In the case of concretes, the yield stress at rest  $\tau_0$ , is of the order of a few thousand Pascals (Pa) and the viscosity,  $\mu_p$ , is of the order of several tens of Pascal seconds (Pa.s), see Ref.8. Modern concrete causing problems mentioned above are generally formulated with a low water/cement ratio (in mass) and strongly adjuvanted. They exhibit a yield stress of the order of a few hundreds of Pa and a viscosity of the order of several hundred Pa.s.

Our measurements of radius of action of a vibrating poker are made with cement pastes, traditional concretes and high viscous concretes. Formulations are presented in Table 1. Samples of our studies are based on Calcia cement CEM III/A 52.5 CE PM-ES-CP1 NF. For concrete, aggregates (sand and gravel) are semi-crushed and from the Seine. Our aggregates are completely dried before mixing. In addition, we use a plasticizer. It is either the plasticizer Plastiment HP Sika in the case of ordinary concrete or superplasticizer ViscoCrete Tempo 12 Sika in the case of modern concretes.

Table 1. Formulations of cement pastes and concretes.

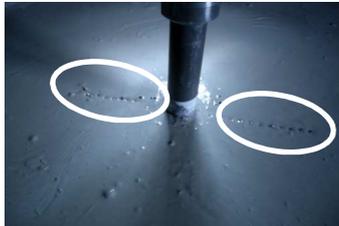
	Cement paste				Ordinaries concrete		High viscous concrete	
	1	2	3	4	S3	S4	S3M	S4M
Name					S3	S4	S3M	S4M
Water/Cement (-)	0.35	0.30	0.40	0.55	0.60	0.60	0.45	0.45
Amount of cement (kg.m <sup>-3</sup> )	/	/	/	/	300	320	358	381
% addition	0,30	0	0	0	0.410	0.410	0.82	0.510
Yield stress at rest (Pa)	20	180	40	8	1700	830	1800	860

For traditional concrete, only the variations in volume of the cement paste (or the total volume of the aggregate skeleton) determine the consistency of the material. The volume of the cement paste of modern concretes is equal to that of traditional concrete. However, the reduction in water/cement ratio increases the amount of adjuvant to ensure same consistency. Yield stress values of our concretes were calculated from the model developed in Ref. 9.

In order to identify precisely the characteristics of vibration (amplitude and frequency) provided by our vibrating poker we measure its acceleration in air. These calibrations are based on three accelerometers mounted along on the vibrator and a stroboscope. The vibrating poker has a diameter of 25 mm.

For our study of the measurement of the radius of action of a vibrator, we have chosen a container large enough to prevent reverberation of vibration through the walls. Shock absorbers are arranged on the underside of the recipient to minimize the transmission of vibration from the floor. For each test, we cast a bucket cylinder (diameter equal to 0,70 m) with 0,06 m<sup>3</sup> of fresh material. To measure the radius of the vibrator immersed in the cementitious materials, we have disposed markers on the surface of fresh concrete, (Cf Fig. 2). Into the liquid region, markers drop inside the sample. Thereby, they indicate the effective diameter of the vibrator. The vibration period is long enough to present no evolution in the moving of the markers.

*Figure 2. Cement paste during vibrations. Markers are on the surface.*

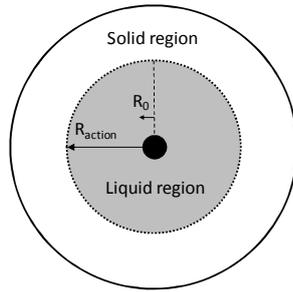


### **ANALYTICAL MODEL OF PREDICTING THE RADIUS OF ACTION**

We perform a calculation equilibrium forces between the area vibrated and the non-vibrated, as shown in Fig. 3. At the surface of the vibrator, the material is flowing. Its yield stress is modeled by the equation (1). At the maximum radius of action, the shear rate is equal to zero because the material is not liquefied. The height of the vibration is equal to length of insertion of the poker,  $H_0$ . On a dimensional point of view, the shear rate at the surface of the poker is like equation (2).

$$\dot{\gamma} = \frac{kfa}{R_0} \quad (2)$$

Figure 3. Modeling of the radius of action of a vibrating poker.



$R_0$  : radius of poker, m  
 $R_{action}$  : radius of action, m  
 $f$  : frequency, Hz  
 $a$  : amplitude, m

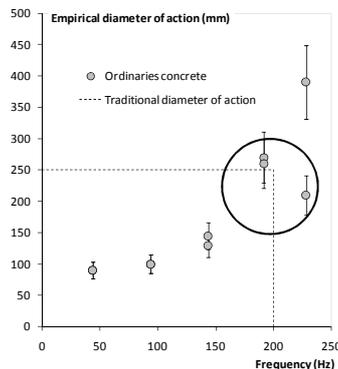
Finally, we obtain equation (3)

$$R_{action} = R_0 \sqrt{1 + \frac{\mu_p k f a}{\tau_0 R_0}} \quad (3)$$

This simple analytical model (3) predicts the radius of action of a vibrating poker immersed in a cementitious material according to the rheological properties of the material and vibration characteristics. The factor  $k$  determines the real form of the shear rate. It is possible to calculate it analytically from complex equations such as those developed in Ref. 10.

## RESULTS

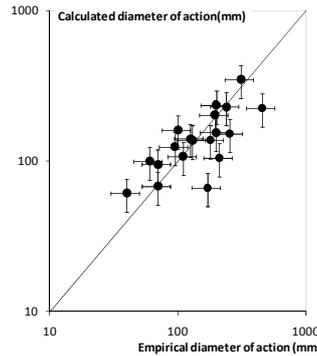
Figure 4. Empirical results of a vibrating poker with 25 mm diameter immersed in traditional concretes.



At first, for traditional concrete and frequency at 200 Hz, we find experimentally the current recommendations regard that the radius of action of a vibrating poker is approximately equal to ten times the radius of the vibrator, as shown in Fig 4.

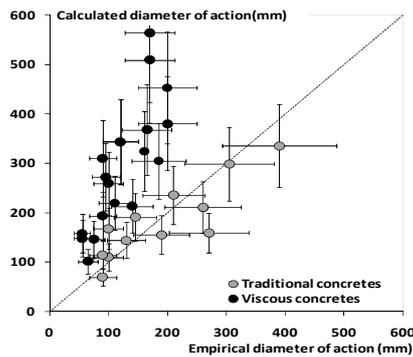
We set the value of the factor  $k$  from tests on cement pastes. For these materials, we quantified precisely their level and viscosity with a rheometer. In addition, they have the advantage of a better homogeneity than concrete samples. Fig 5 shows that the equation (3) is validated in the case of cement pastes with  $k = 50$ . For our studies on traditional and viscous concrete, we keep the same value of the coefficient  $k$ .

Figure 5. Correlation between the analytical model and empirical measures on cement pastes.  $k=50$ .



In the case of traditional concretes, we also have a good correlation between our experimental and our analytical model. However, Fig 6 shows that for high viscous concretes, the theoretical effective diameter is greater than the diameter of action real.

Figure 6. Diameter of action as a function of theoretical diameter experimental action in the case of ordinary concrete and viscous concretes.



## DISCUSSION

We note that according to equation (3) the radius of action is expected to increase the viscosity of the concrete. Nevertheless, our results indicate otherwise. This demonstrates the capacity limit of the prediction of the analytical model.

Several hypotheses have been advanced. First, creation of a local shear-thickening of material around the vibrating poker prompts total blockage of particles near the vibrator. The peculiar situation of Figure 7.

*Figure 7. Hole left by a vibrating poker*



Secondly concretes with high viscosity may require for their thinning, more mechanical power effective from vibrator which would no longer be able to ensure its vibration point.

To quantify our second hypothesis, we consider the dimensionless ratio of the mechanical power ( $P_m$ ) issued by a vibrator and power that the material is able to dissipate, denoted  $P_d$ . From a dimensional point of view, with  $F_c$ , the centrifugal force of a vibrator we have the equation

$$P_m = F_c \cdot f \cdot a \quad (4)$$

From the manufacturers' data and the analytical model [4],  $P_m$  is approximately  $10^3$  W. Similarly, we can estimate the dissipated power in the form of the formula [5] with  $H_0$ , the indentation depth of the vibrator in concrete:

$$P_d = \mu_p \cdot \dot{\gamma}^2 \cdot R_{\text{action}}^2 \cdot H_0 \quad (5)$$

The orders of magnitude of the velocity gradient and the radius of action show that  $P_d \approx 10 \mu_p$ . In the case of ordinary concrete, the viscosity is less than a hundred Pa.s. The ratio  $P_m/P_d$  would be greater than 1. The vibrating equipment is still able to provide necessary power to the implementation of the material. In the case of modern concretes high viscosity  $\mu_p$  is greater than 100 Pa. Then the ratio  $P_m/P_d$  may become less than 1. Therefore, vibrators current would not issue sufficient power to liquefy these materials properly. Technological change seems, in this context, possible to keep the range expected despite higher viscosities of modern concretes.

## CONCLUSIONS

These results confirm the technical recommendations for standard concrete and show range for application from the current vibration with the equipment used in practice in the case of concrete with low water/cement ratio.

In addition, a measure of the real amplitude of the vibrator plunged into a cementitious material provide complementary basis for reflection about the origin of the drop measured radius of action and may help confirm that the power of the vibrator becomes insufficient. This measure, however, is difficult in practice.

Finally, a study of the radius of action of a vibrating poker plunged into reinforced concrete beams would allow us to consider a possible reflection and transmission of the vibration through the walls of the molds.

## ACKNOWLEDGMENTS

The authors thank the Federation National des Travaux Publics (FNTTP) and the Federation Francaise du Batiment (FFB) for constructive comments during meetings and for their financial participation. Finally, the authors thank Atlas Copco Compagny for the provision of a vibrating poker with variable frequency.

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