University „Dunărea de Jos” din Galaţi
Doctoral School of Engineering

DOCTORAL THESIS
SUMMARY

DYNAMIC ANALYSIS IN THE PROCESS OF CONCRETE VIBRATION TO MAINTAIN THE RESISTANCE CAPACITY

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Chapter IV

Chapter V

Cuvinte cheie

Fresh concrete
Dynamic compaction
Concrete vibration
Indoor vibrators
Outdoor vibrators
Strength of concrete

INTRODUCTION

The purpose of the present thesis is to analyze the structural and functional laws underlying the interaction of the vibrating machines and the compacted material. Two fundamental characteristics of the vibratory system are emphasized: the dynamic model with viscous dissipation and the degree of compaction, especially the energy density in the compaction environment.The results obtained from the analysis of the used types of vibrators and rheological models are confirmed by experiments on different types of concrete, which highlight the way of transmission of the energy from the source to the concrete mass as a result of the maintained excitation vibrations, obtaining the concrete compaction through the generated waveform.

As a result, it is intended to increase the strength of the concrete elements, achieved during the vibration compaction of the fresh concrete put into work. Based on the analysis of the existing types of vibrators, dynamic models are created with viscous and elastic elements and solutions are developed for the use of different types of vibrators, which generate different vibration modes in different situations so that a uniform distribution of the controllable porosity in concrete may be obtained, aiming to increase the strength of the concrete after reinforcement to values superior to the present solutions.

It is also studied and analyzed the system of regulating the parameters of the vibration regime so that the degree of transmissibility of the action is maximally represented by the hysteresis internal dissipation ellipse as well as by the rheological parameters of response (stiffness and amortization) of the fresh concrete that is to remain within optimal limits.

Highlighting the energy state of the system can be achieved by means of pressure, wave propagation speed, vibration parameters as well as dissipative energy.

By the performed studies and research, the present work provides a series of calculation tools and practical recommendations necessary for the production of cast and precast concrete elements.

The PhD thesis is structured into 5 chapters, described in 120 pages, containing 50 figures, 20 charts and 115 references. During the present thesis, is discussed in details the topic and its progressive solution, as well as the conclusions, the personal contributions and the way of capitalizing the obtained results and the future directions of the research.

Chapter I covers the current state of research on vibration compaction of fresh concrete and the objectives of the thesis. In this chapter it is also presented the influence of rheological factors on concrete compaction process.

In **Chapter II** are presented the rheological characteristics of concrete, the structure and its components. It also highlights the viscous, elastic and plastic rheological models of the fresh concrete during the vibrating compaction process, which presents the dynamic response of the fresh concrete by the dynamic application of the load, namely the vibration regime, which causes changes in the structure of the fresh concrete and of its rheological characteristics.

Chapter III presents a dynamic analysis of inner and outer vibrators. In this chapter it is also the optimization of the fresh concrete compaction in order to increase its resistance capacity, achieved by an efficient correlation of the physical and mechanical characteristics with the vibration parameters (amplitude, frequency). It presents the characteristic of the vibration regime, the waveform and wave propagation equations generated by vibrations, including dissipative propagation waves.

In **Chapter IV** „Experimental Determinations for Establishing the Duration of Vibration on Concrete Classes” are provided the experimental determinations for evaluating the dynamic response of the fresh concrete in the compaction process, taking into account especially the processes of mixing and vibration of the fresh concrete, the study being presented starting from the choice of the mixture components until its preparation by mixing, casting and vibrating the fresh concrete, including the presentation of machines and laboratory equipment being used.

In **Chapter V**, entitled "Conclusions. Original contributions" are presented the aggregations that can be highlighted based on the results of the researches carried out in the elaboration of the present PhD thesis and the personal contributions of the author regarding the vibration parameters of the concrete to increase the resistance capacity, the theoretical and experimental analysis of the vibration parameters and of the vibrating machines from a constructive and functional point of view, for the successful application in practice.

Chapter I

THE PRESENT STAGE OF THE RESEARCH RELATED TO FRESH CONCRETE COMPLECTION BY VIBRATION. OBJECTIVES OF THESIS

The concrete for structures of resistance in civil engineering, industrial and agricultural constructions, roads, bridges, due to its physical and mechanical characteristics, is the material with the highest rate in construction technologies.

The production, transport and placing of fresh concrete are processes with a high degree of mechanization, which leads to increased productivity, quality and cost as well. The way concrete is placed and especially the degree and the compacting regime have a great influence on its structure.

Concrete vibration, being a simple and efficient process, is the most used means of compaction for concrete, both on construction sites and in precast factories.

Selecting the machines to achieve efficient compaction, in conditions of high productivity and minimal energy consumption, is a difficult problem for users.

The technological processes of compacting concrete by vibration require knowledge of both rheological characteristics of fresh concrete and the influence of vibratory parameters of dynamic regime on the quality of the compaction process.

I.1. VIBRATION COMPACTION PROCESS

The vibration of the concrete, in the fresh state, leads to a compaction process able to increase greatly its strength after hardening.

The concrete compaction process can be optimized for the vibration operation if only the other technological operations are perfectly determined and respected as follows:

- concrete components (water, cement, aggregates, additives);
- dosage;
- mechanical mixing.

The reaction of fresh concrete, under the influence of mechanical vibrations, is determined by particle agitation that results in fluidised concrete, improved workability, and a degree of compaction higher than that obtained by simply mixing the concrete. When vibration ceases, the concrete instantly returns to its initial state, but with a higher degree of compaction. The energy delivered at the mass of concrete allows a high compaction degree even in mixtures with less than 5 cm compaction, viscous, moist, seemingly water-free consistency. In fig. I.1.1. the values of the total volume of the voids are stated, relative to the water volume of the non-vibrated and vibrated concrete.

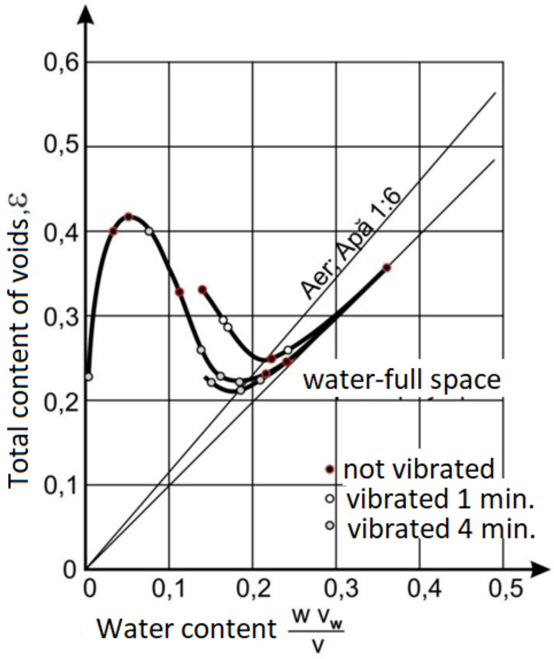

Fig. I.1.1. Variation of total volume of voids versus water volume [10]

The energy transmitted to the concrete through vibration favours the physical and chemical reactions of hydration hydrolysis of the cement, increasing the bonding forces and bringing the constituents into the pit of potential.

Concrete strengths are directly influenced by the vibration and the volume of concrete voids (Figure I.1.2).

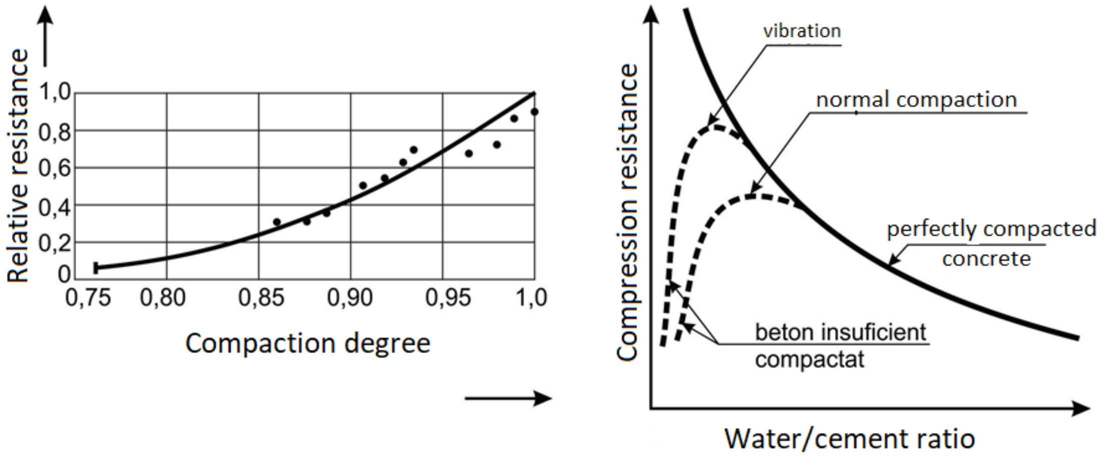

Fig. I.1.2 Variation of compressive strength of concrete due to vibration [10]

Repeating the vibration, after a period of time or the rewinding process, which emerged from the need to provide a suitable monolysis of the successively cast concrete structures may have positive influences (Figure I.1.3) if applied over the appropriate period of time 1-2 hours. Increasing the resistance of the concrete by means of a new vibration can be explained by decreasing the a/c ratio after the first vibration.

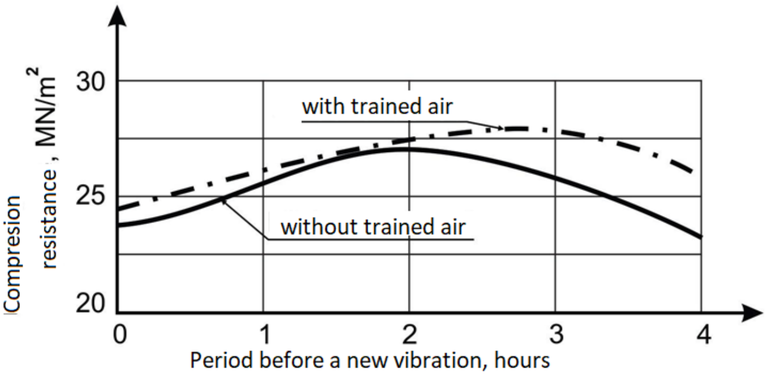

Fig. I.1.3 Variation of concrete resistance to a new vibration [10]

It is mentioned that late application leads to the destruction of coagulation crystallization recipes and crystallisation condensation of the cement, which, unlike coagulation recipes, are definitively destroyed, adversely affecting the quality of the concrete.

The compaction quality is determined by the characteristics of the vibrogenerator, the vibration amplitude, the frequency and magnitude of the disruptive force.

The amplitude may vary between a minimum value at which no compacting of the concrete occurs and a maximum, which causes excessive agitation, called boiling or overgrazing the concrete and preventing compaction. An over vibration can be reached.

The new vibration can lead to aggregation stratification according to size or segregation, with negative influence on concrete resistance. Thus, after vibration, concrete consolidation consists of two stages, namely:

- forming the aggregate skeleton by casting and creating a stable concrete structure as a result of achieving a balance between viscous forces, internal friction and vibration, in this state, the concrete has a wet and glossy surface and its structure is characterized by its thixotropic properties.

From the physical and mechanical processes study to vibration compacting of the concrete, it is concluded that in the dynamics of the vibration-concrete system, two phases can be defined from the rheological point of view: the transitional phase and the phase of the regime.

In the transitional phase, which occurs at the beginning of the vibration, the internal energy of the particles increases, important changes appear in the rheological characteristics of the concrete, resulting in the conversion of the concrete into a suspension of aggregates in the cement paste with viscous fluid characteristics.

These thixotropic phenomena occur in a relatively short period of compaction, having a duration of 5-15% of the compaction process.

In the phase that is installed after the vibration-conditioned concrete fluidization, considered as a **phase of the regime**, the vibratory system works at quasi-constant parameters, taking into account their slow, asymptotic variation, towards stable values.

Compaction can be **natural** and **forced.**

Natural compaction [10] takes place in the following way: random outward actions destroy the balance between friction forces, adhesion, and particle weight. For a short time, the weight of the particles' own weight is greater than the friction and adhesion forces. Under the action of their own weight, the particles move in, tending to occupy the lowest position. A rearrangement of the particles is produced in a compact way, the volume of the mixture is reduced and the mixture compacts.

Forced compaction [10] is made in an analogous way: through an action from the outside, it is sought to be annihilated the friction and adhesion forces between the particles of the mixture and to be sent them those movements in which takes place the rearrangement of particles in a compact way, the distance between the particles is reduced, and the mixture is compacts. Each particle of the mixture must receive an initial impulse enough to disrupt its frictional forces and adherent to the neighboring particle, and then receive further impulses to maintain its oscillatory or chaotic motion.

I.2. INFLUENCE OF RHEOLOGICAL FACTORS IN THE VIBRATION COMPACTING PROCESS OF CONCRETE

LM Krakinovskii [2] assimilates the movement of particles of vibrated mixture with the movement of a point placed on a plane inclined horizontally at a certain angle (Figure I.2.1)

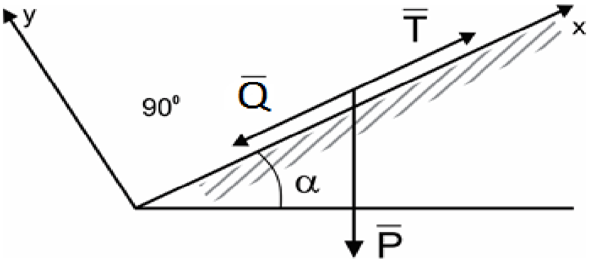

Fig. I.2.1. The movement of vibrated mixture particles according to L.M. Krakinovskii [2]

The mechanism of vibro compaction, according to M. Alexander [3], consists in ensuring vortices and turbulent motion in the mix. He considers that static pressure compaction is accompanied only by deformations, both elastic and residual. In the case of vibrocompaction, only finite particle displacements are produced, without deformation, therefore the marking of the differential equations of the mixture with compact medium is superfluous. On the contrary, I.D. Dewar [7] considers the deformation processes as the main ones.

In fact, static and dynamic compaction are accompanied by both finite displacements of the mixture particles and deformations of the mixture as a continuous medium.

The existence of deformations and finite displacements make it difficult to study the movement of the mixture, because in addition to the continuous parameters characterizing the whole mixture, for which a system of differential equations can be written, there are also some displacements of the mixing points. Each "physical" point of the mixture takes part simultaneously in two movements:

- a general one representing the displacement corresponding to the continuous deformations of the mixture as a resilient, elastic and viscous/ elastic, plastic and viscous body etc.;
- a relative one, which represents the displacement of a particle as an absolutely solid body. Accordingly, we have the tensions P_{ik} (i, k = 1, 2, 3), U_i displacement, six finite displacements x_j, y_j, z_j, ψ_j, θ_j, φ_j.

Depending on the researcher's point of view on the role of one type or another in mixed motion, the study of the mixture is treated as a continuous medium or as a system of „physical” material points.

The compaction mechanism, according to L.P. Petrunkin [6], is close to the compaction mechanism according to M. Alexander [3]. During vibration, the particles of the mixture move like a gas. The existence of relative motion of the particles and the crossing of their trajectories create the possibility of impulse exchange, the statistical result of which resists the external pressure, the weight and the forces of adhesion of the particles.

The compaction mechanism, according to J. Kolek [8], has three stages: the re-positioning of the components, their proximity and compaction by compression. The first two stages are valid for vibration compaction, as with their content they coincide with the corresponding phases, according to the theory of A.E. Desov [5].

In the compaction mechanism suggested by various authors, the nature of the external action that causes compaction of the mixture is not always taken into account. The compaction mechanism depends on the type of compaction system used: centrifugal, compactor cylinder, vibrator or their combination.

a) Self-compacting (natural compacting)

Analyzing a mineral component of the mixture - a physical material body - we can notice that the force of its own weight and the force of the environment act on it. In the case of movement, the material point reaches only some of the particles of the mixture. There are always two kinds of friction in mixing: the rubbing corresponding to liquids and the rubbing corresponding to solid bodies. We will consider the forces of the environment as being composed of the hydraulic holding forces (calculated according to the law of Archimedes) P_a, the dry friction forces of the slip and the forces of the viscous friction. The dry friction force T_0 of slip is presented in the form:

$$\bar{T} = f\bar{N} + \overline{k_0} \qquad \text{(I.2.5.)}$$

where: N is the normal pressure;

k_0 – the adhesion force between the particles of the mixture;

f – friction coefficient of the slip.

b) forced compaction in dynamically stabilized regime

For analysis, at least two conditions are required:

- remove the points of the mixture from the equilibrium condition, in which the resultant of the forces that produce the compaction must be greater than the resultant of the forces that prevent compaction;
- for compaction it is necessary for the particles of the mixture to undergo an unstable oscillatory motion around the middle positions. In order to maintain the oscillatory motion, the particles of the mixture must be continuously transmitted a corresponding amount of energy, which should not be less than the work of the friction and adhesion forces acting on the given particle.

c) Partial conclusions

The mechanism of vibration compaction requires studying the movement of both the vibrator and the mixture. The most general model: vibrator - a two-body system (vibrator body and axle) and mixing - a system of material points (bodies) in any continuous environment. In this case, the system points are all possible mineral components of the mixture, and the environment is a rheological body with certain properties. Depending on the problem conditions and the degree of precision required, simplifications are introduced in the model. Thus, if only the movement of the vibrator must be studied, the action of the mixture is replaced by forces, and its movement is neglected. Replacing the mixture with forces can be justified only if the movement of the mixture does not have an essential influence on the vibration motion or does not represent an interest to the problem. But in the matter of compacting the concrete, the greatest interest is its movement. Therefore, when compacting the concrete both the movement of the mixture and that of the vibrator must be considered.

I.3. THE INFLUENCE OF VIBRATIONS ON CONCRETE COMPACTION

The main vibration parameters on concrete compaction are:

a) Defining parameters of vibrocompaction of concrete:

- vibration frequency: it is chosen depending on the rheological characteristics of the concrete, the useful concrete mass to be vibrated, ie its ratio to the total vibration mass and to the design solution, namely the system's own pulsation, respectively the geometric/ dimensional characteristics of the concrete workpiece;
- the system's own pulsation: it is a function of the useful and functional working masses, respectively of the intermediate and final damping elements, determines the functional working regime;
- vibration amplitude: it is chosen depending on the rheological characteristics of the concrete and the vibration frequency;
- vibratory force/ static moment of the vibrator: it is chosen depending on the mass of the concrete workpiece, the total mass of vibration, the useful amplitudes to be obtained and the rheological characteristics of the concrete, which involve well-defined vibration acceleration levels;
- vibration time: it is chosen depending on the vibration frequency in relation to the system's own pulsation, the working regime, the geometric and functional characteristics of the concrete workpiece and the rheological characteristics of the concrete.

b) Basic physical and mechanical parameters of vibro-compact concrete:

- expected workability and stiffness C;
- compressive resistance R_c;
- density and compaction coefficient, expressed by the ratio between the volumetric mass per test specimen and the sum of the mass components;
- durability, depending on:
- the compressive resistance limit, of test specimen subjected to frost stability tests;
- the volumetric mass of test specimen subjected to frost stability tests;
- ultrasound speed in test specimen subjected to frost stability tests;
- full porosity, determined on the basis of water absorption.

c) Variation of physical and mechanical parameters of concrete during vibration:

Vibration actions on structural systems can be divided into two phases:

- in the first phase with the T_s duration takes place the destruction of the structural bonds and, consequently, the reduction of the viscosity;
- in the second phase occurs the displacement of particles in accordance with the external vibration action within the low-viscosity environment.

I.3.1. <u>Compaction threshold and the amplitude</u>

The conditions in which the particles of the compacting mixture go into motion define the vibration compaction threshold of the mixture. Analyzing a physical material point of the mixture, located according to Fig. I.3.1. and subjected in principle to the same forces, except for the force of its own weight, Φ, it is observed that if $Q \geq T$, the material point enters into motion under Φ force, where:

$\Phi = P + zS(\gamma_C - \gamma_0) - P_a$ (I.1.28.)

for P – the weight of the material point;

P_a – the forces of hydrostatic maintenance (the force of Arhimede);

In the compaction process, the vibro compaction threshold will change due to the change in the specific weight of the mixture, the height of the z-column, the force of Archimede, P_a, of the k_0 adhesion forces. Therefore, it follows from the above condition that compaction is possible only in the case of a time-varying acceleration, i.e. in the case of a time-varying frequency and amplitude .

So the vibration compacting threshold is determined by:

- the height of the mixture;
- shear limitation effort;
- the radius of the mixture components and varies during compaction.

The amplitude varies between a minimum value at which no compacting occurs and a maximum one, which causes the concrete to be over vibrated, therefore reducing its resistance.

I.3.2. Rigidity and viscosity of concrete

The main factor determining the elastic properties of the mixture during vibration is considered the unsprung air of the mixture as it has the greatest deformation capacity. Then the rigidity of the concrete mixture, considering its own weight, is determined using the formula:

$$C_0 = \frac{S_2(P_0+P_{cm})(P_0+P_{cm}+\gamma_a h_b)}{\varepsilon h_b P_0} \qquad \text{(I.1.45.)}$$

where: S_2 is the area of contact with the mixture, of the pattern;

P_0 – atmospheric pressure;

P_{cm} – static pressure, determined with all types of additional load;

ε – porosity;

γ_a – the specific weight of the mixture;

h_b –the initial height of the concrete mixture.

Therefore, the rigidity of the compacted mixture in the vibration process will vary. The same is worth for its own frequency. As the time or frequency is increased, or both sizes, the rigidity will also increase. The same will happen with its own base frequency. Hence, the need for a varying excitement regime.

Experimentally, it has been found that as the concrete mixture is compacted, its modulus of elasticity increases from about 1 to 5 Mpa for vertical oscillations and from 0.2 to 1.4 Mpa for horizontal oscillations.

The mass of vibro compact concrete mixtures can be equated with low-strength thixotropic solid structures or with structured thixotropic liquids.

In the case of vibration action with constant parameters, the compaction environments acquire newtonian liquid properties (Figure I.3.1). This fact, repeatedly confirmed by elementary experiences, has been scientifically confirmed by flow curves, built for different materials and different vibration parameters.

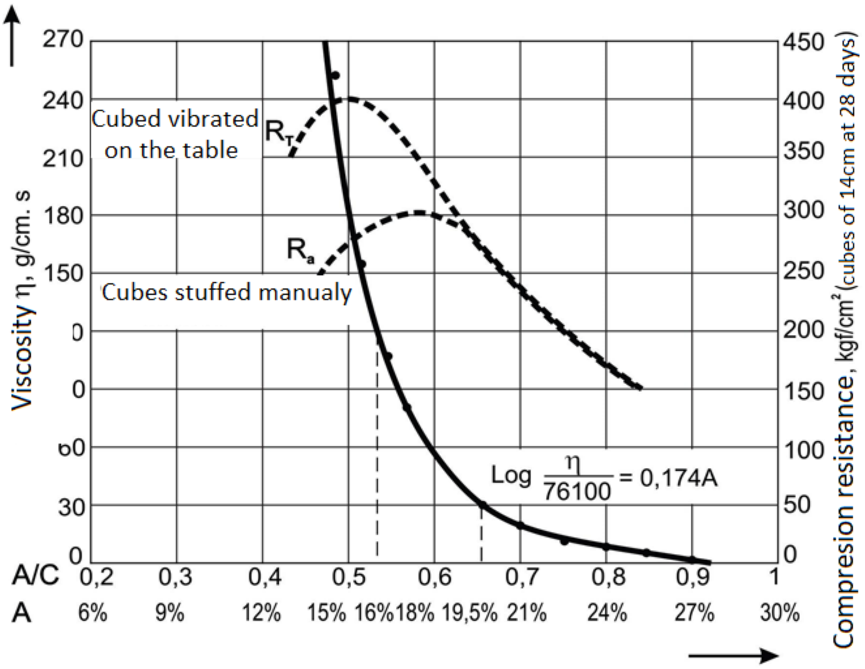

Fig. I.3.1. Viscosity of a concrete in vibration depending on the amount of mixing water [10]

Vibration actions on structural systems can be divided into two phases:

- in the first phase with the T_s duration , destruction of the structural bonds and, consequently, viscosity reduction;
- in the second phase occurs the displacement of the particles in accordance with the external vibration action in the low-viscosity environment.

Viscosity of the mixture during the vibration depends on the vibration processing time, the physical and mechanical mixture properties, the coordinates of the environmental points and the amplitude of the vibration action.

I.3.3. Frequency and amplitude of vibration

Frequency variation in the vibration process contributes to the optimization of mixture compaction, and the best regime for forming the products is obtained at a varying frequency, starting from the low one, when the vibrational intensity will be optimal for the given product.

Also, the resistance of concrete grows as the frequency increases in compaction regimes with a vibration acceleration of 20-35m/s^2. At identical frequencies, the resistance of the concrete will be 10-12% higher at higher accelerations.

Particularly efficient is vibration with gradual modulation of frequencies, starting from the lowest, gradually moving to the highest frequencies, as well as the use of alternative frequencies. It has been experimentally established and that the variation of the vibrating platform oscillations amplitude at constant frequency allows a better quality of the compaction of the concrete products, the resistance limit increases by 18-22%.

Theoretically it can also be considered a working regime with different frequencies and different amplitudes. The effect of the simultaneous multifrequency regime of the vibro compaction process can be achieved by combining the vibration, in a constant amplitude-frequency regime, with the percussion.

Another solution in increasing the number of frequencies is to use an additional load generating a static pressure of 0.004-0.006 Mpa applied to the surface of the concrete that is to be compacted. Obviously, its vibrational frequency will be different from that of the main workpiece oscillations.

In conclusion, the variation range of frequency and compaction amplitude is chosen in the area of the structure bonds of the mixture that is to be compacted and, namely at their highest degree of destruction or the area of greatest viscosity reduction.

Chapter II

THE RHEOLOGICAL MODELLING OF FRESH CONCRETE IN THE DYNAMIC COMPACTION PROCESS

II.2. VISCOUS, ELASTIC AND PLASTIC RHEOLOGICAL MODELS OF FRESH CONCRETE IN THE DYNAMIC COMPACTION PROCESS

The reaction of fresh concrete under load presents itself as a difficult problem taking into account the number of factors that influence its characteristics.

The rheological properties of the concrete must be supplemented by a measure of the degree of its homogeneity.

II.2.1. Simple rheological models

One of the first rheological models used for concrete was the Ross model. It illustrates the concrete reaction in time, but it has a number of drawbacks, among which is the fact that it does not reflect correctly the relaxation phenomenon.

Another simple model describing the rheological behavior of the concrete is the Kelvin-Hooke series.

The Burgers and Fluge models are designed to describe the stable and stiff creep of the concrete and the slow flow under the load.

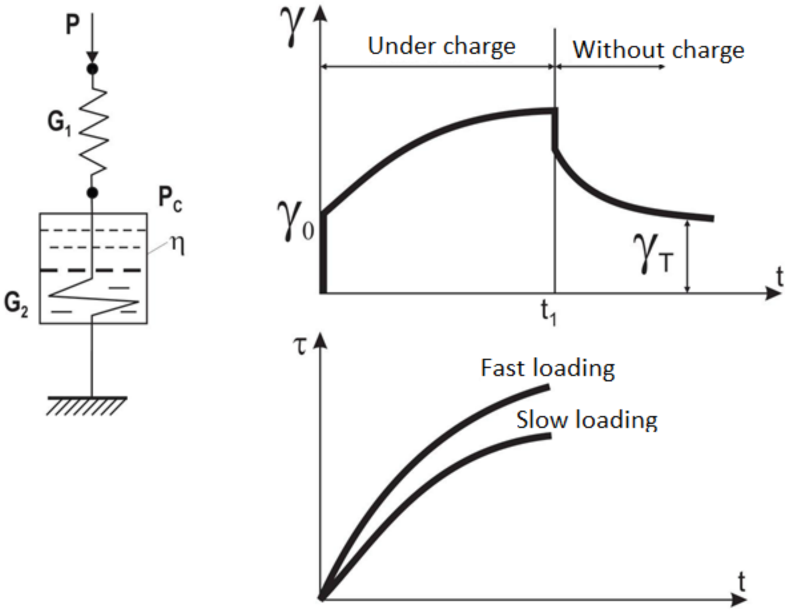

Fig. II.2.1. The Ross Model [10]

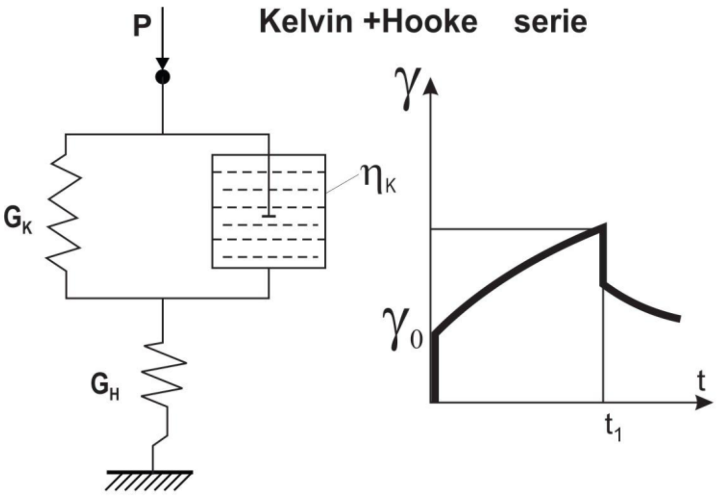

Fig. II.2.2. The Kelvin+Hooke Model [10]

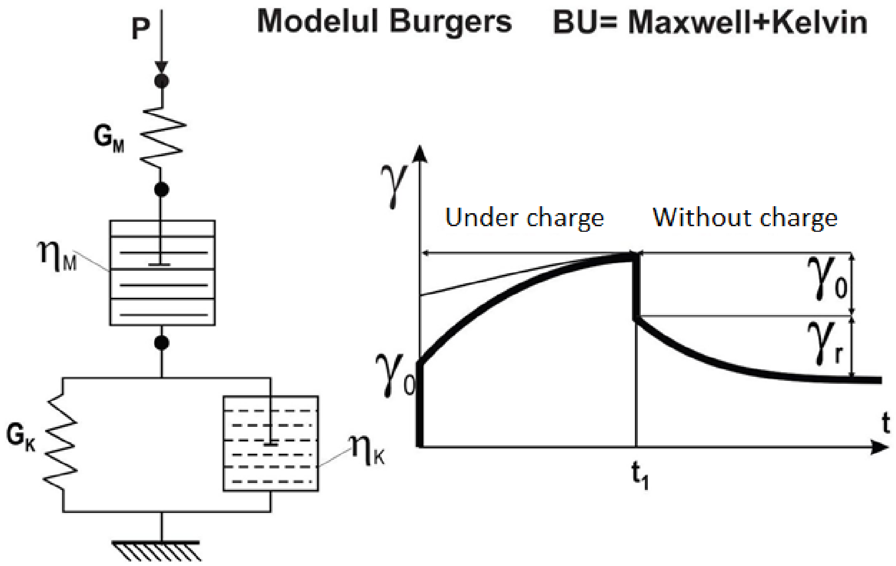

Fig. II.2.3. The Burgers Model [10]

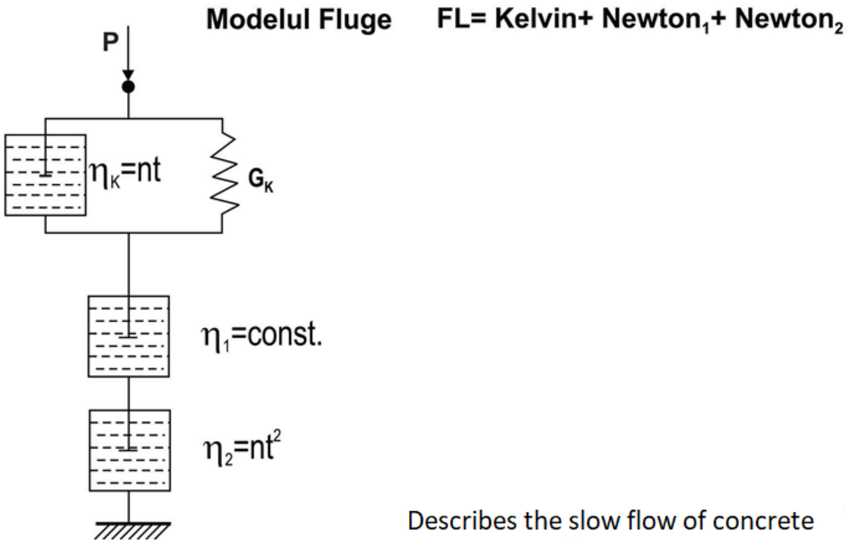

Fig. II.2.4. The Fluge Model [10]

II.2.2. Compound rheological models

Compound models, consisting of several simple and better describing the charging models, are those made by Neville, Cowan and Freudental. Through Hooke elastic elements, they describe the fast loading while Kelvin, Burgers, Newton elements, describe the slow loading. One of such models, the most compound one, is the Toroja Paez model.

A model describing the plastic flow as well is the Stolnikov model. It inserts a Kelvin element with a Maxwell Schwedow body that exhibits also plastic deformation.

A compound model is the Uliţkii model, which takes into account the elastic and plastic deformations of the concrete constituents.

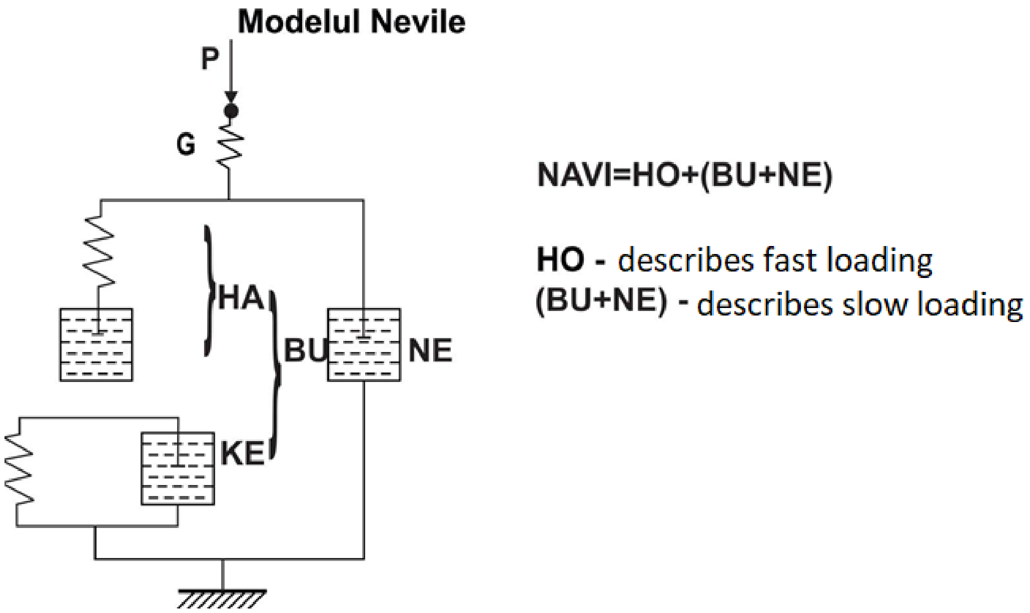

Fig. II.2.5. The Nevile Model [10]

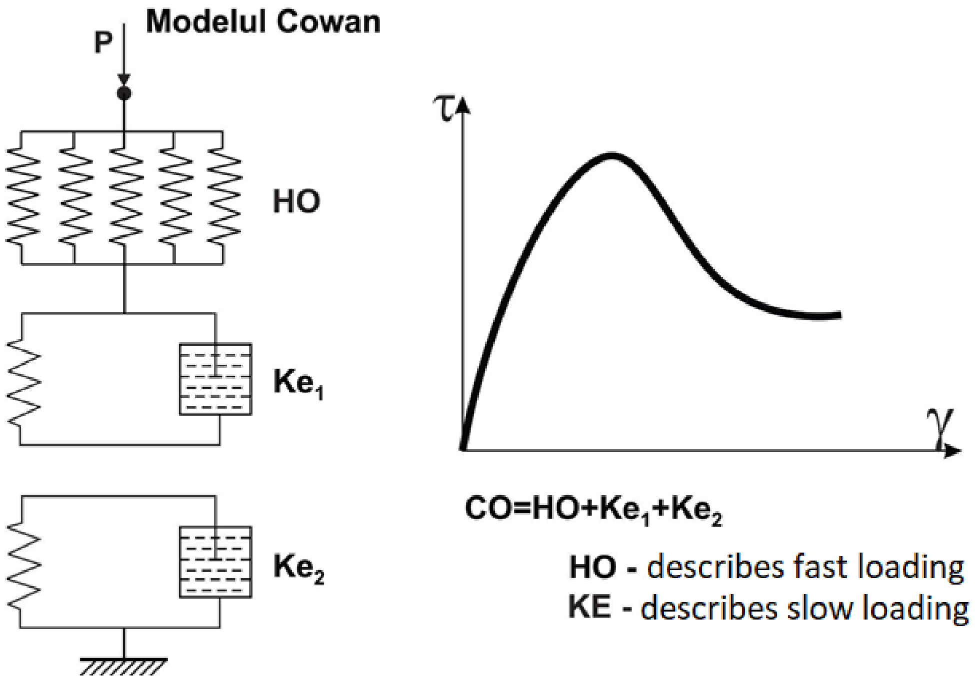

Fig. II.2.6. The Cowan Model [10]

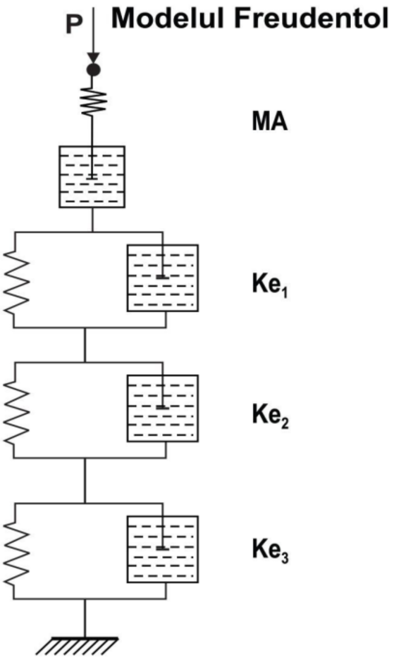

Fig. II.2.7. The Freudentol Model [10]

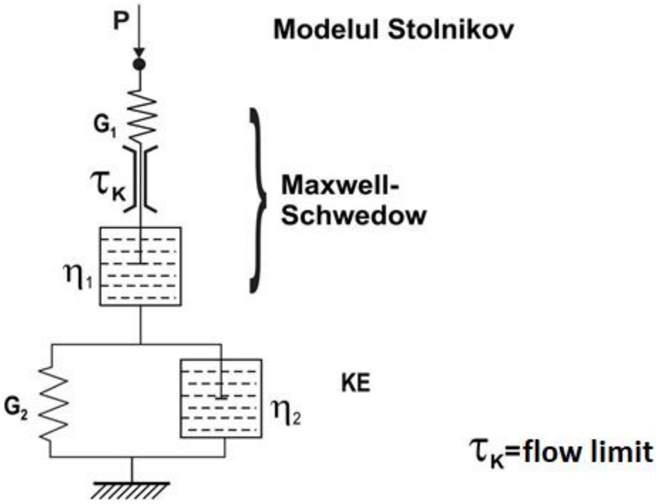

Fig. II.2.8. The Stolnikov Model [10]

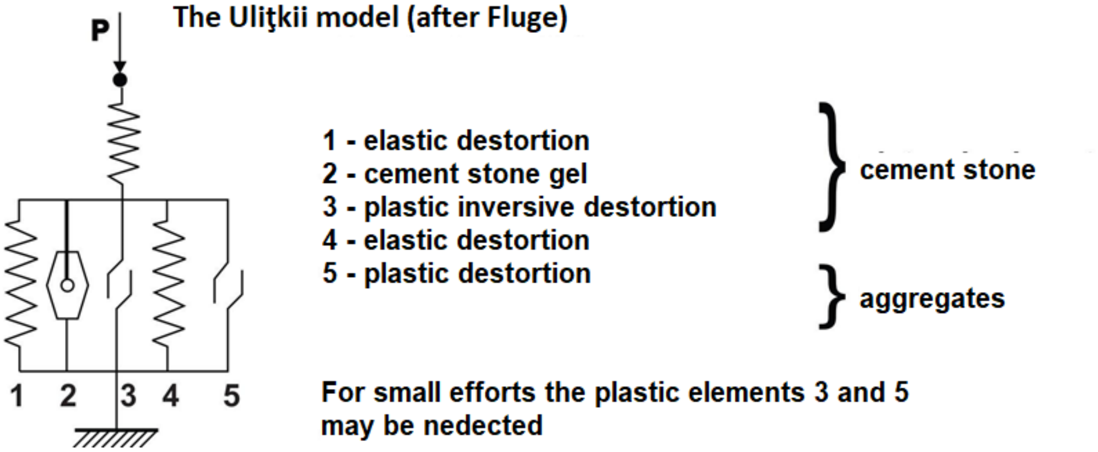

Fig. II.2.9. The Uliţkii Model [10]

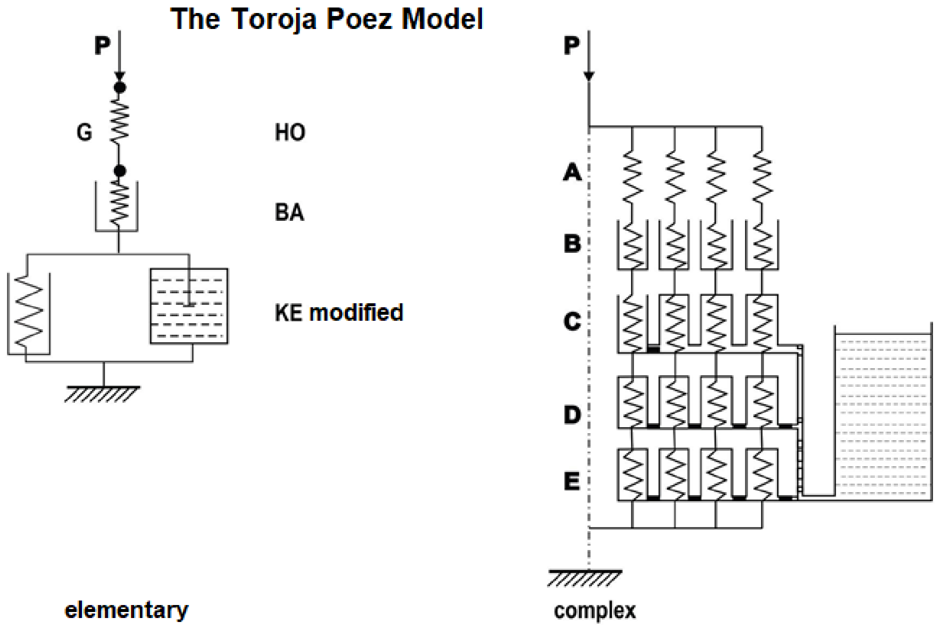

Fig. II.2.10. The Toroja Poez Model [10]

II.3. STRUCTURE AND COMPONENTS OF FRESH CONCRETE

Component materials should not contain harmful substances in quantities that may have a detrimental effect on the durability of the concrete or cause corrosion of the reinforcement, they must be suitable for the intended use of the concrete.

According to [140], for concrete only components with the fitness for use set for specific requirements must be used.

The composition of the concrete and component materials with specified properties or the prescribed composition must be chosen to meet the specified requirements for fresh and hardened concrete, including consistency, bulk density, resistance, durability, corrosion protection of embedded steel parts, taking into account the production processes and the method by which the concrete works are intended to be executed.

II.3.1. Aggregates for concrete

Natural aggregates can be pitched and/ or quarried, sorted and/ or crushed. They must comply with the product standard [142] and have certain characteristics required by the existing rules for preparation of concrete [140] and [141].

II.3.2. Cement

The basic requirements for the use of cements to obtain concrete are in accordance with the requirements of [140], but which must meet the requirements and comply with [153].

II.3.3. Mixing water

The basic requirements for using water to obtain concrete are in accordance with the requirements of [140] and which show that the general suitability for use is set for the mixing water and flushing water recovered from concrete production according to [158].

II.3.4. Additives

The basic requirements for the use of additives in the production of concrete are in accordance with [140]. The additives used must meet the conditions and comply with SR EN 934-2 + A1.

II.3.5. Supplements

The general ability to use mineral powder supplements (mineral fillers and pigments) is in accordance with CP 012-1. The used supplements must meet the requirements and comply with SR EN 450-1, SR EN 450-2, SR EN 13263-1 + A1 and SR EN 13263-2 + A1.

II.3.6. Characteristics of fresh concrete. Factors of influence

The composition of the concrete and the component materials with specific properties or prescribed composition must be chosen so as to meet the specified requirements for fresh and hardened concrete, including consistency, bulk density, resistance, durability and corrosion protection of incorporated steel parts . The production processes shall be taken into account and the method by which the concrete works are intended to be carried out.

Chapter III

DYNAMIC ANALYSIS OF VIBRATION PARAMETERS IN THE COMPACTION PROCESS

III.1. THE STUDY OF INNER VIBRATORS MOTION

The most widespread constructive solutions of interior vibrators [1] are based on the generation of a spinning rotating force radially intersecting the cylindrical body of the vibrator.

Since the movement of the vibrator is characterized by circular trajectories, the oscillatory movement of the vibrator body is transmitted to the concrete in all radial directions in parallel horizontal planes.

The phenomenon of propagation of the waves generated in the fresh concrete is characterized by the realization of plane, cylindrical or spherical waves.

Therefore, for an overall estimation of energy propagation from the source at any x distance it is explained as follows:

- for plane waves, $a = a_0 e^{-\beta^{x}}$;
- for cylindrical waves, ; $a = a_0 e^{-\beta^{x}} \sqrt{\frac{r_0}{r_0 + r_x}}$;
- for spherical waves, $a = a_0 e^{-\beta^{x}} \sqrt{\frac{r_0}{r_0 + r_x}}$;

where: a_0 – the amplitude of the wave generator; r_0 – radius of the vibrator cylinder; β – the coefficient of the wave effect amortisation in the concrete mass; x – the distance from the source to the point of analysis of the wave effect.

The first calculation hypothesis that refers to the vectors of all forces applied to the body at the same plane as the center of mass of the vibrator body that performs a parallel plane motion in a system in which the elastic elements are missing (Fig. III.1.1) , have the following amplitudes:

$$x_a = \frac{m_0 r\omega}{(m_1 + m_0)\sqrt{\omega^2 + 4h_x^2}};\quad y_a = \frac{m_0 r\omega}{(m_1 + m_0)\sqrt{\omega^2 + 4h_y^2}} \qquad \text{(III.1.1)}$$

and the shift between force and displacement is, as follows:

$$\varphi_x = arctg\left(-2h_x/\omega\right);\quad \varphi_y = arctg\left(-2h_y/\omega\right) \qquad \text{(III.1.2)}$$

Because the problem is axially symmetrical, the motion equations can be condensed based on the use of the polar co-ordinate system (Fig. III.1.2).

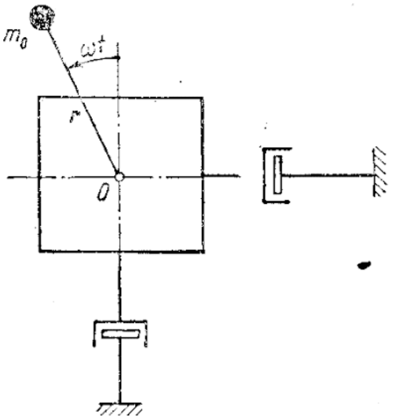

Fig. III.1.1. Model of calculation without elastic elements [1]

The second calculation hypothesis [1] is based on the fact that the vibrator grip of the manipulator must have a much diminished displacement, almost null.

In order to obtain the null point, it is necessary that the center of the eccentric mass to be placed below the center of vibrator body mass. In this case, the movement of the vibrator body can be studied by means of four degrees of freedom, according to the diagram in figure III.1.3.

At point A the center of mass of the eccentric is considered, and in A' - the projection of A point on the u - u' axis.

The result of the concrete resistance forces is considered to be applied at D point , and the vibratory mass center along with the concrete mass participating in the vibrational movement is at G point .

We note with $n = EA'$ the distance from the center of the entire vibrator mass projection to the center of the eccentric mass; $n' = ED$ the distance from the center of the entire vibrator mass projection to the point of dissipative force application; $n'' = EG$ the distance from the center of the entire vibrator mass projection to the body mass center.

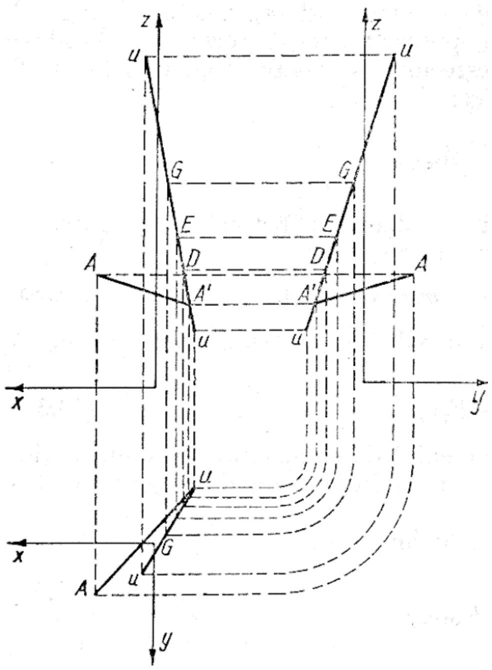

Fig. III.1.3. Diagram of the position of a vibrator at a certain moment [1]

In order to simplify the calculations without too much mistaking, it is considered that the E point is the center of the whole vibrator, a case in which the differential motion equations of the vibrator are:

$$\begin{aligned}
&(m_1 + m_o + m^{'})\ddot{x} + b(\dot{x} + n^{'}\dot{\psi}) = m_0 r\omega^2 \cos\omega t \\
&J_1\ddot{\psi} + bn^{'}(\dot{x} + n^{'}\dot{\psi}) = m_0 r\omega^2 n\cos\omega t \\
&(m_1 + m_o + m^{'})\ddot{y} + b(\dot{y} + n^{'}\dot{\varepsilon}) = m_0 r\omega^2 \sin\omega t \\
&J_1\ddot{\varepsilon} + bn^{'}(\dot{y} + n^{'}\dot{\varepsilon}) = m_0 r\omega^2 n\sin\omega t
\end{aligned} \qquad \text{(III.1.9)}$$

where J_1- is the central moment of inertia of the entire vibrator to a horizontal axis, perpendicular to the axis $u-u$, passing through the mass center; x, y- the coordinates of E point ; ψ, ε- the angle between the Oz axis and the $u-u$ axis projections on the *Oxz* and *Ozy* planes.

Differential equations can be separated because the movements are decoupled, the first two and the last two.

It can be noticed that the left side of the first and third equations, respectively the second and fourth equations are analogous. The parts differ only through a $\pi/2$ phase, corresponding to the *Ox* and *Oy* axes. For these reasons, only the first two equations will be analized, taking into account the fact that:

$$x = a\psi \qquad \text{(III.1.10)}$$

where *a* is the distance from the mass point of the whole.

In this case, the first two differential equations obtain the form:

$$\begin{aligned}
&(m_1 + m_o + m^{'})\ddot{x} + b(1 + \frac{n^{'}}{a})\ddot{x} = m_0 r\omega^2 \cos\omega t \\
&(\frac{J_1}{na}\ddot{x} + b\frac{n^{'}}{n}\left(1 + \frac{n^{'}}{a}\right)\ddot{x} = m_0 r\omega^2 \cos\omega t
\end{aligned} \qquad \text{(III.1.11)}$$

Because the right side is the same, in order to have the same solutions, there must be equality between the $\dot{x}$ and $\ddot{x}$, size coefficients, as follows:

$$n' = n$$

$$a = \frac{J_1}{\left(m_1 + m_0 + m'\right)n} \qquad \text{(III.1.12)}$$

The distance from the null point to the transverse plane of the mass center of the eccentric is:

$$l = \frac{J}{\left(m_1 + m_0 + m'\right)a}\,, \qquad \text{(III.1.13)}$$

where $l = n + a$, and $J = J_1 + \left(m_1 + m_0 + m'\right)a^2$ is the moment of inertia to the horizontal axis passing through the null point and is perpendicular to the *u - u* axis.

Considering that $n' + a = l$, we have:

$$\left(m_1 + m_0 + m'\right)\ddot{x} + b\frac{l}{a}\dot{x} = m_0 r\omega^2 \cos\omega t\,,$$

with the solution

$$x = x_a \cos(\omega t - \varphi),$$

where the phase shift φ and the x_a amplitude are given by the equations:

$$tg\varphi = -\frac{bl}{a\left(m_1 + m_0 + m'\right)\omega};$$
$$x_a = \frac{m_0 r\omega a}{\sqrt{a^2\left(m_1 + m_0 + m'\right)^2 \omega^2 + l^2 b^2}} \qquad \text{(III.1.14)}$$

If there is a null point, the case with the vibrator in the air, then the vibrator axis will describe a circular cone with the tip at this point.

If the null point does not occur, the case with the vibrator in concrete, then the vibrator symmetry axis describes a hyperboloid surface (Figure III.1.4).

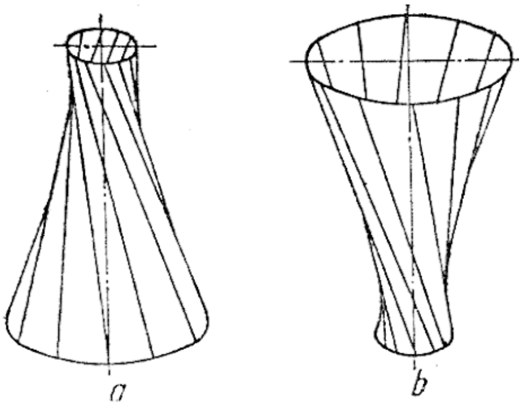

Fig. III.1.4. Successive positions of the symmetry axis of the vibrator body during operation [1]

For the correlation between constructive and functional parameters, the following formula is recommended:

$$f = 80\left(1 + \frac{100}{d}\right)[Hz] \qquad \text{(III.1.15)}$$

where *d* is the diameter of the vibrator body, in mm.

The vibration amplitude is recommended at 0.5 ... 0.7 mm for frequency less than or equal to 200 Hz and 0.3 to 0.5 mm for frequencies ranging from 200 to 250 Hz . In order to avoid concrete segregation, it is advisable to avoid amplitudes exceeding 1.2 to 1.3 mm

III.1.2. The dynamics of elastic systems operated with outer vibrators

External vibrators [1] are placed on formworks, patterns or elements of this category that interact with the freshly laid concrete mass.

In order to achieve a maximum compacting effect and a higher homogeneity of the concrete mass, the vibration regime transmitted to the concrete must be stable, controllable and at the parameters imposed by the working technology.

For the calculation of the constructive and functional parameters of the external vibrators with inertial disturbing force, several simplifying hypotheses are introduced, namely:

- the vibratory system - the gripping element is considered to be a system with a degree of freedom;
- the vibrator is placed in the weight center of the elastic element that fulfills the role of printing, formwork, etc.

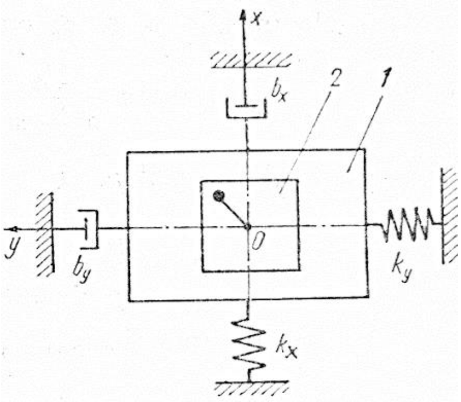

Fig. III.1.5.Dynamic calculation model of an elastic system composed of an external vibrator with rotating disturbing force and formwork [1]

The differential equations of movement of the elastic system (Figure III.1.5), excited by a rotating disturbing force, are of the following form:

$$(m_1 + m_0)\ddot{x} + b_x\dot{x} + k_x x = m_0 r\omega^2 \cos\omega t$$

$$(m_1 + m_0)\ddot{y} + b_y\ddot{y} + k_y y = m_0 r\omega^2 \sin\omega t$$

(III.1.16)

where *m0* is the total mass of the eccentric; *r* - the distance from the center of the eccentric mass to the axis of rotation called eccentricity; ω - the angular velocity of the eccentric mass and the disturbing force pulse; *kx, ky* - equivalent stiffness coefficients of the elastic system corresponding to the *x* and *y* directions, respectively; *bx, by* - equivalent coefficients of dissipation forces proportional to the $\dot{x}$ and $\dot{y}$ speeds, respectively.

For the dynamic model in Figure III.1.6, which takes into account that elastic forces, resistance and disruption are competing in the mass center of the elastic system, the differential movement equations are written as:

$$\begin{aligned}(m_1+m_0)\ddot{x}+b_x\dot{x}+k_x x&=m_0 r\omega^2\cos\alpha\cos\omega t\\(m_1+m_0)\ddot{y}+b_y\dot{y}+k_y y&=m_0 r\omega^2\sin\alpha\sin\omega t\end{aligned}\qquad\text{(III.1.21)}$$

The solutions of equations (III.1.13) expressing the stabilized regime of forced vibrations are:

$$x=x_a\cos(\omega_t-\varphi_x)\,,\ y=y_a\sin(\omega_t-\varphi_y)\,,\qquad\text{(III.1.22)}$$

The amplitudes corresponding to the displacements along the *Ox* axis and *Oy,* respectively are of the following form:

$$\begin{aligned}x_a&=\frac{m_0 r\omega^2\cos\alpha}{(m_1+m_0)\sqrt{(p_x^2-\omega^2)^2+4h_x^2\omega^2}}\\y_a&=\frac{m_0 r\omega^2\sin\alpha}{(m_1+m_0)\sqrt{(p_y^2-\omega^2)^2+4h_y^2\omega^2}}\end{aligned}\qquad\text{(III.1.23)}$$

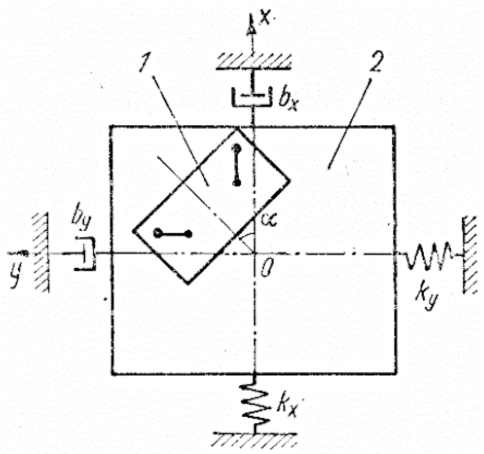

Fig. III.1.6. Dynamic computing model of an elastic system composed of an unidirectional disruptive force external vibrator and formwork [1]

III.2. THE STUDY OF VIBRATING MASS-CONCRETE SYSTEM MOTION

The dynamic model is shown in Figure III.2.1 and is characterized by the fact that between the concrete mass and the vibrating platform, the connection adopted is of the viscous and linear type with *c* coefficient, ie. the viscous binding force is of the following form $Q(t)=c(\dot{x}_1-\dot{x}_2)$.

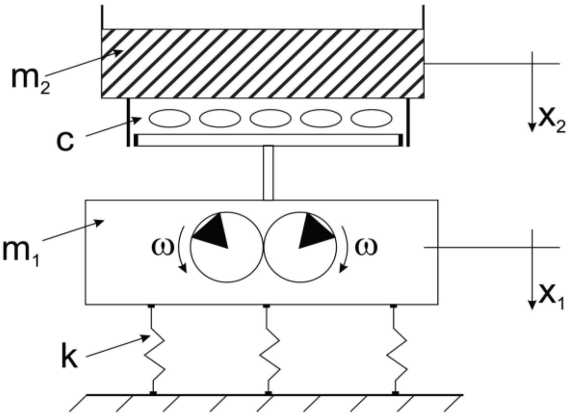

Fig. III.2.1. Dynamic model [10; 12]

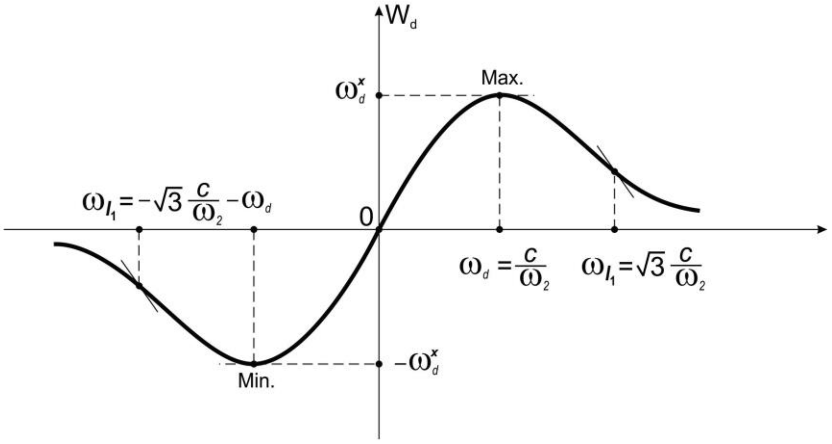

Fig. III.2.2. W_d-ω curve [10; 12]

Figure III.2.3 shows the dissipative energy curves for three distinct variants of *c* and pulse ω = 314 rad/s.

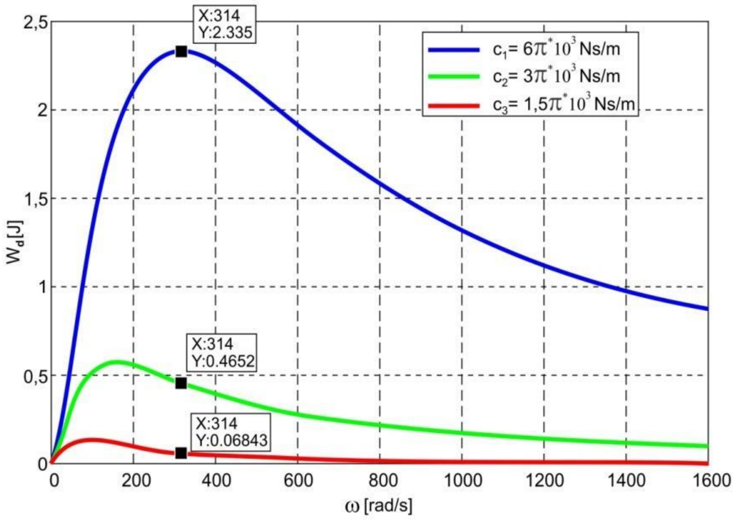

Fig. III.2.3. Dissipative energy curves [12]

Thus, in Figure III.2.4 the hysteresis curves are presented in the form of ellipses for three distinct values of *c* and a pulse ω = 314 rad/s.

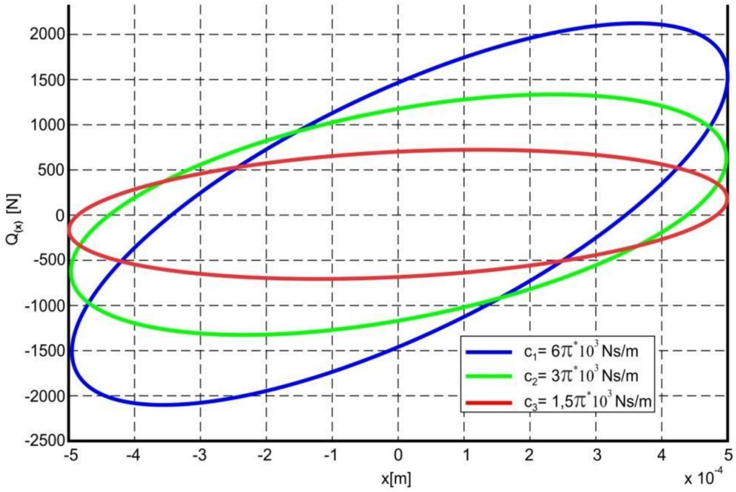

Fig. III.2.4. Hysteresis curves in the form of ellipses [12]

It is noticed that the area of the ellipse, the hysteresis loop, represents the dissipated energy as a clear and significant indicator for the degree of compaction of the freshly vibrated concrete.

Based on the schematic layout of the viscous and linear compaction of the fresh concrete in the vibration regime, the following characteristics can be determined:

a) the law of variation of the energy dissipated in stationary vibration regime for the compaction process;
b) the maximum amount of dissipated energy by the correlation of the excitation pulse with the concrete mass and the viscous energy dissipation constant;
c) lifting the hysteresis loops according to the A_1, ω vibration parameters and m_2 mass and the c damping constant of the fresh concrete.

III.3. THE CHARACTERIZATION OF THE VIBRATION REGIME

Propagation of vibrations in concrete

From the vibratory concrete system dynamics study results that the vibrated concrete undergoes important changes from the solid phase to the viscous fluid, the vibrational energy raising the internal energy and the mobility of the concrete aggregates.

After passing the transient phase, the vibrator concrete system is stabilized to operate with quasi-stabilized parameters and remains so as long as the vibro generator is operating, which transmits the moving energy to the concrete.

The transmission of energy from the source to the vibrating environment called the vibration field takes place in the form of waves.

The propagation of the waves is attenuated to a limit where the transmitted energy is insufficient to determine changes in the concrete structure.

The disruption produced by the wave at a point in the vibration field produces a compression followed after a certain amount of time by a depression, the wave propagation being translated by a variation of the pressure at the considered point .

The instantaneous pressure of the wave comprises the total pressure at a certain moment at the considered point, which reduces the strict pressure at that point.

III.4 CHARACTERIZATION OF THE WAVING PROCESS

The waving process is characterized by the differential equations of the waves.

III.4.1 Three-dimensional differential equation

According to the fundamental law of Newton's dynamics, taking into account the forces acting on the volume element (figure III.4.1) along the Ox axis.

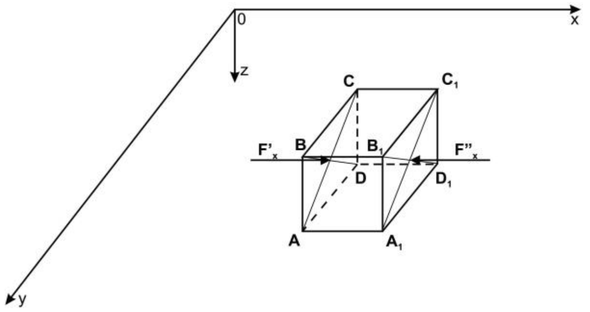

Fig. III.4.1. Scheme of forces on the volume element [10]

The expression of the differential equation of the waves can also be written in another form taking into account that the propagation of the wave is a rotational movement. If the swirl vector is always null at all points of the environment, then to the movement of each point can be assigned a function:

$$\phi = \phi(x, y, z, t) \qquad \text{(III.4.20)}$$

called gear potential, so that

$$v_x = \frac{\partial \emptyset}{\partial x};\ v_y = \frac{\partial \emptyset}{\partial y}; v_z = \frac{\partial \emptyset}{\partial z} \qquad \text{(III.4.21)}$$

III.4.2 The one-dimensional equation of the flat wave

Considering the wave propagation in one direction $v_y = \frac{\partial \emptyset}{\partial y} = 0$ and $v_y = \frac{\partial \emptyset}{\partial y} = 0$and $\emptyset = \emptyset(x, t)$, the relationship (III.4.26) becomes:

$$\frac{\partial^2 \emptyset}{\partial t^2} = C^2 \frac{\partial^2 \emptyset}{\partial x^2} \qquad \text{(III.4.27)}$$

III.4.3 The equation of cylindrical wave

Considering the cylindrical axes system and the dV volume element (Figure III.4.3.) with the following relations:

$$x = rcos\varphi$$
$$y = rsin\varphi$$
$$z = z$$

$V_z = 0$; $\frac{\partial^2 \phi}{\partial z^2} = 0$,respectively, the three-dimensional differential equation (III.4.26) becomes:

$$\frac{\partial^2 \emptyset}{\partial r^2} + \frac{1}{r}\frac{\partial \phi}{\partial r} + \frac{1}{r^2}\frac{\partial^2 \emptyset}{\partial r^2} = \frac{1}{C^2}\frac{\partial^2 \emptyset}{\partial t^2} \qquad \text{(III.4.47)}$$

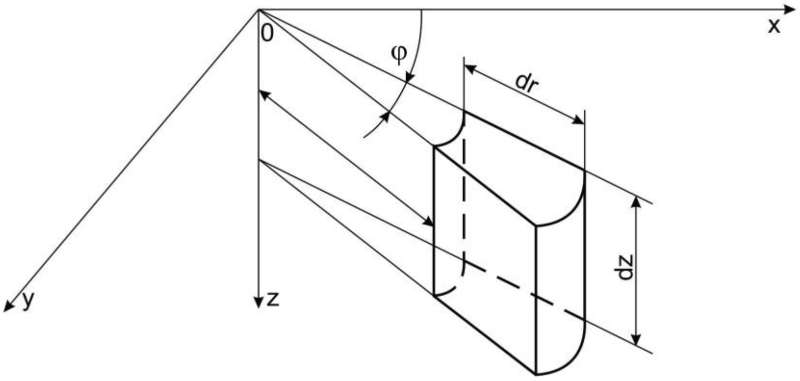

Fig. III.4.3. The volume element in cylindrical coordinates [10]

III.4.4. The equation of spherical wave

Considering the spherical axes system and the volume element dV (fig III.4.4), as well as the equations:

$$x = rsin\theta cos\varphi$$
$$y = rsin\theta sin\varphi$$
$$z = rcos\theta \qquad \text{(III.4.56)}$$

where: θ – polar angle

φ – azimuth

the laplacian takes the forme:

$$\nabla^2\emptyset = \frac{\partial^2\emptyset}{\partial r^2} + \frac{2\partial\phi}{r\partial r} + \frac{1}{r^2 sin\theta}\frac{\partial}{\partial\theta}\left(sin\theta\frac{\partial\phi}{\partial\theta}\right) + \frac{1}{r^2 sin^2\theta}\frac{\partial^2\phi}{\partial\varphi^2}$$

ie. the three-dimensional equation of the spherical wave is: $\frac{\partial^2\emptyset}{\partial t^2} = c^2\left[\frac{\partial^2\emptyset}{\partial r^2} + \frac{2\partial\phi}{r\partial r} + \frac{1}{r^2 sin\theta}\frac{\partial}{\partial\theta}\left(sin\theta\frac{\partial\phi}{\partial\theta}\right) + \frac{1}{r^2 sin^2\theta}\frac{\partial^2\phi}{\partial\varphi^2}\right]$

III.4.5 Propagation equation with dissipation

Since the fresh concrete acts as a viscous friction dissipation environment, the equation of motion$-\frac{\partial p}{\partial x} = \rho_0\frac{\partial v}{\partial t}$ is modified taking into account the proportionality factor of the resistance to η velocity, as follows:

$$-\frac{\partial p}{\partial x} = \rho_0\frac{\partial v}{\partial t} + \eta v \qquad \text{(III.4.68)}$$

The pressure created by the progressive wave is given by the relationship:

$$p_A = -\rho_0 c^2\frac{\partial\xi}{\partial x} = \rho_0 c^2(\alpha + i\beta)A_1 e^{i\omega t}e^{-(\alpha+i\beta)x} \qquad \text{(III.4.78)}$$

and the particle velocity in the wave motion is follows:

$$v_x = \frac{\partial\xi}{\partial t} = i\omega A_1 e^{i\omega t}e^{-(\alpha+i\beta)x} \qquad \text{(III.4.79)}$$

It is stated the fact that wave propagation parameters depend on ω, A_1 and β.

Chapter IV

EXPERIMENTAL DETERMINATIONS FOR ESTABLISHING VIBRATION DURATION BY CONCRETE CLASSES

IV.1 COMPONENT MATERIALS

The composition of concrete and component materials with specified properties or the prescribed composition must be chosen to meet the specific requirements for fresh and hardened concrete [150], including consistency, bulk density, resistance, durability, corrosion protection of embedded steel parts, taking into account the processes of production and the method by which the concrete works are intended to be executed.

The composition of the concrete must be set in such a way as to minimize the phenomena of segregation and separation of water from the fresh concrete.

For concrete, composition specification is limited to:

- natural aggregates of normal density;
- powder supplements as long as that they are not taken into account in the calculation of cement dosage and water/cement ratio;
- the minimum cement dosage ;
- type of cement;
- additives, except for air trainers;
- compositions fulfilling the criteria for initial type tests.

IV.1.1 Choosing cement

The cement must be chosen from those whose usability is established, taking into account:

- the execution technology of the work;
- the final use of the concrete;
- treatment conditions (eg. technical treatment),
- the structure dimensions (the development of hydration heat);
- aggressions of the environment to which the structure is exposed;
- potential reactivity of aggregates to alkali from component materials.

IV.1.2 Use of aggregates

Type, dimensions and aggregate categories, for example, flattening, frost-thaw resistance, abrasion, resistance, fine parts content, etc. must be broken down taking into account:

- the execution technology of the work;
- the final use of the concrete;
- characteristics of the environment to which the concrete will be subjected;
- all requirements for apparent aggregates or aggregates for decorative concrete.

The maximum upper nominal size of the aggregate must be selected taking into account the thickness of the concrete cover of the fittings and the minimum size of the section of the elements.

IV.1.3 Use of additives

The total amount of additives possibly used should not exceed the maximum dosage recommended by the additive manufacturer and must not exceed 50g of additive (in delivery) per kg of cement unless it has been established the influence of a higher dosage over the concrete performance and durability .

Additives used in a lower amount at 2g/kg of cement are allowed only dispersed from the mixing water.

IV.1.4 Concrete execution equipment: mixer and vibratory table

The mixer used is a mixer used in the laboratory and has the following features: 120 liter capacity, engine power 0.6kw/3000rpm.

The vibratory table has the following features: power 1000W, amplitude 3000 rpm, pulse of disruptive force 314 rad/sec, frequency 50Hz.

IV.2. TEST METHODS FOR CHECKING THE QUALITY OF THE CONCRETE

After each batch of concrete, were made the following measurements both on fresh concrete and on stiffed concrete.

Fresh concrete:

- density determination - Annex IV.2.1;
- compaction determination - Annex IV.2.2.

Stiffed concrete:

- determining the density of stiffed concrete - Annex IV.2.3;

- determining the compressive resistance - Annex IV.2.4;
- determining the tensile resistance - Annex IV.2.5;
- determining the depth of pressurized water - Annex IV.2.6.

IV.3. TESTS REQUIRED TO CHECK THE QUALITY OF MINERAL AGGREGATES (natural and/or crushed aggregates):

- granulometry - Annex IV.3.1;
- coefficient of flattening - Annex IV.3.2;
- shape coefficient - Annex IV.3.3;
- sand equivalent - Annex IV.3.4;
- resistance to crushing - micro Deval - Annex IV.3.5;
- wear resistance - Los Angeles - Annex IV.3.6;
- water absorption - Annex IV.3.7;
- abrasion resistance - Annex IV.3.8.

IV.4. TESTS REQUIRED TO CHECK THE QUALITY OF THE CEMENT :

- determining the lead time - IV.4.1 Annex;
- determining the stability - IV.4.2 Annex;
- determining the mechanical resistances - IV.4.3 Annex.

IV.5. DETERMINING THE OPTIMUM DYNAMIC COMPACT DURATION

Determining the optimum vibration duration of dynamic compaction on two concrete classes, namely C30/37 and C45/55.

In order to establish a concrete recipe, several factors have to be taken into account:

- characteristics and resistances of the aggregates used;
- mechanical resistances of concrete;
- fine particle content of concrete, cement, sand and additions if necessary;
- type of used additive .

A concrete must simultaneously meet three categories of requirements:

- workability, in order to be put into work;
- mechanical resistances to withstand mechanical requirements;
- durability, to withstand environmental physical and chemical actions.

The elaboration of a concrete recipe is a complex problem because all the knowledge regarding the properties of the materials and the concrete must be taken into account in connection with the reaction of the concrete constructions.

Determining the optimal duration of vibration was achieved by successive attempts, and namely, the same class of concrete under the same conditions was vibrated at different times. After the maturity of the concrete, the samples taken at different vibration times were tested and the mechanical resistances of the concrete were determined. In Figure IV.5.1, the minimum and maximum points of the curve can be observed, thus the optimal vibration duration and compressive resistance for each concrete class are observed.

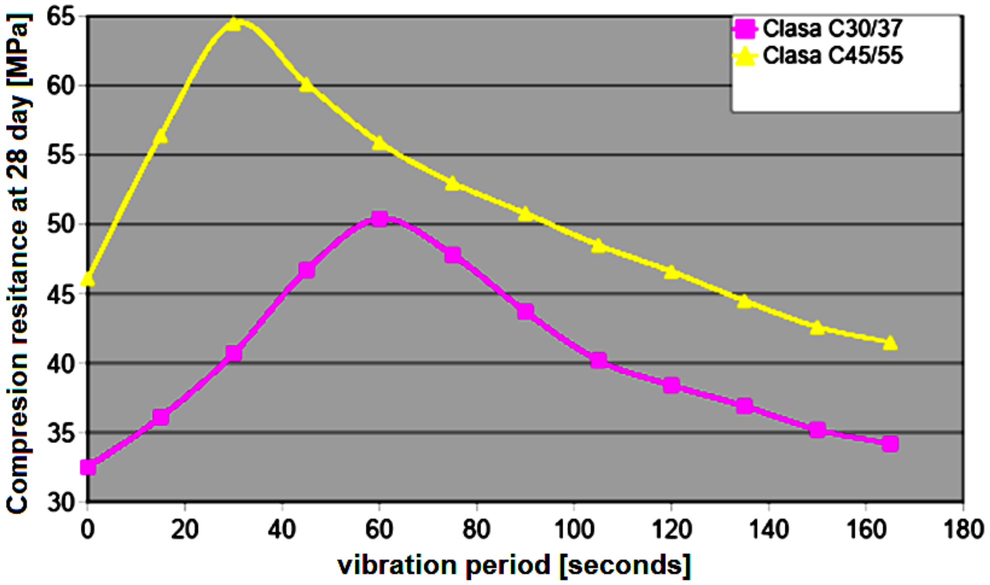

Fig. IV.5.1.Graphic representation of compressive resistances at 28 days on concrete cubes

Conclusions:

The vibration duration below the optimum time value results in low values of the stiffed concrete resistance and the vibration times much higher than the optimal duration can lead to compromising the achieved concrete, ie. the decrease of the resistances and, therefore, the segregation by overcompaction.

IV.6. DETERMINING THE OPTIMUM MIXING DURATION IN RELATION TO THE OPTIMAL VIBRATION DURATION

Determining the optimum mixing duration was achieved by successive tests, ie. the same class of concrete achieved in the same conditions was mixed at different times and the concrete cubes achieved at the optimum vibration. After achieving the maturity of the concrete, samples were taken at different mixing times and vibrated at optimum vibration time, and mechanical resistances of the concrete were determined. In Figures IV.6.1, IV.6.2 and IV.6.3, the minimum and maximum points of the curve can be observed, therefore the optimal mixing time for each class is observed.

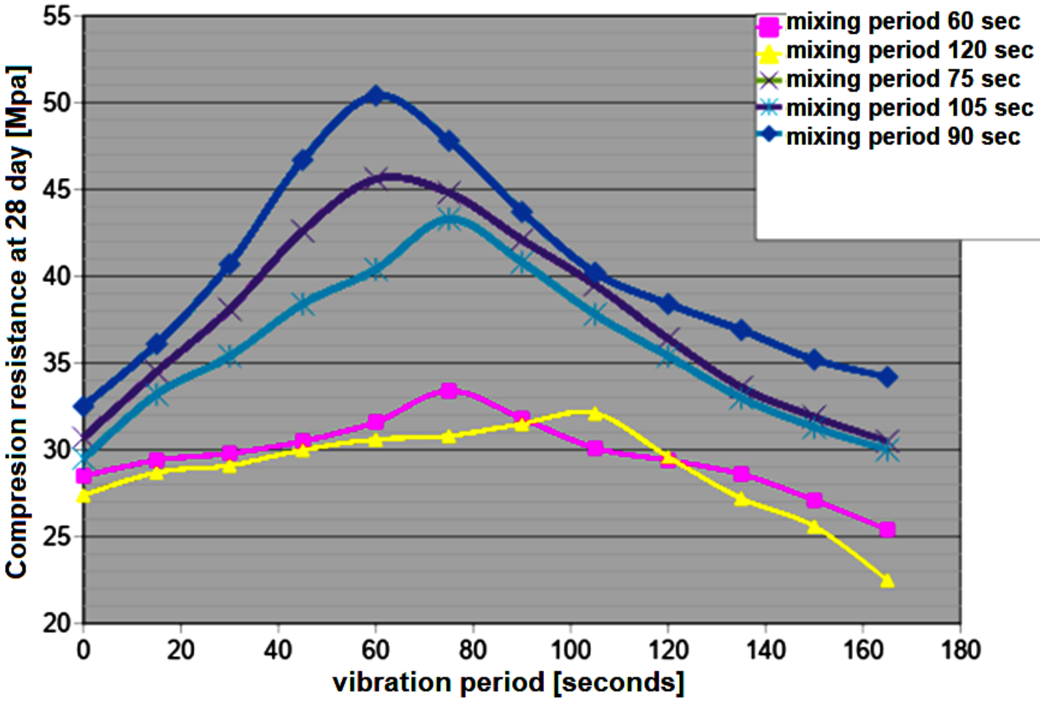

Fig. IV.6.1. Graphic representation of compressive resistances at 28 days on C30/37 concrete cubes

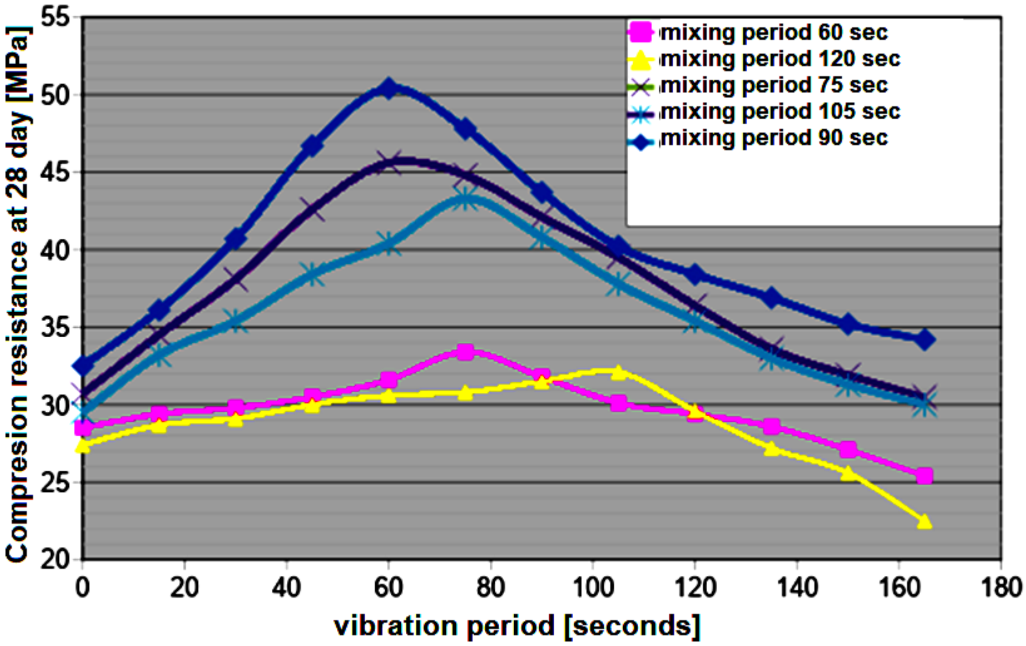

Fig. IV.6.2. Graphic representation of compressive resistances at 28 days on C45/55 concrete cubes

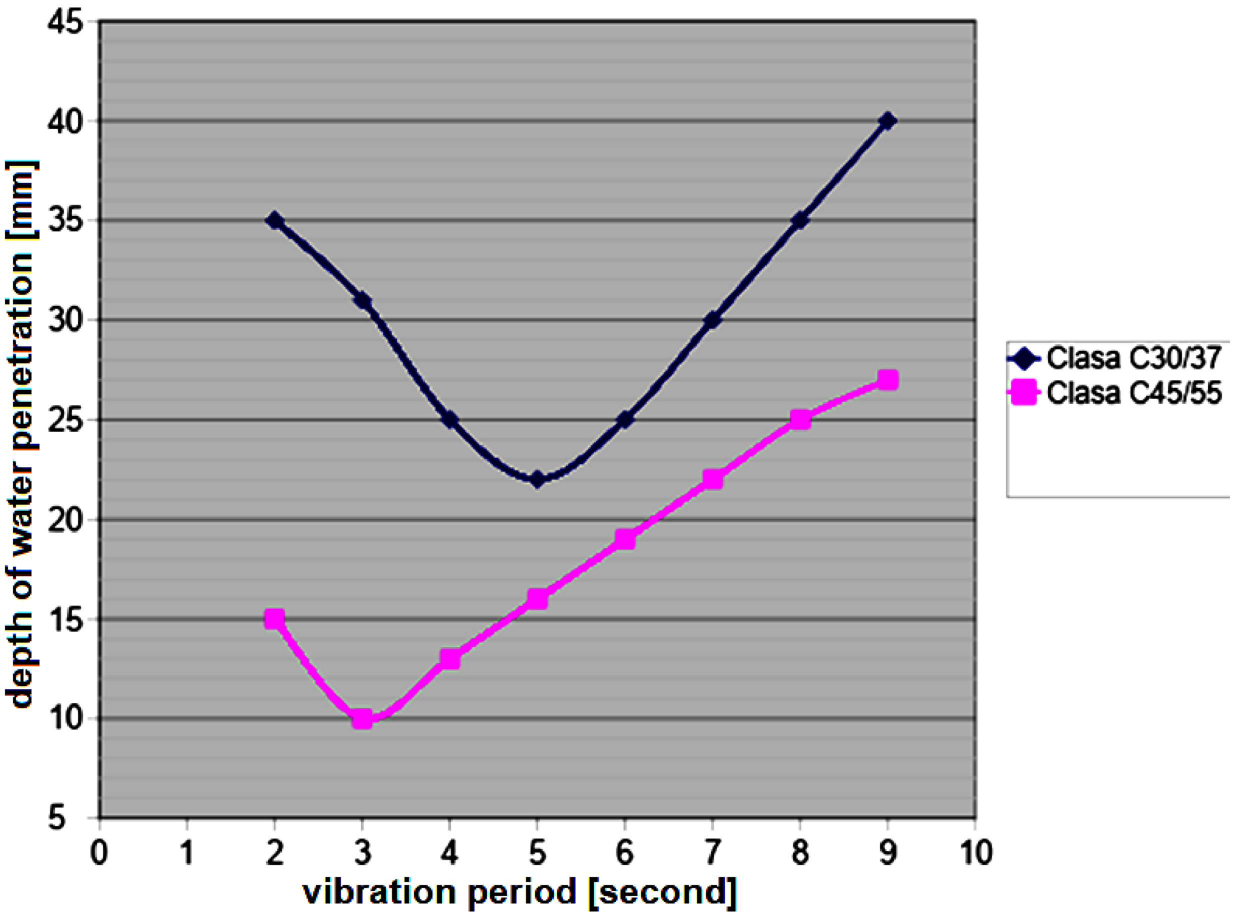

Fig. IV.6.3. Graphical representation of water penetration depth in concrete cubes

Conclusions:

The optimum duration of mixing for vibration in an optimal period can be characterized as follows:

- shorter mixing period than an optimal mixing one implies reaching a compressive resistance lower than the optimal resistance;
- the mixing duration whose values exceed the optimum mixing duration results in values of the resistance that are on a decreasing branch of the curve shown in Figures IV.6.1. and IV.6.2.

Chapter V

CONCLUSIONS. PERSONAL CONTRIBUTIONS

The results of the researches that are synthesized in the thesis can be highlighted by rheological methods and models of fresh concrete in the vibration process. The set of partial conclusions corresponding to each phase of the thesis provides the basis of the general conclusions in correlation with the requirements imposed by the initial objectives of the thesis, which can be synthesized as follows:

- ➢ Analysis of the influence of components from the structure of concrete recipes: aggregates, cement, water, additives, additions.

- ➢ Characterization of macroscopic and microscopic processes of concrete, in vibration regime, by the following physical quantities:
- stiffness;
- dynamic viscosity;
- internal energy dissipation;
- rheological parameters.
- ➢ Characterization of fresh concrete in the vibration process can be structured as follows:
- parameterisation of the wave process, ie. propagation of the longitudinal and transverse (weak) waves of the superficial layer;
- parameterization of the compacting process in the concrete mass in order to reduce the volume of the ovoid air and reduce the water in the concrete.
- ➢ Establishing the energy methods specific to the fresh concrete vibration compacting process as follows:
- modelling the concrete mass system compaction surface in the form of Kelvin, Maxwell and Newton diagramming;
- adoption of the two-mass system with a viscous link between them based on the Newton model with harmonic rotating inertial excitation of the $F(t) = m_0 r\omega^2 sin\omega t$ form;
- formulation of differential motion equations in stationary forced vibration regime;
- establishing and verifying the vibration energy established both on the Wd energy function in relatio to ω which must be in accordance with the area bounded by the hysteresis loop in the shape of an ellipse.
- ➢ Establishment of experimental methods and procedures for verifying optimum vibration characteristics, exposure to vibration regime and the duration of mixing of fresh concrete. Thus, the following were substantiated:
- determining the optimal duration of vibration by exposing the fresh concrete within the compacting process to a stable dynamic regime, ie. to ω = 314 rad/sec (3000 rpm) and the vibration amplitude of 0.5mm with a disrupting force corresponding to $F(t) = m_0 r\omega^2 sin\omega t$ value. Consequently, as a result of the experiments, the optimum vibration duration was obtained as a characteristic of the concrete mixture as follows:
- ● the law of variation of the energy dissipated in stationary vibration regime for the compaction process;
- ● the maximum energy dissipated by the correlation of the excitation pulse with the concrete mass and the viscous energy dissipation constant;
- ● lifting hysterical loops according to the A_1 vibration parameters, ω and m_2 mass and the c damping constant of the fresh concrete
- ● determining the optimum mixing time for a vibrated concrete mix at the optimum vibration time.
- ➢ The curves partly obtained for each experimental stage apart both for mixing and vibration are characterized by an optimum of the concrete resistance at compresion corresponding to a suitable duration;
- ➢ Maximum values of compressive resistances of stiffed concrete at vibration times and mixing, resulting from the laws of fresh concrete reaction in the vibration process when the optimal mixing time has been set.

V.1. PERSONAL CONTRIBUTIONS

The results of the researches carried out as well as the innovative technical solutions adopted can be made in relevant contributions of the author of the present PhD thesis as follows:

- rheological modelling of the compacting process of the fresh concrete;
- establishing the vibration parameters expressed by the amplitude of the concrete mass, the amplitude of the vibrating pattern, the maximum force transmitted to the concrete;
- establishing the dissipative energy in relation to the ω pulse, the concrete mass and the viscous damping coefficient of the concrete;
- establishing the hysteretic curve equations in the form of ellipses parameterized by ω pulse to ω_1, ω_2, ω_3 discrete values and drawing the hysteretic Q-x curves ;
- optimization of mixing and vibrating times to achieve maximum resistances of the stiffed concrete after 28 days, both on experimental basis and on the basis of theoretical results achieved by the adopted modelling.

V.2. FUTURE RESEARCH DIRECTIONS

Future research directions take into account the objectives and results of this thesis by the fact that the obtained results provide the basis of a future development of new widespread deployment methods of fresh concrete vibration compacting process when putting into work.

In this respect, we suggest the following main directions for the further research, namely:

- establishing the parametric correlation methods of the transfer functions between the virtual and the real system;
- designing and developing of efficient vibration systems for the obtaining of concrete elements without the risk of segregation;
- designing and obtaining a Vibration Generating System with variable parameters (amplitude, frequency) that will be designed to be able to transmit punctual vibrations, vibrations distributed on the surface, as well as vibrations distributed in the concrete volume in the form of elastic waves;
- designing and obtaining an instrumental and computer system for real time control and regulation of the vibration parameters and the response parameters that characterize the rheological reaction of the fresh printed concrete during the compaction process;
- obtaining, in a modular design, of vibratory table systems, vibrant print stands with variable vibration regime over which is located the pattern of the concrete element;
- designing and obtaining variants of recipes (minimum 5) by modifying the microstructural composition and by nonlinear rheological modelling of the fresh concrete with the possibility of monitoring the dynamic stiffness and the viscous analysis coefficient according to the vibration field, the excitation and the evolution of the porosity;
- increasing the degree of dynamic compaction of concrete with influences favorable to parametric measurement, structure formation, reduction of porosity and permeability to water and gas and increasing of concrete resistances.

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