CONCRETE QUALITY VERSUS MIXING TIME

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The purpose of this experimental research was to consider the efficiency of the mixer through the analysis and subsequent evaluation of the homogeneity of the produced mixes.

To this end, a mix has been defined "homogeneous" when all its components have resulted to be fully mixed together, thus originating a concentrated mix in which every considered portion has proved almost equal to the others.

With a view to verifying such a condition, the procedure applied in the ambit of an appropriate testing, was to draw a few samples of mix soon after mixing, articulating the drawings in order to intercept five distinct and significant points of every mix under consideration.

Then, the considered portions have been equally distributed between the beginning and the end of the mixer outlet.

It is opportune to state that mixes of about 0.6 cu.m were employed and that the drawing of the various portions of mix took place on the conveyor belt transporting the mix to the block-making machine.

The checking of the composition of the fresh concrete has been carried out following the methodology provided for by the UNI-6393 specifications and acting on samples of 3 to 4 kg approx.

Soon after their drawing, the samples of fresh mix have been introduced in appropriate containers in which - after adding denatured alcohol - the disaggregation of the mix and the dispersion of the elements composing it has been carried out through a vigorous and prolonged shaking.

The granulometric analysis of the obtained dry residue was executed after sedimentation of the solid part, recovery of the water-alcohol solution and subsequent drying in a thermostatic stove.

The various stages of batching and introduction of the various components as well as the mixing time result to be articulated as follows:-

1) Batching of the different granulometric classes in 25 seconds, and with mixer in operation;
2) Addition of the cement starting 10 seconds after the end of the introduction of the aggregates;
3) Addition of the water in the mix 15 seconds after ending the introduction of the cement;
4) Mixing time (calculated from the end of the water introduction) corresponding to 45 seconds.
5) Total time of the mixer operation and consequently total duration of the time of batching, mixing and discharge of the concrete: 120 seconds.

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The mix which has been used for the present test results to be composed as follows:-

- Natural Sand 0/7 .....:	385 kg
- Quarry Sand 0/5 .....:	385 kg
- Chips 3/10 .....:	330 kg
- Cement .....:	270 kg
- Added water .....:	61 lts.
Total for every mix	1431 kg

During the mixer feeding stage, various samples were drawn from every fraction employed. These samples, duly mixed and devided into quarters, have constituted the sample used for the granulometric analyses.

The results of these analyses can be summarized in the following way: (FIG. No. 1).

As mentioned, every sample of dry mix out of the considered five, has been submitted to granulometric analysis obtaining the following values: (FIG. No. 2).

The subsequent processing of the data obtained from each screening (processing executed through the calculation of the Average Value, Average Quadratic Discard and Coefficient of Variation), can provide useful elements of judgement about the homogeneity of the drawn samples and, consequently, the efficiency of the ways and methods used to produce concrete mixes with the Contra-Flow type Planetary Mixer.

The same experiment has been carried out with another model of mixer, a Two-Horizontal-Shaft Mixer, with a view to obtaining further information on the validity of the selected checking method as well as on the homogeneity of the mixes obtained.

For a better interpretation of the results, the same recipe of the previous test has been used, repeating, however, the granulometric analyses of the employed fractions at the time of the new test.

The results of these analyses can be summarized as follows: (FIG. No. 3 - FIG. No. 4).

The comparison of the two experiences leads, therefore, to the conclusion that the second mixer, for its characteristics, is less reliable than the former one since the dispersion of the data results to be about three times larger.

In order to complete the research, a test has been carried out to ascertain the capacity of the two-horizontal-shaft mixer to disperd the binder homogeneously using a mix only composed with 0/7 mm sand and cement.

Proceeding with the same operative modalities, the following results have been obtained: (FIG. No. 5).

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From the examination of the three experiences mentioned hereby, it is evident that for any type of mixer, the greatest difficulty is represented by the capacity of distributing the finer fractions in an homogeneous way.

As a matter of fact, in all the examined cases, the Coefficient of Variation trends to increase as such fractions are analysed.

It is therefore correct to think that the addition of filler and/or pigments can represent further causes of heterogeneity inside the same mix and that, consequently, the small elements produced can show such differences.

From the present report, it is evident that the role of the mixer has a remarkable importance for the preparation of homogeneous mixes, above all, for the production of small concrete elements.

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Now, let us analyse the effects of vibration on the machine production rhythm, as well as on the mechanical and dimensional characteristics of the paving units.

All block-making machines avail of vibration, generally associated with a mechanical compression, as essential way for getting the compactness of concrete. Obviously, the best vibration is the one allowing the production of paving units of homogeneous quality in every point of the mould in the shortest possible time.

The quality of an interlocking paving unit is determined by the mechanical resistance, precision in dimensions, as well as by the degree of absorption and density. These parameters have been prescribed in Italy by the PAVITALIA Specifications.

Therefore, in order to optimize a paving unit, it is necessary to intervene on a few vibration parameters. This can be done during planning, if the block-making machine is only destined to the production of interlocking paving units, or - in case of block-making machines used to manufacture different types of products - by arranging appropriate devices enabling to vary these parameters continuously.

First of all, we will give a definition of these parameters and subsequently we will explain the influence of these parameters on the concrete reaction.

To explain these influences, we will avail ourselves of the results of a research carried out by CERIB (French Centre of Studies and Research in the Industry of Concrete).

A vibration is characterized by the following parameters: direction, frequency, amplitude, speed and acceleration.

DIRECTION

It is possible to have different directions of vibration in compliance with the types and applications of the vibrators in various arrangements. We will take into consideration the vertical unidirectional vibration. It is the most frequent case, as far as the European stationary block-making machines are concerned.

The method consists in rotating, in the opposite direction, 2 eccentric masses fitted on two parallel shafts. The rotation is synchronized by two gears.

The components of the horizontal centrifugal forces neutralize each other, whilst the components of the vertical centrifugal forces sum up (FIG. No. 6).

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Its change in the time is sinusoidal (FIG. No.6). It is comprehensible that a vertical vibration can be better transmitted inside the concrete, owing to the gravity effect which acts on the aggregates and grains of cement. In addition, a vertical vibration facilitates the concrete sliding on the vertical walls of the mould.

FREQUENCY

The frequency "f" of a vibration is given by the number of cycles per second and is indicated in Hertz. The frequencies of vibration utilized for the most recent block-making machines vary between 50 and 85 Hz.

AMPLITUDE

The amplitude of a vibration is given by the total displacement of one point around its position of equilibrium. The amplitude of a harmonic vibration is a sinusoidal function of the time and it can be indicated as follows:

$$x = X_{max} \cdot \sin \omega t \qquad (1)$$

SPEED

The speed of a vibration represents the speed of displacement for a harmonic vibration and it is sinusoidal in the time.

$$v = \frac{dx}{dt} = \omega \cdot X_{max} \cdot \sin\left(\omega t + \frac{\pi}{2}\right) \qquad \text{where} \qquad (2)$$

$$V_{max} = \omega \cdot X_{max} \qquad \omega = 2\pi f \qquad \text{hence} \qquad V_{max} = 6.28 f X_{max}$$

For instance :
a vibration having f = 50 Hz. and X max.= 2 mm. has a speed of 0,63 m/sec.

ACCELERATION

The acceleration of a harmonic vibration is : $a = A_{max} \cdot \sin(\omega t + \pi)$

$$\text{where} \quad A_{max} = \omega^2 \cdot X_{max} = 39.5 \cdot f^2 \cdot X_{max} \qquad (3)$$

The acceleration makes it possible to characterize the efficiency of a vibration, above all in relation to the forces to be brought into action for creating said vibration.

cont'd

We can represent these three parameters in Figure No. 7.

The three parameters are interdependent each other.
We can represent them in a Figure No.8.

The dashed area represents the field in which are included the characteristics of the vibrations utilized to manufacture paving units with the block-making machines.

In the right lower part of the dashed area, the parameters in question take optimum values for the production of paving units; acceleration values between 15 and 20 g.; frequency values included between 70-85 Hz; oscillation included between 0,5 - 0,8 mm. On the contrary, the normal values for the production of blocks usually are: acceleration 10-13 g.; frequency between 50-60 Hz. and total amplitude between 2-3 mm.

DURATION

The settling of concrete submitted to vibration is connected with the duration of application of the vibration itself. A vibration time of 5-7 sec. during pressing has proved to be the most favourable to obtain paving units with excellent resistance. The resistance ends to increase with an asymptotic flow when the vibration time rises over 7 sec.

cont'd

Now, reference is made to the experimental tests carried out by CERIB concerning the influence on concrete of amplitude, speed, frequency and acceleration.

Figure No. 9 illustrates the concrete settling in function of time, for vibrations of identical amplitude, but with variable frequency, speed and acceleration.

It can be noticed that during the first 3 sec. of vibration, the distribution bendings are indistinct. The amplitude is therefore the essential parameter during this initial stage in which the distribution takes place thanks to the agitation of the coarse grains of concrete.

Figure No.10 , in which settling is carried out through vibrations with constant speed, shows that after a settling of 15 mm. approx. and up to 40 mm., the settling progression is identical (parallel bendings in this area).

The speed of vibration is therefore an essential parameter of this second stage of settling, which corresponds to a viscous behaviour of the concrete: there is a sliding of the cement paste or of the thin mortar among the coarse grains.

Figure No.11 shows that the last stage of settling is connected with the acceleration of vibration, because the bendings with constant acceleration are remarkably parallel in this area.

In the case of this final stage, there is an agitation of the concrete in its whole, which causes a liquefaction and allows the completion of settling.

This theory of the concrete compaction under vibration demonstrates that:

- at the beginning of vibration, we have the agitation of the large particles, and the reaction of concrete is like a spring; the essential parameter is thus the amplitude, since for a spring the strength necessary for its compression is proportional to amplitude.

- in a second stage, there is a viscous sliding and the concrete reacts like a shock absorber; the essential parameter - in this case - is the speed, as the strength necessary for the compression of such an element is proportional to the speed.

- in the final stage there is a liquefaction of the concrete,which has the same behaviour of a mass; the essential parameter is therefore the acceleration, since to put a mass into movement, the strength is proportional to acceleration.

The application of this theory to the production of paving units, enables us to think that, keeping into account the production rhythms for which it is a must to have short vibration times, the amplitude is the main parameter, in spite of the fact that the speed is also important to keep the vibration times within 4 to 5 sec.

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It is then necessary to establish the optimum value of the vibration amplitude and its frequency.

The results of tests carried out on newly-made products having different heights lead to a first answer. (FIG. No. 12 - FIG. No. 13).

This can be confirmed with two comments regarding the technological problems that can arise to produce this optimum vibration :

- From one side, it is necessary to establish a limit for acceleration, because the forces to be brought into action to produce and transmit vibration are directly proportional to the acceleration.
  The practice teaches that it is not convenient to exceed 15/20 g

- From the other side, the amplitude must be limited if one wishes to obtain a good precision in the thickness of products in case of vertical vibration.
  The practice demonstrates that it is necessary not to exceed 1,5 mm. (i.e. 3 mm total displacement) for the production of elements having a height of 15 to 25 cm, while it is necessary not to surpass 0,75 mm (in other words 1,5 mm total displacement), when producing the paving units.

Examining the Figure No. 4 and keeping into account the above comments, we come to the conclusion that a frequency around 50 Hz. seems to be optimum for blocks, whereas a frequency of 80 Hz. approx. is optimum for interlocking paving units.

Evidently, this conclusion is very important with regard to the possible technology for the production of vibration.

2) TECHNOLOGY OF VIBRATION FOR BLOCK-MAKING MACHINES

The choice of the best system for vibration to be used for block-making machines obviously has to keep into consideration the previous mentioned conclusions. Nevertheless, such a choice is related to the technology utilized, which must satisfactorily fulfill the following conditions:

- the characteristics of the vibration transmitted to the mould and consequently to the concrete must be identical in every point. This to guarantee a production of uniform quality, whatever the arrangement of paving units in the mould may be.
  Therefore, the mechanical components and the moulds must be as much rigid as possible and the higher the vibration frequency is, the more these parts should be rigid.
  This condition becomes difficult to be met as much as the vibrating tables or moulds become larger.

- the characteristics of vibration must be constant in the time and renewable from a cycle to the other.

- the forces to be brought into action for making and transmitting vibration are directly proportional to the mass of the mechanical components; these therefore must be lightened, however avoiding to alter their rigidity and duration which should be maintained at the highest possible levels.

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The technology which better matches these conditions facing the conclusions on the vibration paramenters, is the vertical unidirectional vibration produced by a single vibrating plate, to which a vibrator with counter-rotating masses or a few vibrators synchronized among them can be fitted (FIG.14).

The vibrators in line, two by two, have the main shafts coupled between them by means of a flexible coupling of appropriate dimensions. The masses thus coupled are subject to synchronized rotation.

The motor and the vibrator are coupled together by means of "V"-belts or Cardan joints.

The manufacturer of paving units has no need to vary the parameters of vibration according to the elements he intends to produce, because the paving units require an operation within a narrow band, which can be adjusted acting on an electronically-controlled, frequency converter.

Just to give an example, for having first-class quality paving units, besides the already mentioned mechanical features, it will be necessary to have an operative frequency around 80 Hz. The max. acceleration is 20 g; let us verify the amplitude :

$$A_{max} = 4\pi^2 f^2 X_{max} \quad \text{hence}$$

$$X_{max} = \frac{A_{max}}{4\pi^2 f^2} = \frac{20 \cdot 9{,}81}{3{,}95 \cdot 80^2} = 0{,}00077\ m = 0{,}77\ mm$$

in other words within the dashed section shown on FIG. 8.

cont'd

The results of the experimental tests have pointed out that a block-making machine with vertical vibration, in order to produce exclusively paving units, must meet the following requirements :

1) An acceleration included between 15 to 20 g.

2) Only one rigid vibrating plate on which more vibrators synchronized among them are fitted.

3) A frequency around 80 Hz.
With this value, the total oscillation does not exceed the amplitude of 1,5 mm, so that the mould remains rigidly pressed on the pallet and consequently on the vibrating plate, making in such a way these three elements solidly united among them.
So the vibration is transmitted homogeneously in every point of the mould.

4) An adequate connection among mould, pallet and vibrating plate avoids, moreover, the passage of material under the mould which is the cause of the formation of flashes at the base of the paving units; above all it avoids the differences in weight among paving units of the same stripping.
For pressing the mould on the vibrating plate, special pads are used, the pressure of which can be adjusted according to the type of mould;
otherwise some compressed air puffers are employed, the rigidity of which may be changed by intervening on the pressure value of the compressed air circuit.

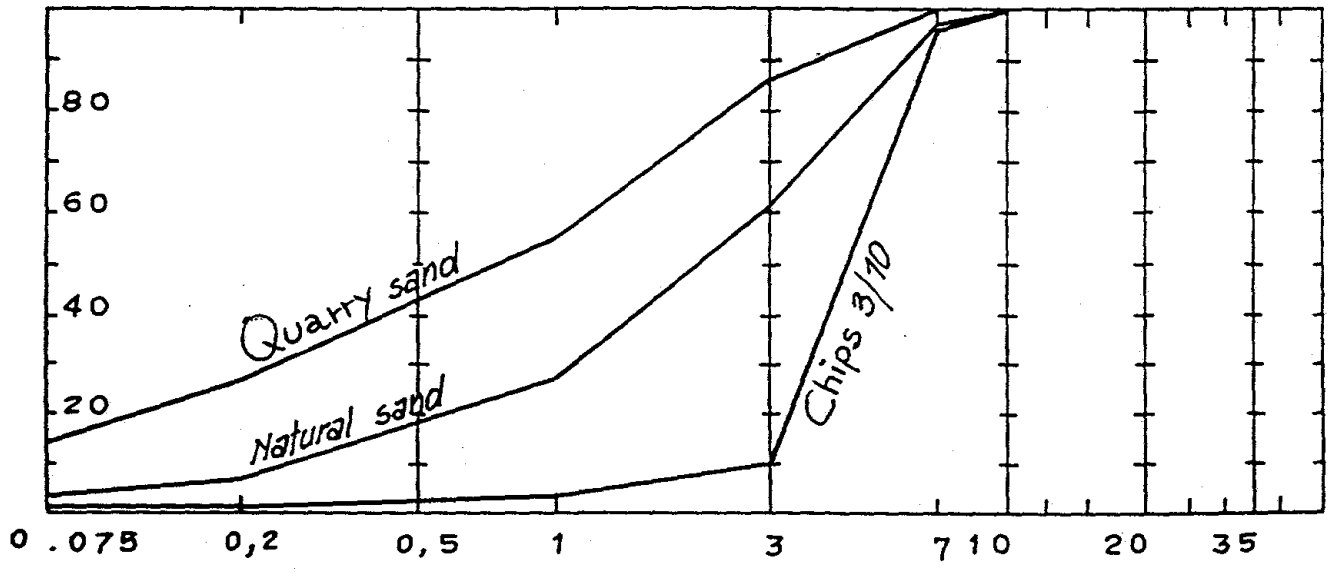
5) The mould must be obtained from a solid steel plate with the LASER cutting method, thus reaching the max. rigidity.

6) To strictly keep the dimensions of the paving unit, it is advisable to make use of plasticized pallets, which maintain their thickness unchanged even after many operations.

WEIGHT CUMULATIVE PERCENTAGE OF UNDERSIZE

UNI SCREENS mm		10	7	5	3	1	0.5	0.2
NATURAL SAND	:	100.00	97.19	85.21	62.38	27.57	18.22	6.86
QUARRY SAND	:	100.00	100.00	99.92	87.01	54.79	43.85	26.67
CHIPS	:	100.00	95.73	47.99	9.19	4.14	2.71	1.29

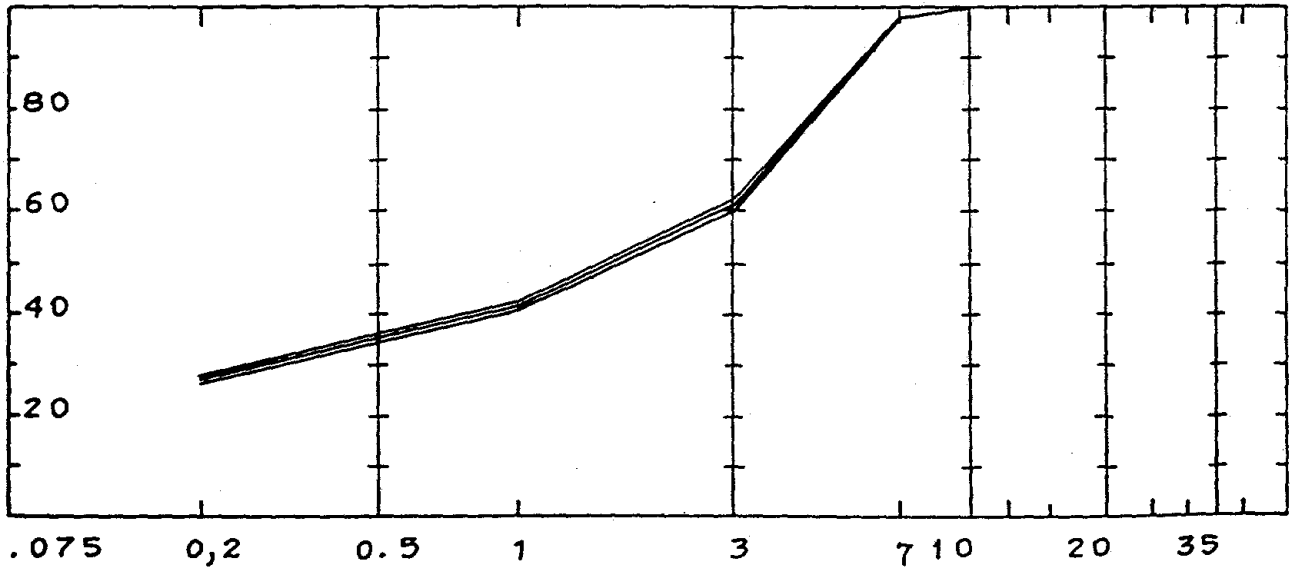
Graph of the Granulometries of the aggregates employed in the experimental mix prepared with a Contra-Flow type Planetary mixer



WEIGHT CUMULATIVE PERCENTAGE OF UNDERSIZE

UNI SCREENS mm		10	7	5	3	1	0.5	0.2
1st sample	:	100	97.75	80.89	61.49	42.06	35.73	28.25
2nd sample	:	100	98.03	81.26	61.79	41.95	35.69	27.86
3rd sample	:	100	98.10	81.08	61.77	41.72	35.31	27.98
4th sample	:	100	97.78	81.57	62.18	42.35	35.97	28.31
5th sample	:	100	98.02	80.91	61.09	41.26	34.78	26.99
Average value	:	/	97.94	81.14	61.66	41.87	35.50	27.88
Average quadratic discard	:	/	0.16	0.28	0.40	0.41	0.46	0.53
Coefficient of variation	:	/	0.16%	0.35%	0.65%	0.98%	1.31%	1.90%

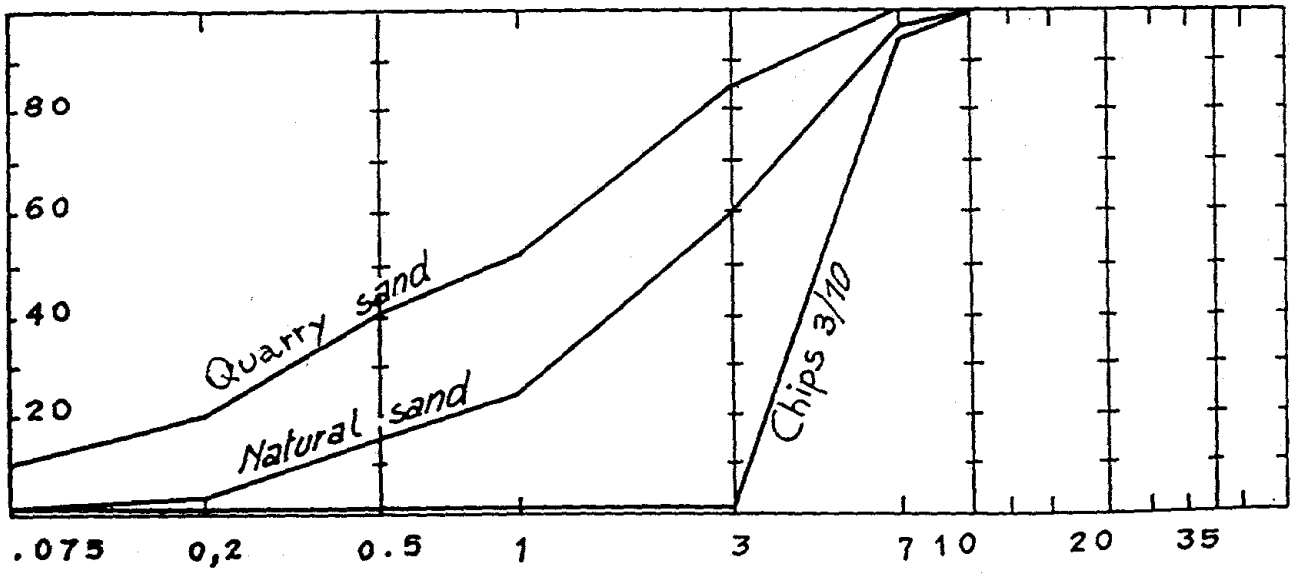
Graph of the Granulometric variable ascertained in five samples drawn, in different points, from the same mix obtained with a contra-flow type planetary mixer



WEIGHT CUMULATIVE PERCENTAGE OF UNDERSIZE

UNI SCREENS mm		10	7	5	3	1	0.5	0.2
NATURAL SAND	:	100.00	97.30	83.80	59.38	24.29	14.71	4.05
QUARRY SAND	:	100.00	100.00	99.93	84.81	52.14	41.16	20.47
CHIPS	:	100.00	93.51	34.18	0.96	0.82	0.75	0.65

Graph of the Granulometries of the aggregates employed in the experimental mix prepared with "2.AO" Concrete Mixer

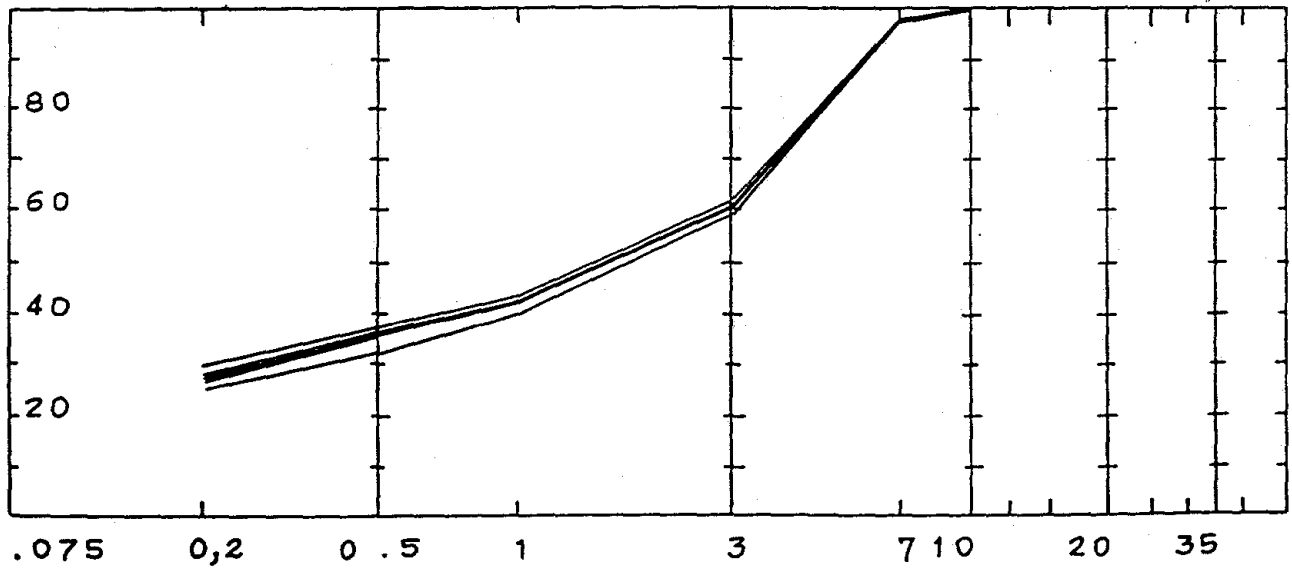


ANALYSIS OF THE RESULTS OBTAINED WITH TWO-HORIZONTAL-SHAFT CONCRETE MIXER

WEIGHT CUMULATIVE PERCENTAGE OF UNDERSIZE

UNI SCREENS mm		10	7	5	3	1	0.5	0.2
1st sample	:	100	97.44	79.02	59.47	39.99	32.16	24.66
2nd sample	:	100	97.49	80.36	61.13	41.55	35.73	27.03
3rd sample	:	100	97.51	79.57	60.57	41.69	35.63	27.88
4th sample	:	100	97.54	80.90	62.33	43.10	37.23	29.87
5th sample	:	100	97.46	80.14	60.77	41.96	35.94	27.69
Average value	:	/	97.49	80.00	60.85	41.66	35.34	27.43
Average quadratic discard	:	/	0.04	0.73	1.03	1.11	1.89	1.87
Coefficient of variation	:	/	0.04%	0.91%	1.70%	2.67%	5.35%	6.83%

Graph of the Granulometric variable ascertained in five samples drawn, in different points, from the same mix obtained with 2.AO concrete mixer



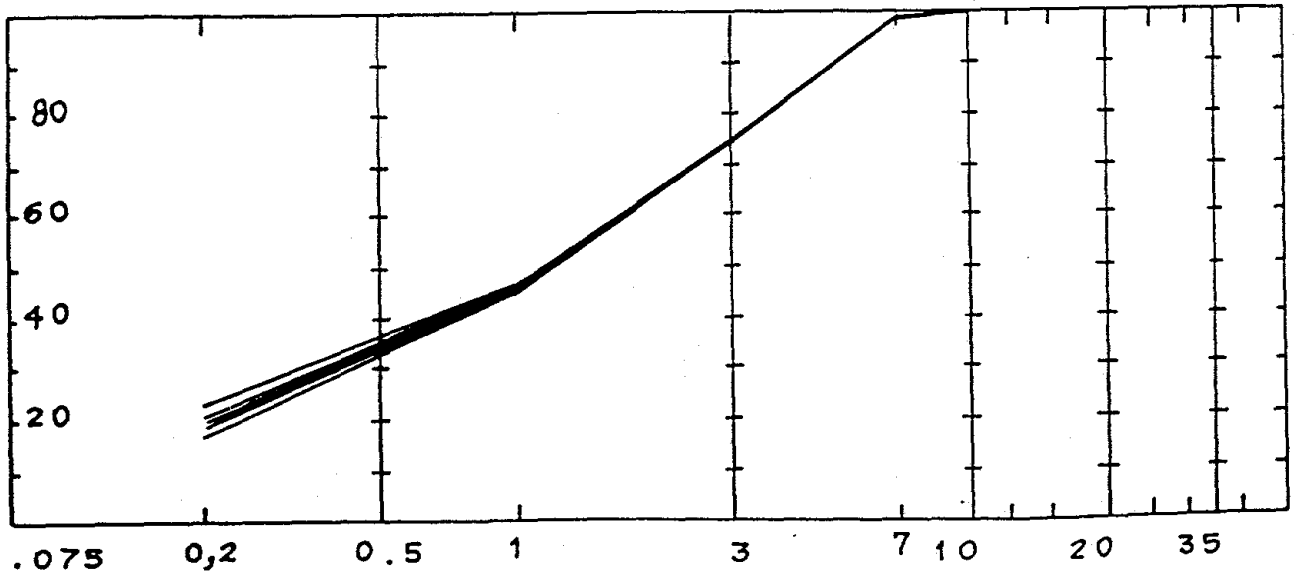
ANALYSIS OF THE RESULTS OBTAINED WITH TWO-HORIZONTAL-SHAFT CONCRETE MIXER

MODEL "2.AO" -- SECOND TEST

WEIGHT CUMULATIVE PERCENTAGE OF UNDERSIZE

UNI SCREENS mm		10	7	5	3	1	0.5	0.2
1st sample	:	100	99.11	91.80	75.42	45.23	34.32	20.76
2nd sample	:	100	98.99	91.15	74.58	45.70	33.81	19.41
3rd sample	:	100	99.00	90.44	73.80	45.28	33.23	17.07
4th sample	:	100	99.03	91.02	74.77	46.46	36.26	22.95
5th sample	:	100	98.94	91.21	74.77	45.98	33.71	20.29
Average value	:	/	99.01	91.12	74.67	45.73	34.27	20.10
Average quadratic discard	:	/	0.06	0.49	0.58	0.51	1.18	2.14
Coefficient of variation	:	/	0.06%	0.53%	0.78%	1.12%	3.44%	10.63%

Graph of the Granulometric variable ascertained in five samples drawn, in different points, from the same mix obtained with a 2.AO concrete mixer



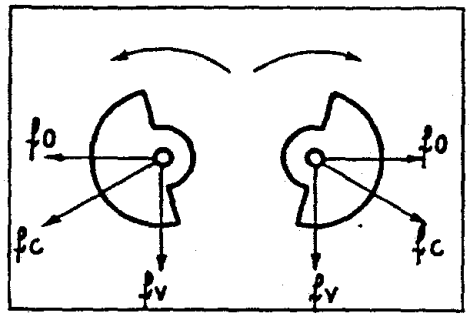


Fig. 6

(1) $x = X_{max} \sin \omega t$

(2) $v = \frac{dx}{dt} = \omega X_{max} \sin\left(\omega t + \frac{\pi}{2}\right)$ where

$V_{max} = \omega X_{max}$ $\omega = 2\pi f$ therefore

$V_{max} = 6{,}28\, f X_{max}$

(3) $a = A_{max} \sin(\omega t + \pi)$ where

$A_{max} = \omega^2 X_{max} = 39{,}5\, f^2 X_{max}$

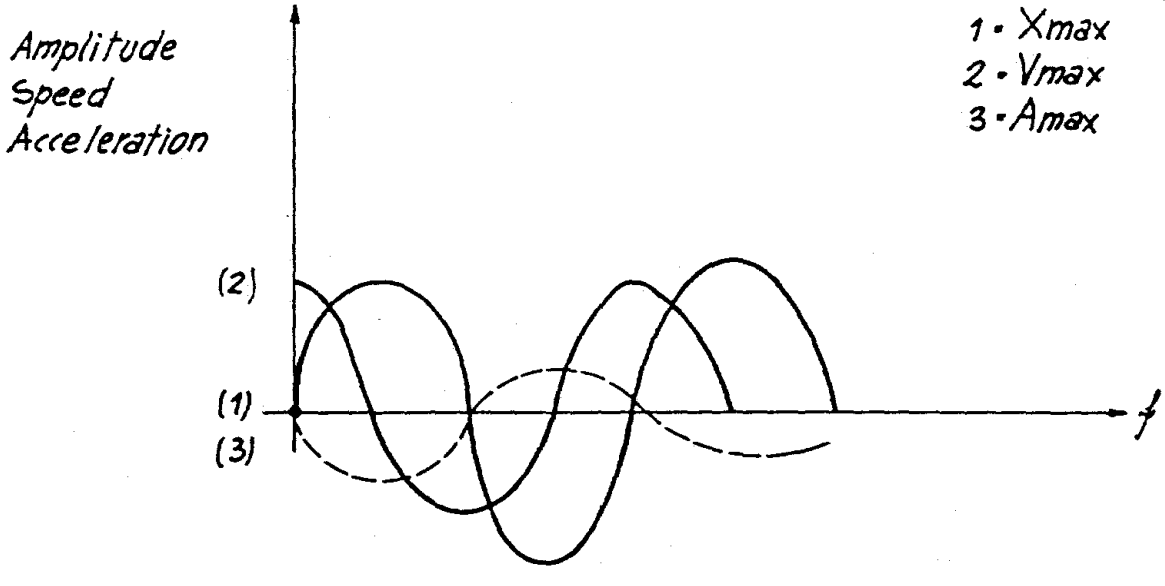
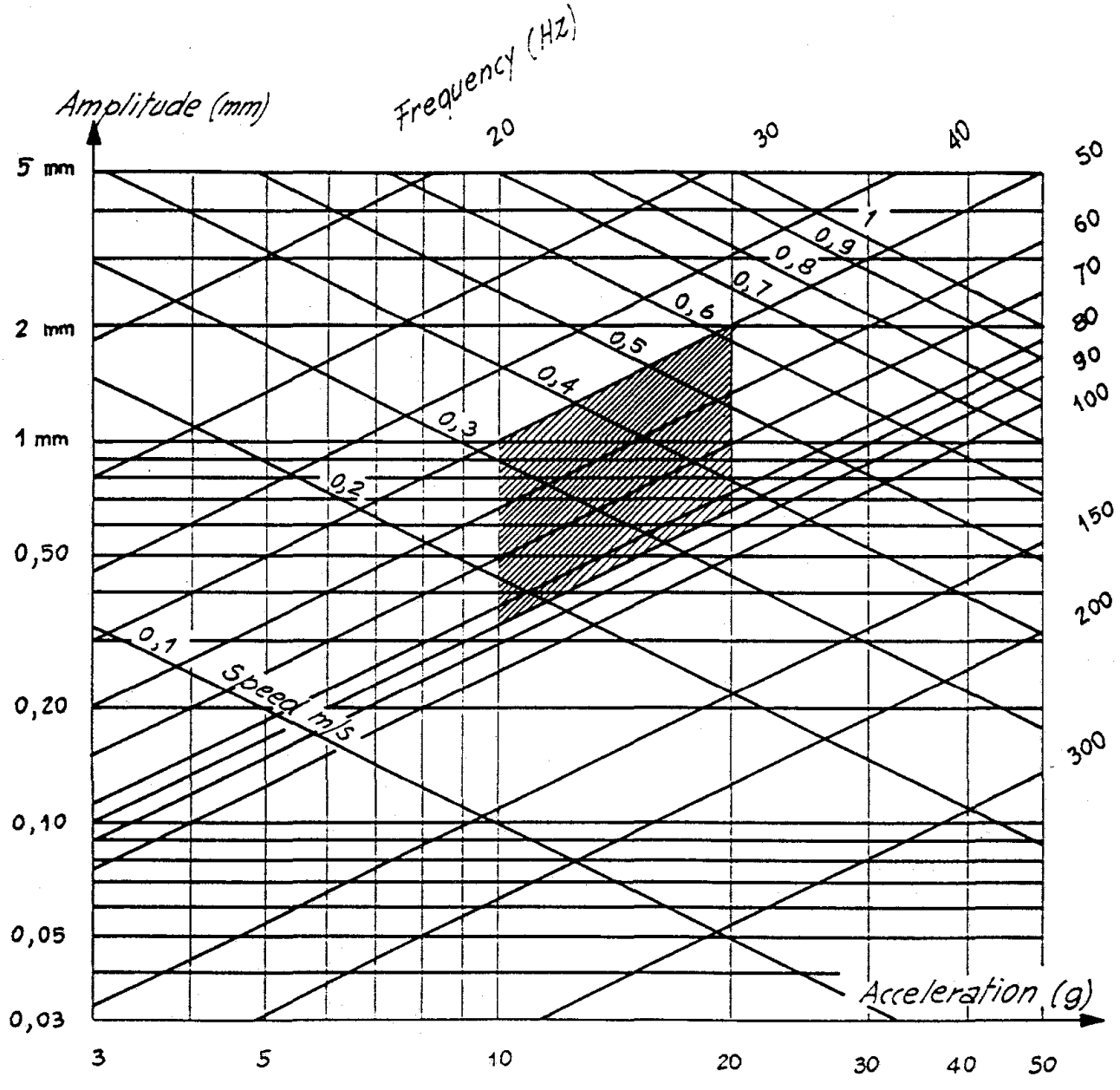


Fig. 7

FIGURE No. 8


Amplitude (mm)
Frequency (HZ)
20
30
40
5 mm
2 mm
1 mm
0,50
0,20
0,10
0,05
0,03
50
60
70
80
90
100
150
200
300
1
0,9
0,8
0,7
0,6
0,5
0,4
0,3
0,2
0,1
Speed m/s
Acceleration (g)
3
5
10
20
30
40
50

CONSTANT AMPLITUDE

	X in mm	f in Hz	A in g.	V in m/ s
+	0,1	50	1	0,031
X	0,1	100	4	0,063
●	0,1	150	9	0,094
o	0,1	200	16	0,125

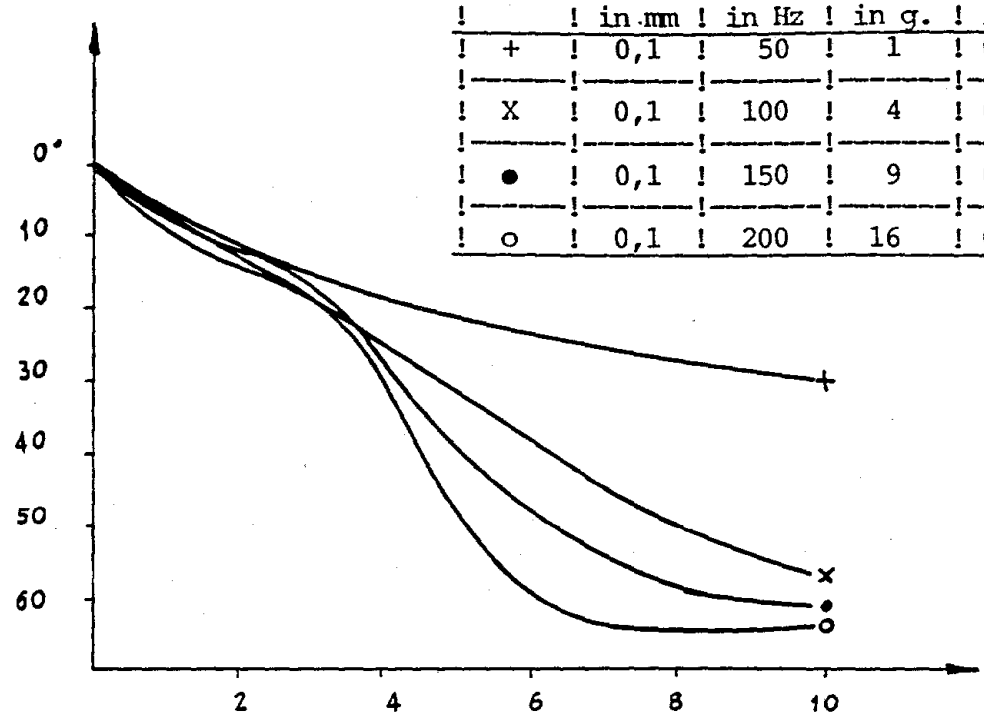


Fig. 9

CONSTANT SPEED

	V in m/ s	f in Hz	X in mm	A in g.
+	0,094	50	0,3	3
X	0,094	100	0,15	6
●	0,094	150	0,1	9
o	0,094	200	0,075	12

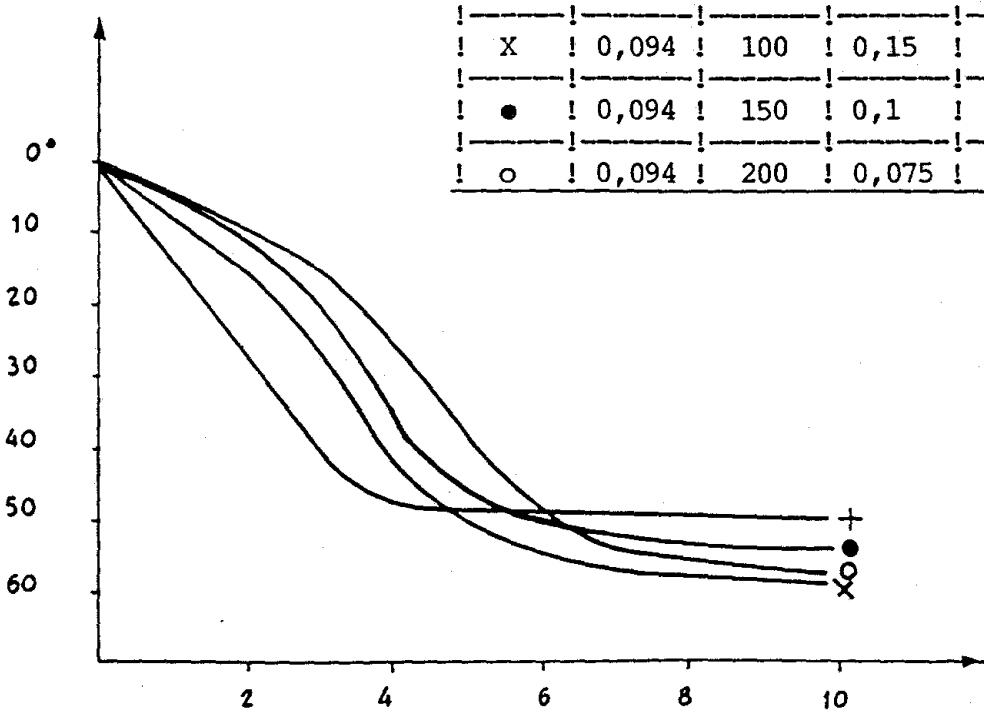


Fig. 10

CONSTANT ACCELERATION

	A in g.	f in Hz	X in mm	V in m/ s
+	6	50	0,6	0,19
X	6	100	0,15	0,094
o	6	200	0,04	0,047

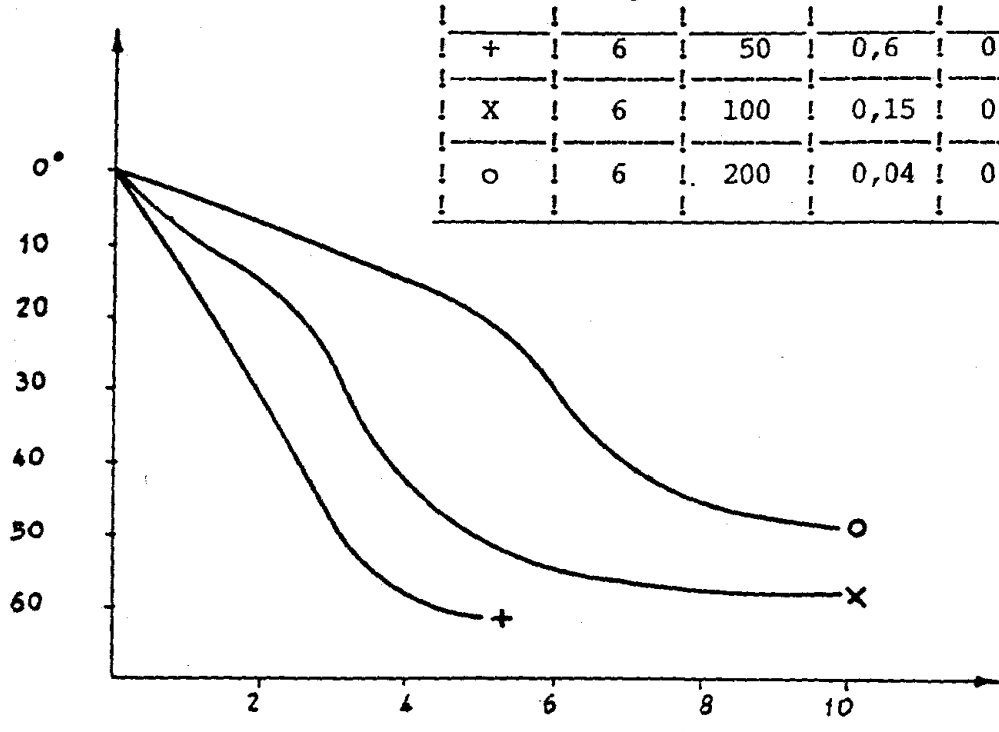


Fig. 11

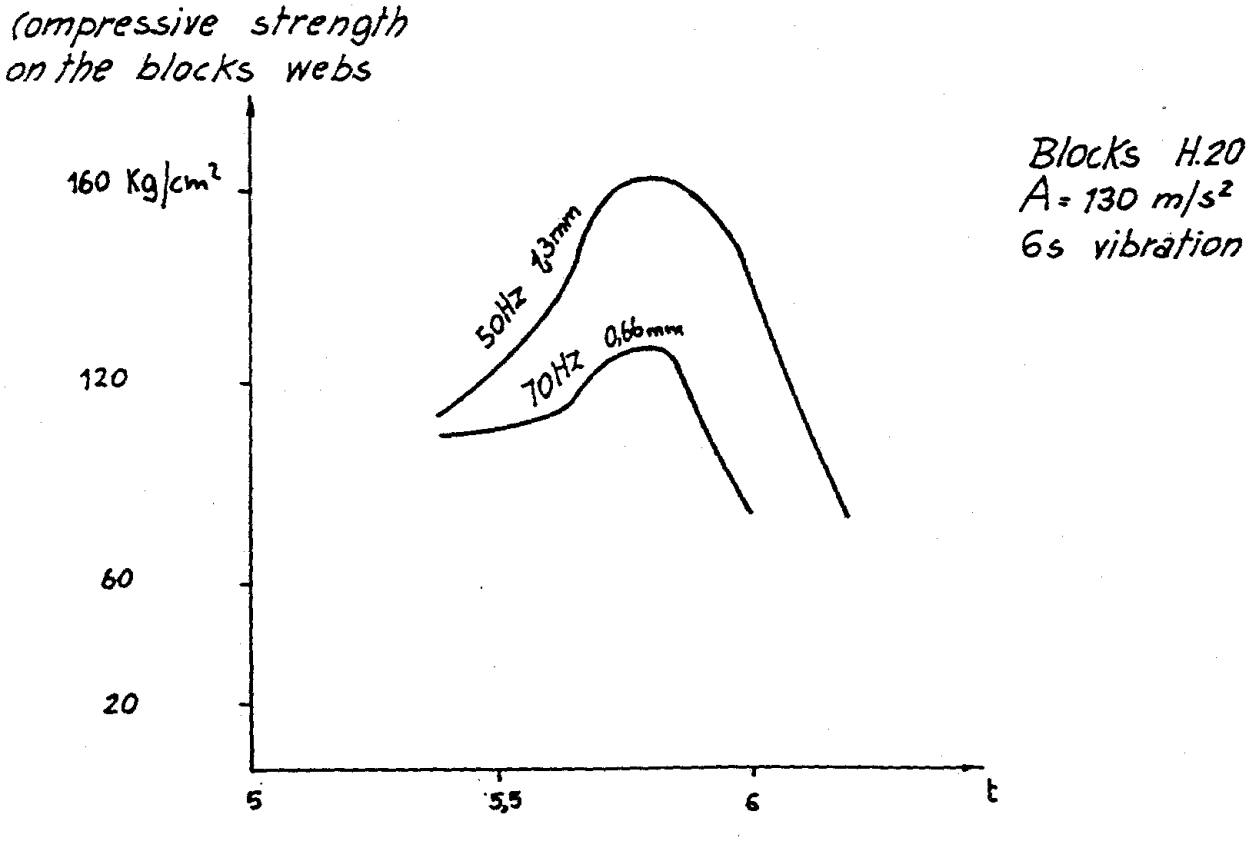


Fig. 12

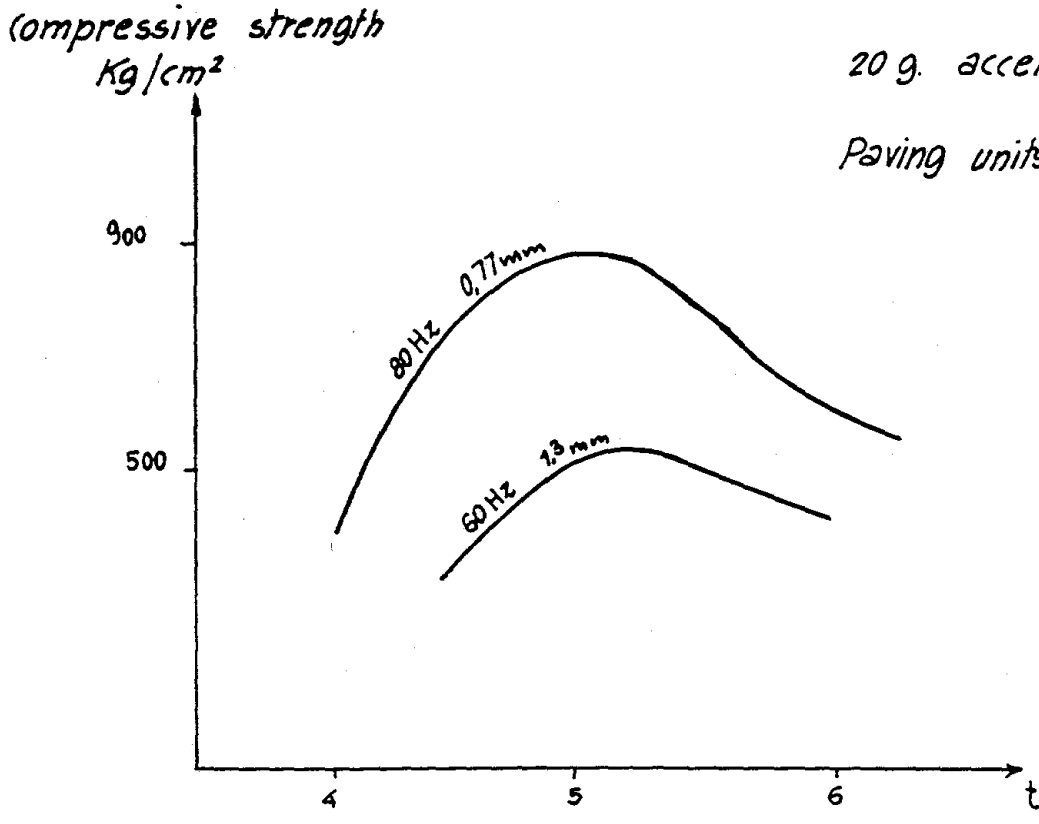

compressive strength
Kg/cm²
20 g. acceleration
Paving units H.6÷8 cm
900
500
80 Hz 0,77 mm
60 Hz 1,3 mm
4
5
6
t

Fig. 13

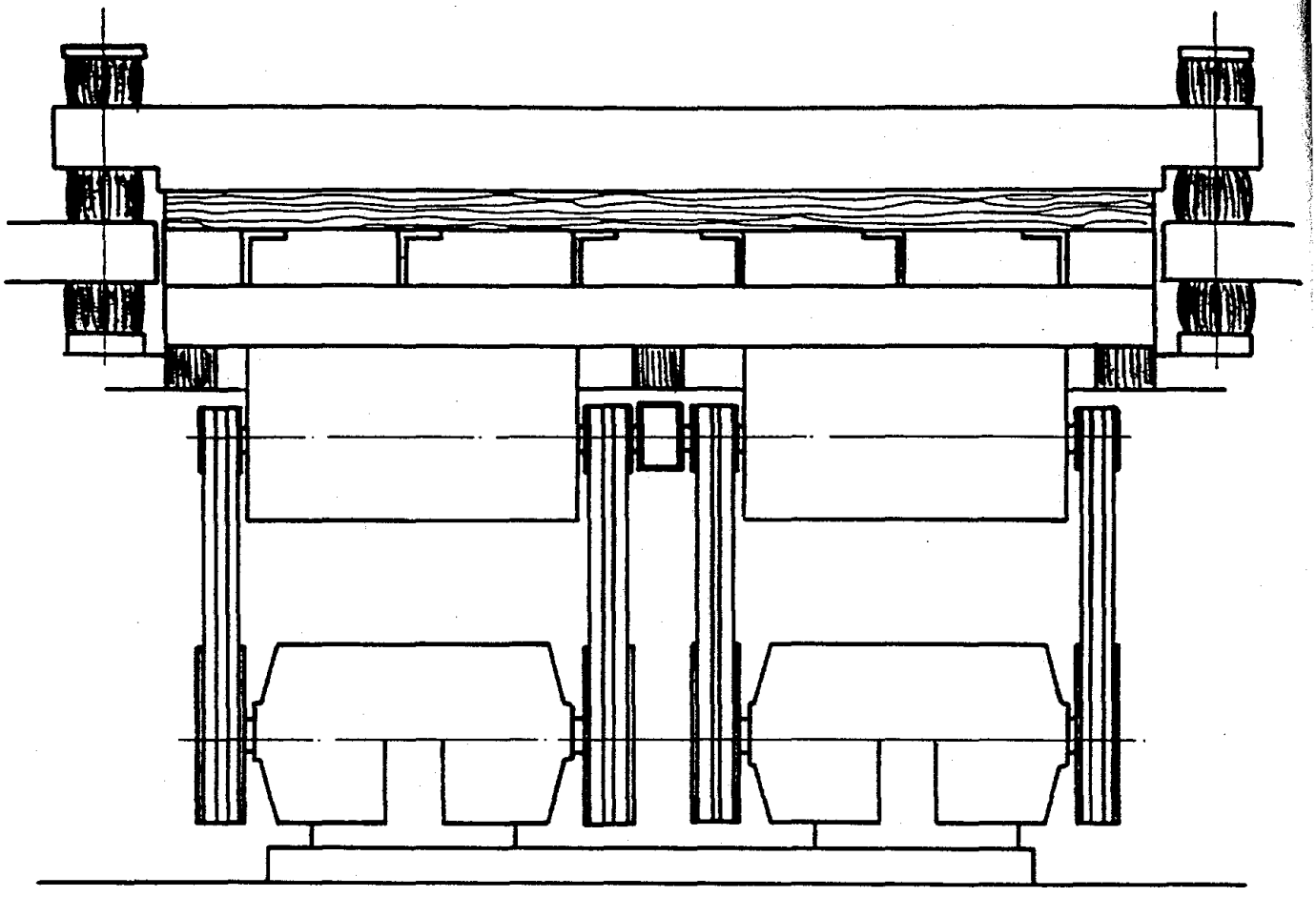


Fig. 14

$$A_{max} = 39{,}5\, f^2 \quad X_{max} \qquad \text{from which}$$

$$X_{max} = \frac{A_{max}}{39{,}5\, f^2} = \frac{20 \cdot 9{,}81}{39{,}5 \cdot 80^2} = 0{,}00077\ m = 0{,}77\ mm$$