27 May 2010, 8:05 pm - 8:20 pm

Machine Foundations and Blast Engineering Vibrations Case Studies

Ion Vlad
Technical University of Civil Engineering Bucharest, Romania

Fifth International Conference on
Recent Advances in Geotechnical Earthquake Engineering and Soil Dynamics
and Symposium in Honor of Professor I.M. Idriss
May 24-29, 2010 • San Diego, California

MACHINE FOUNDATIONS AND BLAST ENGINEERING VIBRATIONS CASE STUDIES

Ion Vlad
Romanian National Center for Earthquake
Engineering and Vibrations (R.N.C.E.E.V.)
within T.U.C.E. Bucharest, 020396 Romania

ABSTRACT

Vibration can cause either serviceability and malfunctioning problems reducing people's comfort to an unacceptable level, or safety problems with danger of failure. The belief of the author is that the presentation of some practical cases of machine foundation vibrations will be of interest, beneficial and helpful for many researchers and engineers involved in both theoretical and practical studies. Therefore, the most relevant case studies on vibrations of machine foundation ensembles, encountered in practice in the last ten years of activity, will be presented. In all malfunctioning or excessive vibration cases the technical assessment has started with a complex program of vibration measurements followed by a sound engineering judgment. A remedial solution was elaborated for the encountered vibration problem and put into practice. The results led to the diminution of the dangerous vibrations and to the avoidance of the annoying ones. Among the cases selected for this paper, the most representative are: the malfunctioning of a "compressor – foundation – supporting soil" system caused both by an incorrect dynamic design process and execution; the annoying vibrations generated by unbalanced forces of an offset printing press and the annoying vibrations produced by weaving looms in an adjoining office building. The second part of the paper presents a safe blast demolition by small controlled explosions of two lateral wings of an existing commercial building. The intervention was caused by a first attempt of demolition which caused severe vibrations of many blocks of flats existing in the near vicinity. The officials of the "State Inspection for Construction" decided the health monitoring of the entire demolition process, especially of the central part of the building which was to remain after the demolition.

SHORT PRESENTATION OF THE CASE STUDIES

In the first part of the paper three selected relevant machine foundation vibration case studies will be presented.

Compressor – foundation – supporting soil system

The first of them refers to a case history related to the interaction of a compressor, its concrete block foundation and the supporting soil system.

The problem that needed to be solved was that of the excessive vibration amplitudes of the above mentioned system. In fact, when the compressor was placed in operation, the foundation and its surroundings started vibrating excessively and, as a result, the vibration amplitudes put the machine out of service short time after it began to work.

"*An essential requirement for adequate design of a machine foundation is that the motion amplitudes under operating conditions do not exceed the specified value. The vibration amplitudes depend upon the natural frequency of the vibrating system, the operating frequency, and the magnitude of the applied dynamic forces and moments. The information on magnitude and characteristics of the dynamic loads imposed by the machine on the foundation is thus vital for a satisfactory design of the machine foundation system. This information is generally supplied by the manufacturer of the machine and should be procured from him. This presents difficulty sometimes since the interests of the client and the manufacturer of the machine are not in unison, and the manufacturer of the machine may not like to admit that large unbalanced forces may occur from operation of the machine supplied by him*".

These aspects were presented by professors Shamsher Prakash and Vijay Puri in the beginning of Chapter 5 of their book "*Foundations for Machines: Analysis and Design*" and I consider that they perfectly characterize the subject of this first example, that is the excessive vibrations case history of a new ensemble consisting of a compressor, its concrete block foundation and the supporting soil, encountered in Romania.

The owner did not know whom to blame for the unsatisfactory performance of the facility and started accusing all parties involved: the manufacturer of the compressor, the designer of the foundation and the builder of the machine foundation. This case is another situation when a "vibration problem" occurred "after the fact", and the machine foundation became "target of blame". However, as it will be seen further on, in the case of this ensemble "compressor – concrete block foundation – supporting soil", only the manufacturer of the compressor that was out of blame.

Offset printing press

In the design of machine foundations or other dynamically loaded foundations, successive corrections are used to reach the final physical system. The end product of the design procedure is the determination of a foundation – soil system which satisfactorily supports equipment or machinery. A special situation is that when the manufacturers of the machinery don't recognize, or are unwilling to acknowledge, the unbalanced forces which are produced by their machine. Another situation, directly related to the above mentioned one, consists of the acquisition of second – hand equipment. This is the situation which has been often encountered in Romania in the last fifteen years due to the poor economical situation of the country and to the appearance of various private companies which could not afford new equipment. *The second case study* presents such a situation, when the owner has acquisitioned a second-hand offset printing press and didn't know whom to blame for the unsatisfactory performance of his facility (vibration generating malfunctioning). The instrumental investigations carried out established which part of the facility was responsible for the annoying vibrations, at which speed these vibrations became excessive, and which were the proposed solutions for avoiding the vibration problems.

The European powerful enterprises, focused on graphic arts industry, having as objective to maintain their position and further strengthen competitiveness in national and international markets, started from mid-2005 to replace stepwise the old offset printing presses ROTOMAN 2000 with the latest generation of pressline systems. Cost pressure in the market has been the main reason for the new investments. Many of these out of date old ROTOMAN 2000 presslines were sold and were installed in different countries, among them being Romania. On August 10, 2006, a ROTOMAN pressline was installed in a steel industrial building in Romania, whose functioning at high speeds generated undesirable vibrations. Firstly, the owner complained to the authors of this paper that the pressline could not be run up to the design speed without tearing the paper, as it ran through the press. Secondly, the owner also complained that at high speeds of operation annoying vibrations are generated and are transmitted to the floor and to the entire industrial building.

Sorting out the source of vibration and correcting the malfunctioning is not always a straightforward process. It is this particular situation which occurred in the case of excessive vibrations of the offset printing press and brought the authors into contact with this category of problems described by the owner as a "*problem generated by the vibrations of the foundation*" at high values of the printing speed. Generally, since the equipment foundations are out-of-sight, they are often out-of-mind during the design process, and are often targets of blame when things go wrong. This fact is particularly true for foundations subjected to dynamic forces.

Seldom do structural engineers analyze machine foundations or other foundations for dynamic loads, even when these loads are expected. As a consequence of this oversight, most foundation dynamics problems arise "*after the fact*", when they are most difficult to correct. The foundation is also often blamed when things go wrong, simply because it is relatively inaccessible and less well understood (Woods, 1987).

Manufacturers of machinery often do not recognize, or are unwilling to acknowledge unbalanced forces which are produced by their machines. The seller which sells second hand machines is always interested in hiding all shortcomings of the equipment that he intends to trade.

The manufacturers of the offset printing presses didn't provide to the designer of the foundation any dynamic unbalanced forces for its design process. Sometimes the manufacturer simply said there were no unbalanced forces. These large, high-speed printing presses are actually long, high structural frames with non-uniformly distributed mass and unbalanced forces at various heights in the short axis direction (transversal direction) (Woods, 1987).

Weaving looms

In 2004, an Italian company has rented in Romania 6000 square meters in a huge, one level industrial building, in order to lay out a weaving mill. Connected to this building there is a small five level office building having 256 square meters in plane. Two categories of weaving looms were installed, 44 air-jet type and 17 rapier type. When the machines started to operate, severe vertical vibrations were generated in the industrial building and annoying acoustical vibrations were induced in the office building, felt especially at the fifth floor.

The owner of the building, together with the Italian company, asked R.N.C.E.E.V. to identify the source of the annoying vibrations and to find a technical solution in order to avoid them.

Demolition by controlled explosions

After the change of the political regime in Romania, in 1989, among the unfinished buildings was also a commercial complex that had a rectangular shape in plane of 110 x 75 m, consisting of three parts named “Body A”, “Body B” and “Body C”. The new owner decided to keep the central “Body B” and to demolish the lateral wings.

Anchor Mall Development & Management, a Turkish company, figured out that the demolition by explosions of the existing building may lead to strong impulsive loading of the central part of the structural system, and to damage (apparent or hidden). This could increase the seismic risk affecting the structural system of “Body B”. In the mean time, the owner was watchful with the process of demolition by explosion in what concerns neighboring buildings and the involved risks to people of the zone. Another aspect was about the experience gained after the analysis of the results of the May 21st, 2003 controlled explosion, for the demolition of “Body A”, in order to establish, if necessary, additional measures needed to be taken for the demolition of “Body C”.

DATA ACQUISITION

The acquisition of the instrumental data was achieved with highly sensitive modern KINEMETRICS equipment for ambient and forced vibrations field measurements. The equipment consists of SS-1 Ranger seismometers, a 16-channel fully portable acquisition unit which controls the outputs from the seismometers, connecting cables and a laptop. For all applications presented in this paper, six to twelve short period velocity-type transducers were used to record motions caused by ambient vibrations, by the operation of a “compressor foundation – supporting soil” system, by the functioning of an offset printing press and of different types of weaving looms. The same equipment was used in monitoring the demolition by small controlled explosions of two lateral wings of a commercial shopping center.

In each case the first step was to select the locations where the motion was necessary to be recorded. The number of measuring points depended on the type and complexity of the experiment and of the type of the encountered problem. Relatively long time intervals were recorded, that contributed to a higher resolution of the Fourier spectra. Consequently, better determination of the closely spaced modes of vibration was obtained.

The following typical types of analysis have been carried out:

- numerical integration in time domain, obtaining in this manner from the basic signal (velocities) the vibration displacements;
- numerical derivation in time domain, obtaining in this manner from the basic signal (velocities) the vibration accelerations;
- Fast Fourier Transform (FFT) of the real signal, both for velocities and displacements (Fourier Amplitude Spectra);
- auto-correlation functions (cross-correlation of an input signal with itself), by means of which it is possible to detect an inherent periodicity in the signal itself and to determine the damping ratio;
- computation of maximum displacement values in points of interest depending of the application;
- simple mathematical combinations (sums or differences) between some primary records to indicate, when appropriate, average movements or rotations in different planes of oscillation;
- Fourier Amplitude Spectra for the above mentioned combinations.

The time domain representations (velocities, displacements, or accelerations) are performed in view of getting an overall image of the spatial motion of the foundation/building subjected to dynamic actions.

The Fourier Amplitude Spectra and the auto-correlation functions emphasize the frequency content of the recorded motions, as well as the increase of the dominant compounds. This led to an accurate identification of the natural frequencies of the foundation/building subject of the instrumental investigations and of the maximum displacement values in different points.

THE FIRST CASE STUDY

Short presentation

A compressor (type 06-NK3, Fig. 1) that was installed in an oil refinery was supported on a concrete block foundation that has been built to match the dimensions suggested by the supplier of the machine. The manufacturer of the compressor also imposed the requirement that the foundation should be designed in such a manner that the “peak-to-peak” displacement amplitudes at operating speed, at the top of the foundation, do not exceed 63.5 μm (microns), which is an extremely severe condition.

In the design of a compressor foundation the knowledge of the dynamic soil properties and the proper understanding of the dynamic soil moduli (with the corresponding elastic spring constants), together with damping, are frequently required. Though the designer knew these aspects he preferred to use the results of an existing geotechnical study, performed at approximately 60 m from the site where the compressor 06-NK3 was to be placed. Before starting the construction of the machine foundation the designer asked to the owner to clear the foundation medium by removing a sewerage pipe (∅ 600 mm), an outlet nozzle, a recirculating water chamber, an electric cable canal and a water processing canal, that existed on site.

Fig. 1. General view of the compressor.

The soil consisted of brown, dry plastic, silty clay, over which was laid a compacted soil padding (compacting degree 98%). At the time when the construction of the compressor's foundation began no water infiltrations existed in the general digging.

When the compressor was placed in operation, the foundation vibrated excessively. It was the foundation-related problem that was held responsible for the malfunctioning of the ensemble "compressor–foundation–supporting soil". In order to solve this situation, the first step was to perform geotechnical investigations on the site of the compressor foundation. Two drills near the compressor foundation were performed (at a distance of 3.15 m on both sides of the transversal axis of the compressor foundation, as shown in Fig. 2).

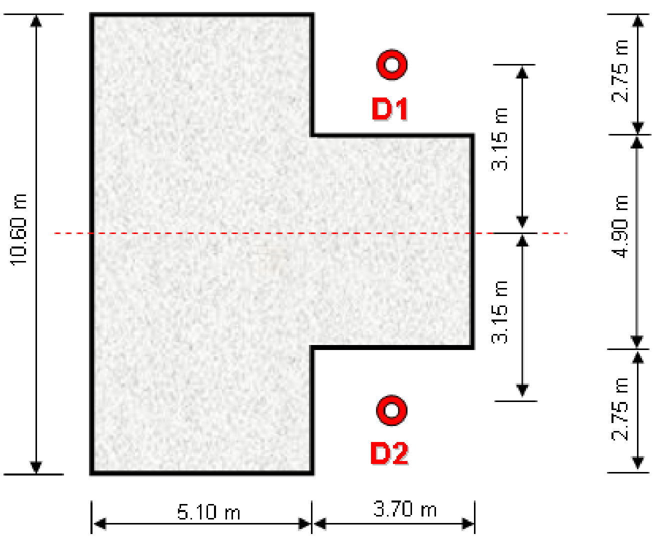
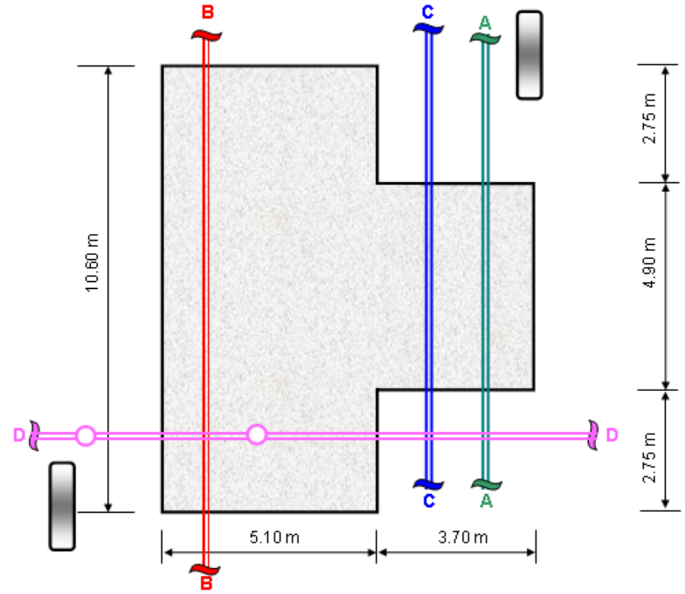


Fig. 2. Layout of the foundation and positioning of the drills.

The first results of the geotechnical study pointed out the presence of water infiltrations and water-saturated soil, at the following depths: 0.90m÷1.60m (D1) and 1.30m÷2.0m (D2). A temporary solution to get rid of the water consisted of two drain pipes operating near the compressor foundation. The existing situation of the pipes below the foundation is presented in Fig. 3.



LEGEND

- (green) - existing sewerage pipe ∅600 mm in soil; the designer asked the owner to remove it but the owner didn't do that; the designer was not informed about that fact;
- (red) - existing canal; the designer asked the owner to demolish it, and the owner pulled it down;
- (blue) - ∅300 mm pipe, discovered during the digging process for the new foundation;
- (pink) - pipe, discovered during the digging process for the new foundation (-0.90m); the designer wasn't notified about it;
- (circle) - holes performed in the ∅1200 mm pipe; through these holes concrete was cast in place;
- (box) - drain water chamber.

Fig. 3. The existing pipes below the compressor foundation.

It is obvious that the first geotechnical study did not contain the necessary basic elements for the analysis of the foundation to dynamic actions. The second one confirmed the fact that one couldn't count on any elastic coefficients for the site. None of the two geotechnical studies provided values of elastic soil moduli obtained either in static or dynamic conditions, for the site. At the time of the technical assessment it was ascertained that there were water infiltrations at the bottom of the compressor foundation, situation in which the behavior of the "compressor–foundation –supporting soil" system was strongly influenced by them.

Instrumental investigations

A set of instrumental investigations was carried out in order to establish the dynamic properties of the compressor foundation, as well as the amplitudes of the vibrations at the operating speed (Stage I).

The main objectives of the instrumental data acquisition were the following:

- identifying the eigen dynamic characteristics of the compressor foundation, when the equipment does not operate, considering as action the microtremors together with the ambient vibrations due to industrial traffic and to the functioning of other facilities in the vicinity;
- identifying of some functioning characteristics of the installation;
- identifying of the dynamic characteristics of the compressor foundation, during idle functioning of the compressor, in the following operation stages: starting moment, idle functioning and stopping moment;
- clarifying the technical causes of excessive vibrations (annoying) generated by the functioning of the equipment;
- establishing the degree of transmissibility of the vibrations through the foundation medium to the vicinity;
- recommending, if possible, the most appropriate solutions in order to avoid the vibration problems.

For this stage, the transducer locations are presented in Fig. 4. In all the instrumented locations there were measured velocities, on both horizontal directions (transversal – "T"; longitudinal – "L") and on the vertical one ("V").

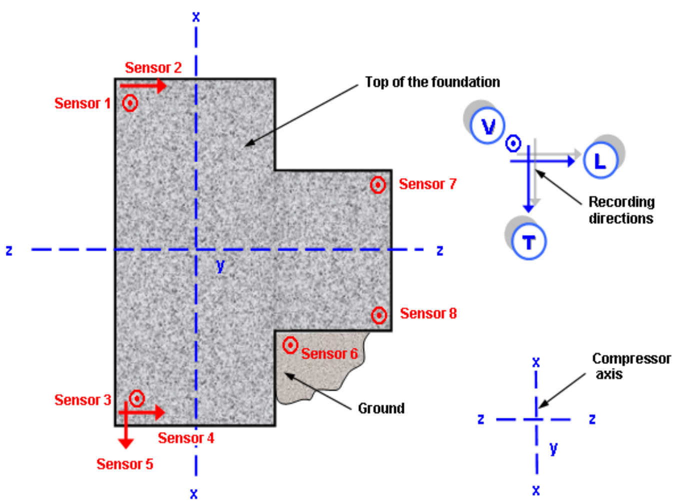


Fig. 4. Stage I. Location of sensors.

The time domain representations (velocities and displacements) were performed in view of getting an overall image of the spatial motion of the foundation subjected to dynamic actions.

Typical time domain velocities and the corresponding amplitude Fourier spectra are shown in Fig. 5 ÷Fig. 10.

The manufacturer of the compressor specified the unbalanced forces and moments on the foundation. He provided the following requirements: *the primary unbalanced forces and moments vary from maximum values on one direction to maximum values on the other direction, for each complete rotation of the shaft corresponding to the functioning frequency of the reference compressor operating speed* (f_1 = *6.18 Hz;* n_1 = *371 rpm); the secondary unbalanced forces and moments vary from maximum values on one direction to maximum values on the other direction (performs this cycle) twice for each rotation of the shaft, at a double functioning frequency of the compressor (*f_1 *= 12.36 Hz).*

The aspect that had to be considered by the designer was that the secondary unbalanced forces and moments occur at the second order frequency of the compressor, equal to 12.36 Hz.

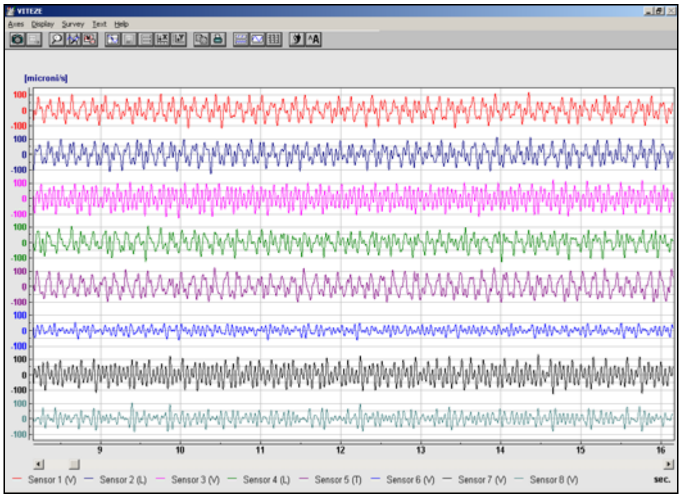


Fig. 5. Ambient vibration time domain; velocities.

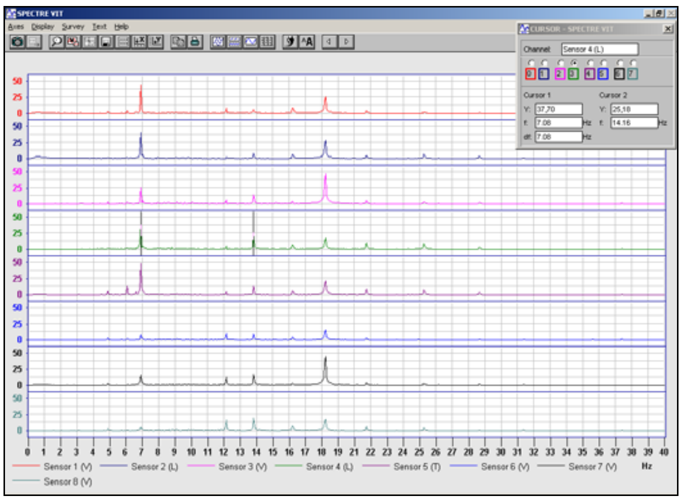


Fig. 6. Ambient vibration data acquisition. Amplitude Fourier spectra; velocities.

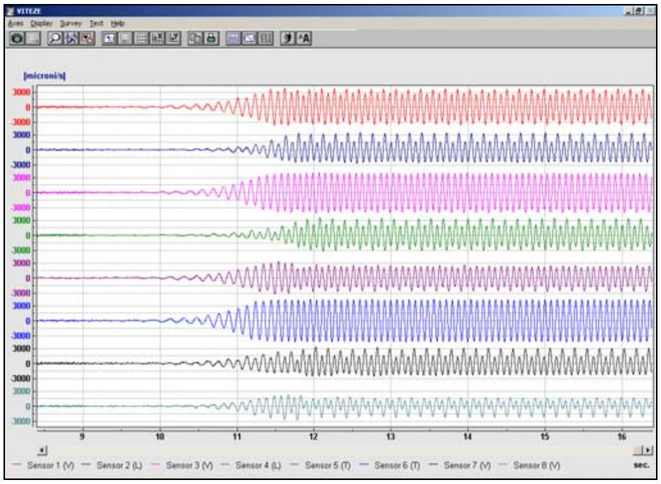


Fig. 7. Functioning of the compressor – starting moment. Time domain; velocities.

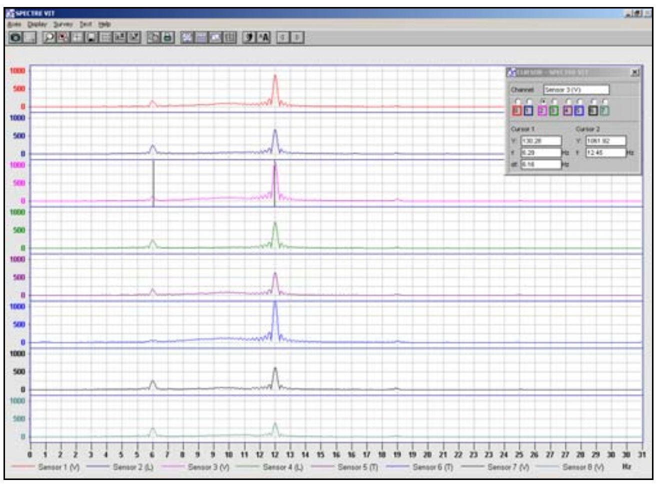


Fig .8. Functioning of the compressor – starting moment. Amplitude Fourier spectra; velocities.

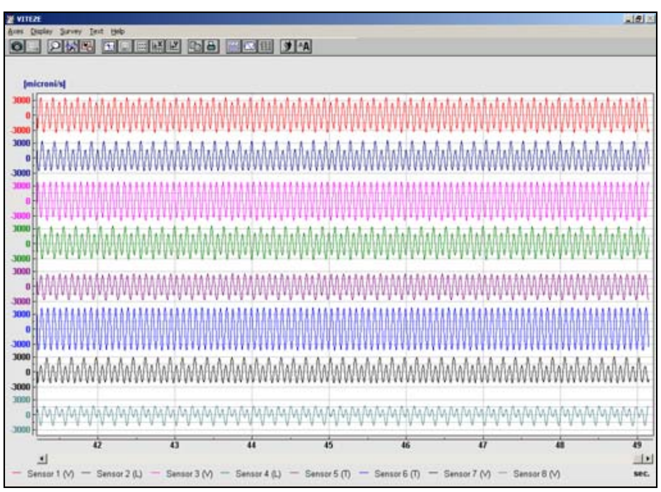


Fig. 9. Functioning of the compressor – idle functioning. Time domain; velocities.

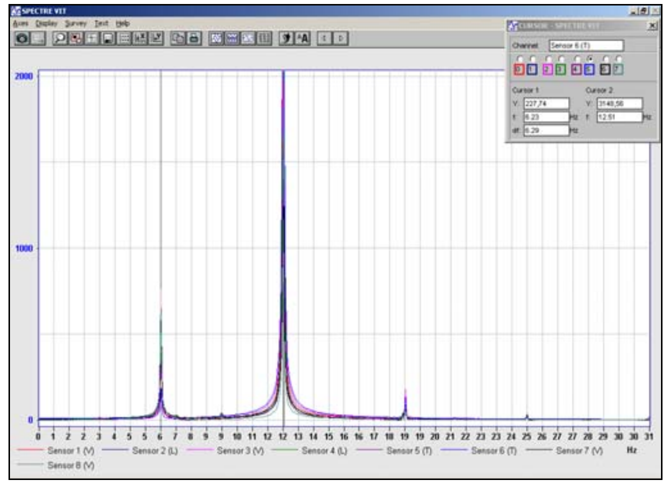


Fig. 10. Functioning of the compressor – idle functioning. Amplitude Fourier spectra; velocities.

The rigid foundation of the compressor 06-NK3 was thus designed and resulted “high tuned” with respect to the first operating frequency of the compressor, which was equal to 6.18 Hz (the eigenfrequencies of the ensemble “compressor – foundation – supporting soil” were greater than the first operating frequency of the compressor).

The excessive vibrations observed during the idle functioning of the compressor were the result of the closeness of certain eigenfrequencies of the ensemble to the second order frequency of the compressor. The eigenfrequencies of the ensemble “compressor – foundation – supporting soil” that were identified by measurements were close to the first and second frequency of the exciting force (6.23 Hz and 12.45 Hz). The eigenfrequencies corresponding to coupled translation and rotation vibrations of the dynamic system, taking into account the different sources of vibration already mentioned (ambient vibrations and steady state vibrations), were: 5.0 Hz; 7.08 Hz; 12.45 Hz; 14.16 Hz; 16.60 Hz; 18.70 Hz; 21.25 Hz.

The maximum vibration amplitude values were determined. In comparison to a “peak-to-peak” value of the displacement at the top of the block foundation specified by the compressor’s manufacturer (equal to 63.5 microns), after performing the instrumental recordings, a value equal to 121 microns was obtained. So, the “peak-to-peak” amplitude of the motion at the idle operating frequencies exceeded the permissible value.

In conclusion, when the instrumental investigations were performed during stage I, a lack of “*frequency calibration*” together with a lack of “*maximum dynamic response calibration*” was highlighted. Remedial measures were proposed, but the owner didn’t entirely consider them.

After performing the first set of instrumental investigations the following additional aspects have occurred:

- the change of the soil parameter characteristics on the site of the foundation because of the appearance of water at its bottom;
- the decision of the owner and of the designer to enlarge the footing of the foundation, by casting in place reinforced concrete completions at the two corners of the compressor foundation (modification of spatial geometry of the compressor foundation).

Thus a new set of instrumental investigations were performed (Stage II). 8 sensors were mounted in the same locations as previously, two more RANGER seismometers being placed on the extensions of the compressor foundation (sensors 9 and 10, on the vertical direction), as a result of the change of its initial geometrical configuration. Sensors 11 and 12 were placed at a distance of about 40 m from the foundation, on the ground, as shown in Fig. 11.

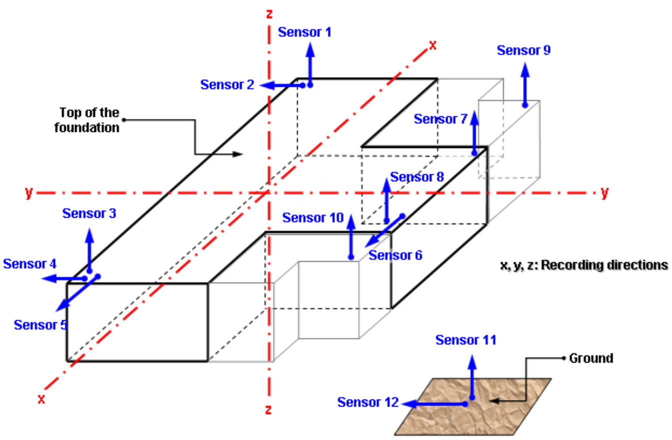


Fig. 11. Stage II. Location of sensors.

Together with the second stage of the instrumental investigations an analytical study based on these results was performed. The main objectives of this study were:

- finding the characteristics of the foundation motion taking into account its six degrees of freedom, by considering the foundation as a solid rigid body;
- deriving from the motion parameters (associated with the six degrees of freedom) the motions corresponding to the measurement directions, in order to verify the validity of the numerical analysis and to estimate the range of the possible measurement errors;
- obtaining of supplementary information in view of finding an accurate proposal for solving the existing situation.

The same types of analysis as in Stage I have been performed. Samples of the time domains and amplitude Fourier spectra are presented in Fig. 12 and Fig. 13. In Fig. 14 are given the maximum displacement values for all the considered directions at the starting, idle functioning and stopping of the 06-NK3 compressor.

Table 1 shows the maximum displacement values corresponding to the frequencies identified by instrumental measurements.

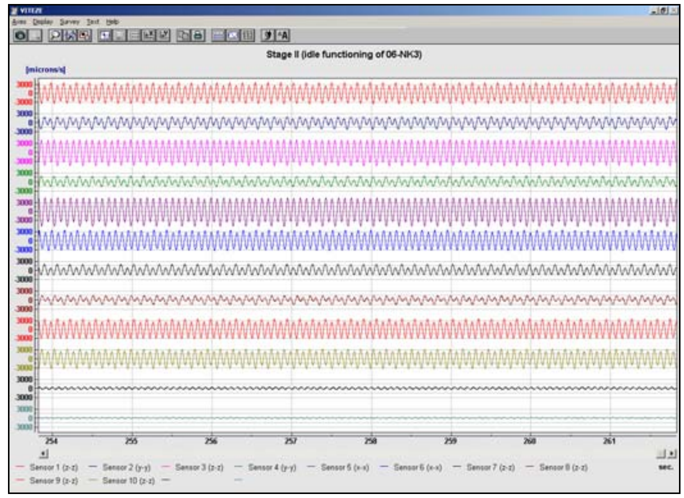


Fig. 12. Stage II. Idle functioning of the compressor. Time domain; velocities.

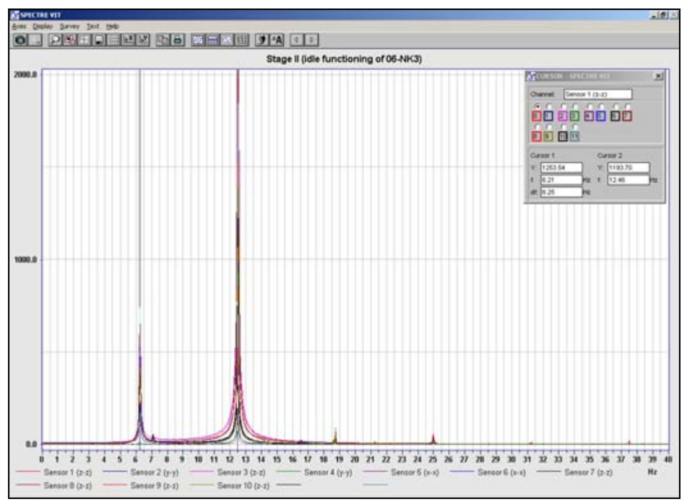


Fig. 13. Stage II. Idle functioning of the compressor. Amplitude Fourier spectra; velocities.

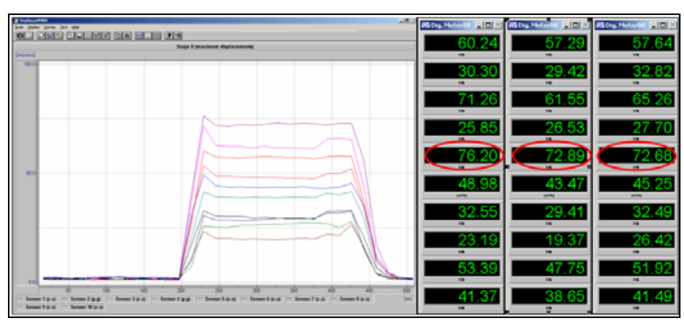


Fig. 14 . Stage II – idle functioning of the compressor. Maximum recorded displacement values [microns].

Table 1. Maximum recorded displacement values.

Recording direction	Functioning of the compressor	d_{max} (μm)
Parallel to x – x axis	starting	76.20
	"idle"	72.89
	stopping	72.68

After performing the instrumental investigation program, a large number of frequencies, corresponding to coupled translation and rotation vibrations of the ensemble "compressor – foundation – supporting soil", to the idle functioning of the compressor and to the operating of the two other compressors placed in the vicinity, have resulted.

The motion amplitudes, expressed in terms of kinematic measures (displacements "0–peak" and not "peak-to-peak"), at starting, idle operation and at stopping of the compressor, have already been specified (Table 1). It can be noticed that the global value of the motion amplitude, in the case of idle functioning of the compressor, has significantly increased (with about 20%), fact that can be accredited on the much higher closeness of the frequency of the coupled motion of the block foundation ($f_{Stage\ II}$ = 10.44 Hz, towards $f_{Stage\ I}$ = 10.25 Hz) to the second order frequency of the excitation ($f_{excitation}$= 12.4 Hz). The processing of the signal (in Stage II) highlighted the fact that the two reinforced concrete extensions had a coupled motion with the initial foundation.

Some conclusions

The unsatisfactory behavior of the ensemble "compressor 06-NK3 – foundation – supporting soil" was due to a complex set of factors, each factor's influence being difficult to be quantified. Among them were:

- the presence of two other compressors in the immediate vicinity has had a certain influence on the unsatisfactory behavior of the new ensemble "compressor 06-NK3 – foundation – supporting soil", due to several potential factors hard to be identified (vibration transmissibility; the generation of a "dynamic asymmetry" of the overall "*ensemble of the three compressor foundations – soil medium*", as a result of the presence of the significant masses of the two existing compressor foundations);
- the two sets of the performed instrumental investigations put to evidence both spectral peaks and amplifications in the bands of frequency associated to the functioning of the existing ensembles "compressor – foundation – supporting soil";
- the designer has used unrealistic soil data for estimating the foundation response; without adequate and meaningful data from the site investigation the engineering analysis was of doubtful value and led to erroneous conclusions;
- in the design process of the 06-NK3 compressor foundation it couldn't be avoided that the eigenfrequency of the ensemble "compressor – foundation – supporting soil" is a integer number multiple of the operating frequency of the compressor, in order to keep away from resonance with higher harmonics; the excessive vibrations generated by the idle functioning of the compressor were the result of the approach of some frequencies corresponding to some coupled motions of the ensemble, to the second order frequency of the excitation (given by the manufacturer of the compressor), or to other higher order frequencies;
- a positive effect of the change of the spatial configuration of the compressor foundation (by increasing its footing) was the increasing of the overall damping of the ensemble "compressor – foundation – supporting soil";
- in what concerns the vibration transmissibility in the vicinities (more significant in Stage II), this was the result of a much stronger coupling of the translation and rotation motions; vibrations due to the compressor idle operation resulted annoying to persons working in an adjoining building.

Remedial measures

The change of the geometrical layout of the compressor foundation, decided exclusively by the designer and the owner, didn't solve the excessive vibration problem. The purpose of the technical assessment by instrumental investigations and checking of the validity of the entire process was to determine which remedial measures were to be taken in order to reduce the foundation's vibration amplitudes to permissible (severe) level given by the manufacturer.

The entire process of investigations led to the following *remedial measure*, having in mind to obtain a "*dynamic response*" calibration (trying to respect the severe condition given by the manufacturer for an amplitude at the top of the foundation equal to 62.5 μm): completely redesign the foundation, process that should have in mind the increase of the total weight of the foundation and whose effect would be the change, in a favorable manner, of the eigencharacteristics of the compressor foundation.

The owner completely agreed with the proposed solution and decided to redesign the foundation.

The task for redesign was given to a Russian company which modified the existing foundation by adding 18 cast-in-place reinforced concrete piles (Fig. 15). Each pile was 6 m long with a diameter of 1170 mm, and an average value of the allowable load of 200 kN (without its own weight).

In Fig. 15 the dashed red line represents the new contour of the foundation. Thus the problem was solved and the excessive vibration disappeared.

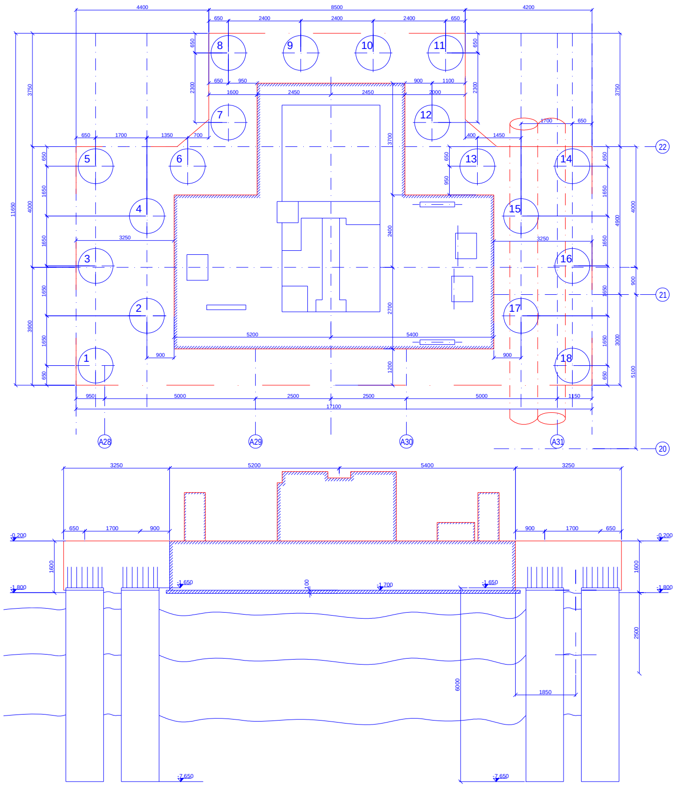


Fig. 15. Adopted remedial solution for the compressor foundation.

THE SECOND CASE STUDY

Short presentation

In Fig. 16 and Fig. 17 are presented photos of the printing press. The machine is actually long (L = 33.20 m) and supported on a mat foundation (Fig. 18). The width of the mat foundation is only slightly wider than the press itself (2.80 m) and the overall length to width ratio of the pressline is of the order 12:1. The press is made up of a number of operational units in a longitudinal arrangement. At intervals along the pressline there are folders servicing units from two directions. The proportion between the weight of the printing press and the weight of the mat foundation is of the order 1:1.50.

As the servicing personnel became more familiar with the operation of the printing press, they tried to increase its speed of operation. When the speeds of operation increased above 40 KIPH rate, some undesirable transverse vibrations began to occur. The publisher contacted the manufacturer and has learned that the press should be able to operate satisfactorily only up to 55 KIPH.

In this situation, the publisher tried to find out what went wrong and caused such vibrations and contacted R.N.C.E.E.V. for solving the problem.

Fig. 16. General view of the printing press.

Fig. 17. Images taken during the instrumental investigations.

Instrumental investigations

The author of this paper learned that the press mat foundation was designed only for vertical static loads and, after studying a geotechnical report made on the site, decided to perform a complex program of instrumental investigations. The main objectives of the instrumental data acquisition had in mind the following aspects:

- establishing of eigen dynamic characteristics of the mat foundation (eigenfrequencies, damping), when the printing press doesn’t operate, considering as vibration source the ambient vibrations;
- establishing of the functioning characteristics for the printing press at different speeds, in order to detect the speed at which the excessive vibrations occur;
- identifying of the dynamic characteristics of the foundation response for the following stages of operation: starting moment, functioning at different speeds, and stopping moment;

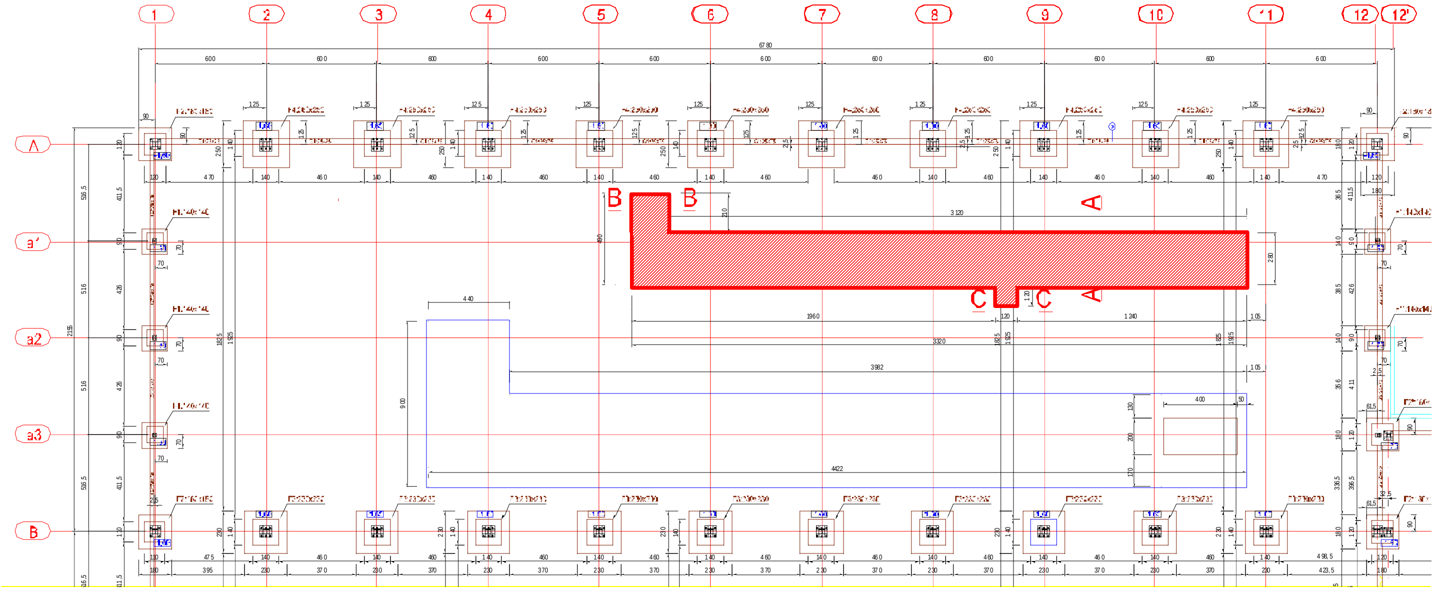


Fig. 18. Overall layout of the industrial building containing the printing press mat foundation (the red outline).

- clarifying the technical causes of excessive vibrations, generated by the functioning of the printing press;
- recommending the most appropriate solutions for avoiding the occurred vibration problem.

In order to identify the speed at which the annoying vibrations occur, the speed of the printing press was progressively increased, as follows: 5 KIPH, 10 KIPH, 20 KIPH, 30 KIPH, 40 KIPH and 55 KIPH. Tests with the press running showed very low vibration amplitudes up to a speed of 30 KIPH, which then increased in a significant manner (not at 40 KIPH, as the owner had initially mentioned). Several configurations for the positioning of the pick-ups on the printing press mat foundation, and on the floor in the vicinity, were adopted (Fig. 19). In all the instrumented locations there were measured velocities, on both horizontal directions (transversal – "T"; longitudinal – "L") and on the vertical axis ("V").

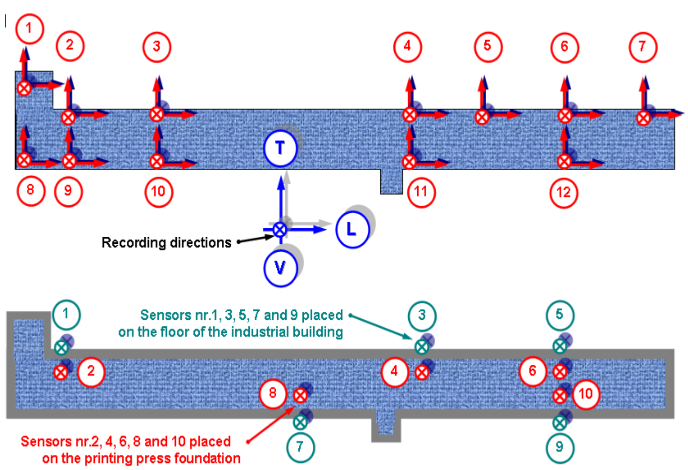
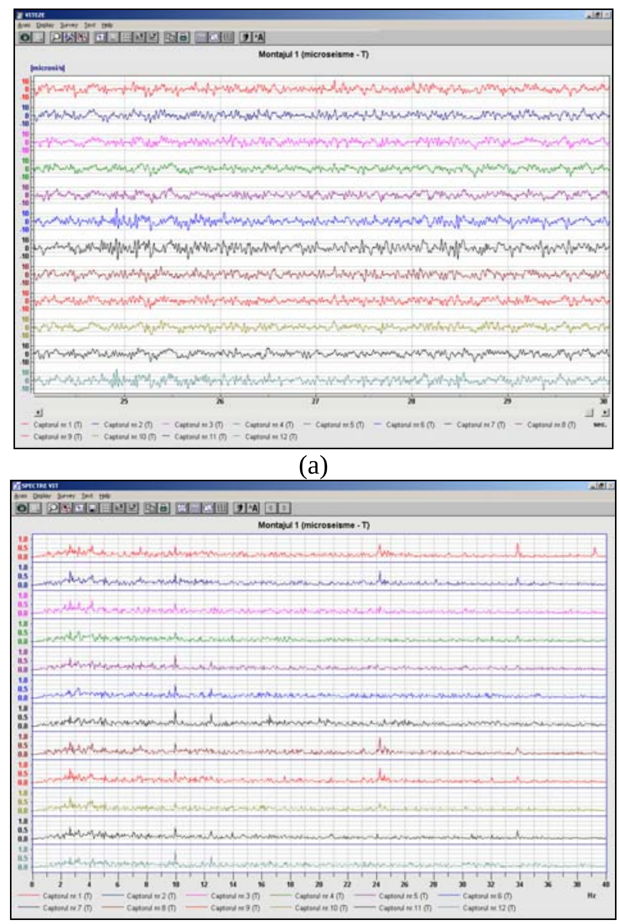


Fig.19. Location of sensors.

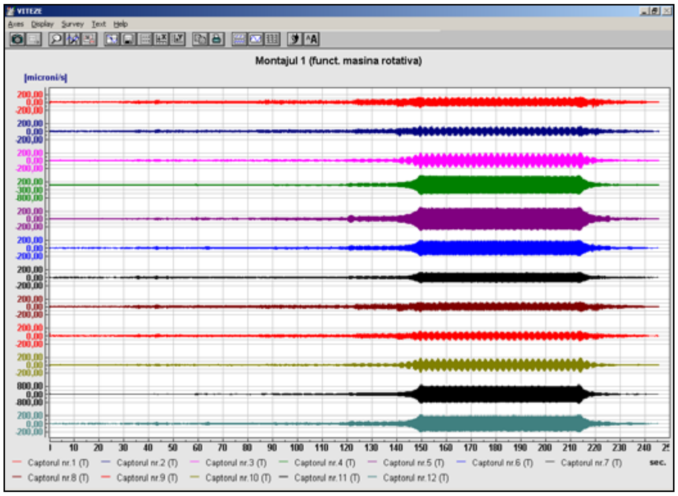
Some of the data acquisition results are shown in Fig. 20÷26.



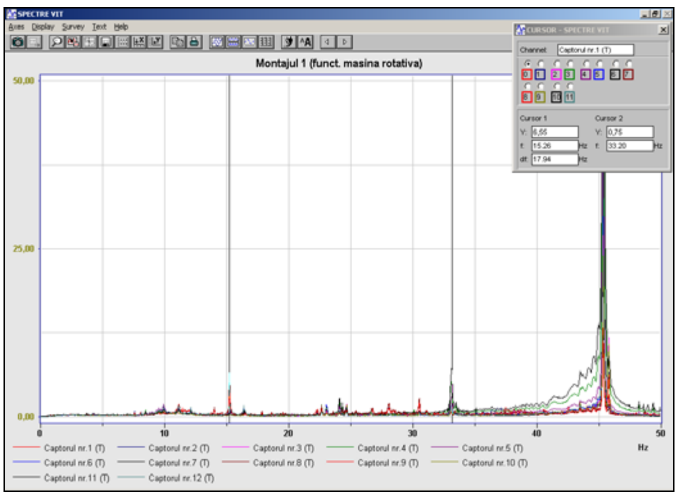
(a)

(b)

Fig. 20. Ambient vibration data acquisition; velocities. (a) time domain; (b) amplitude Fourier spectra.

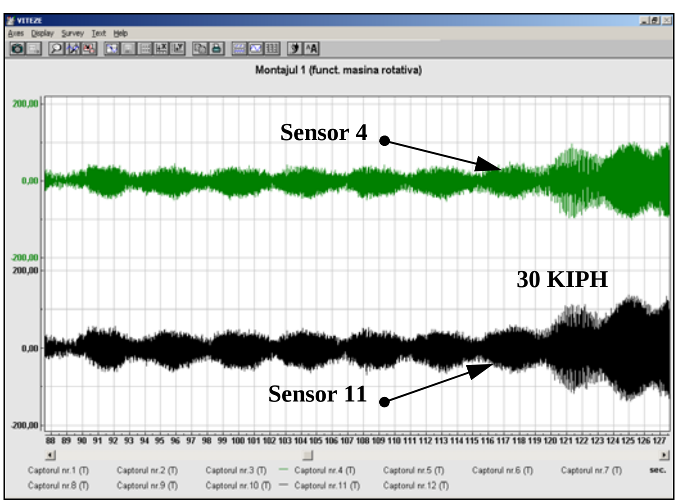


(a)

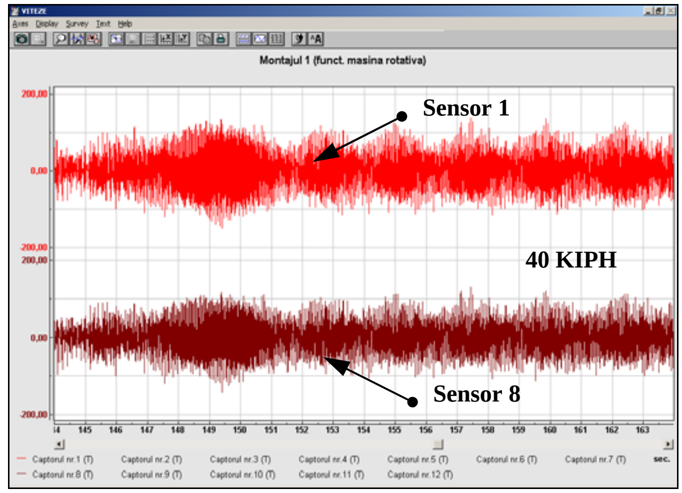


(b)

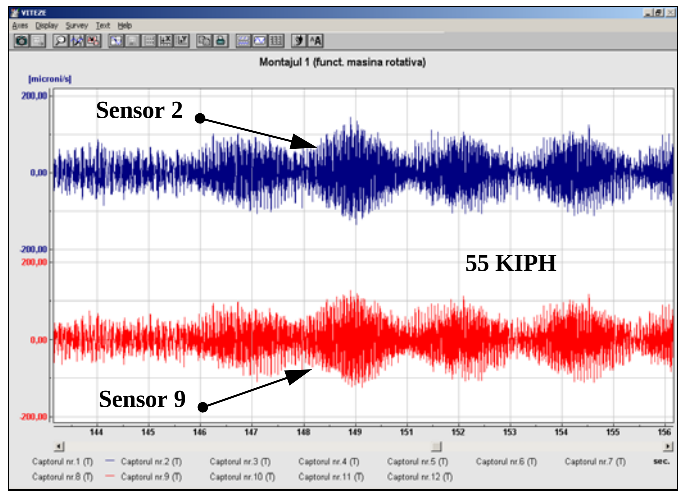
Fig. 21. Printing press operating from 5 to 55 KIPH; velocities. (a) time domain; (b) amplitude Fourier spectra.



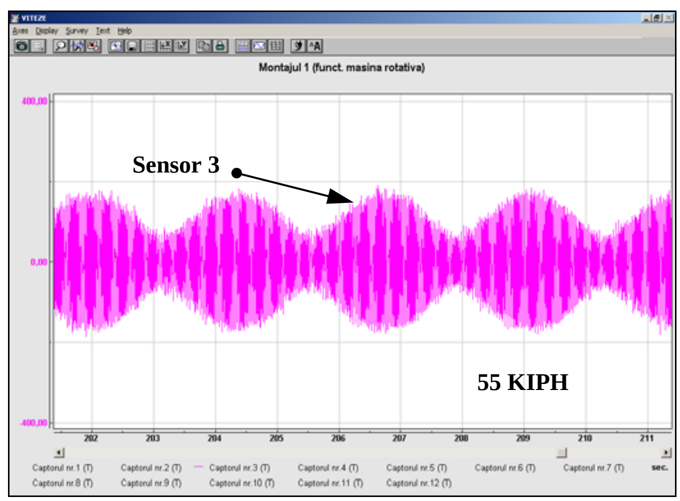
(a)



(b)

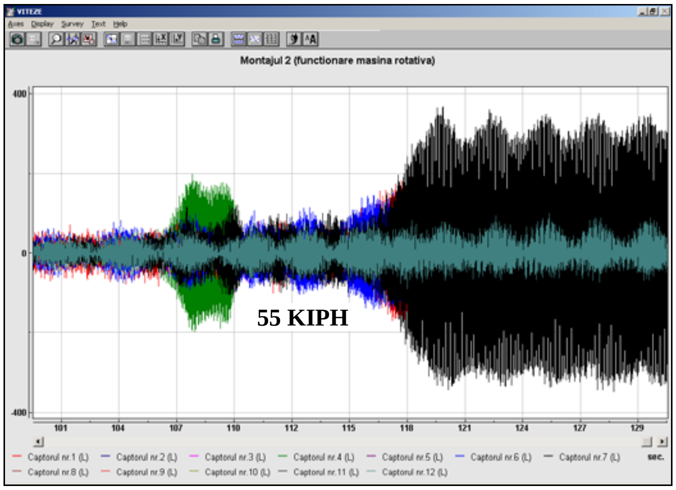


(c)

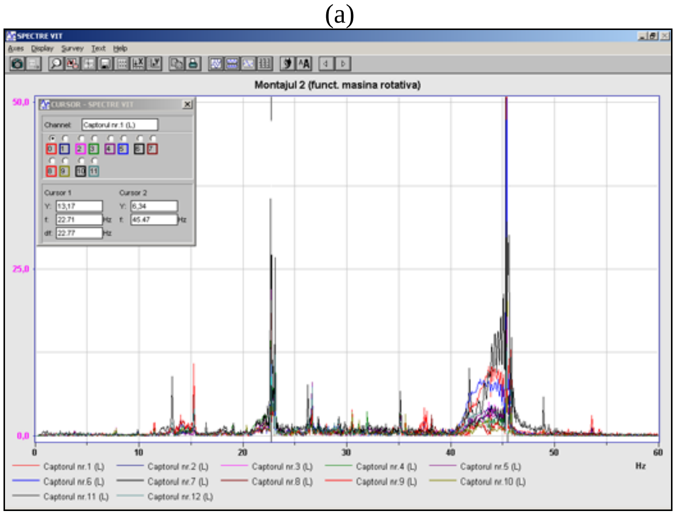


(d)

Fig. 22. (a)÷(d) . Printing press operating at 30...50 KIPH. Time domain; transversal direction; velocities.



(a)



(b)

Fig. 23. Printing press operating at 55 KIPH; velocities; longitudinal directions.
(a) time domain; (b) amplitude Fourier spectra.

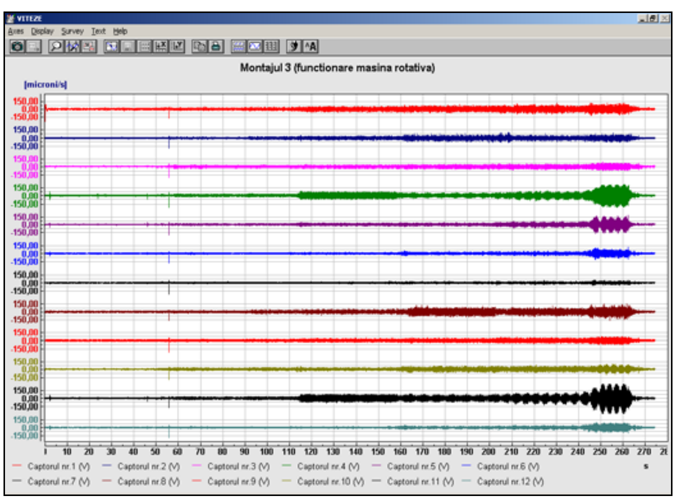


Fig. 24. Printing press operating from 5 to 55 KIPH. Time domain; vertical direction; velocities.

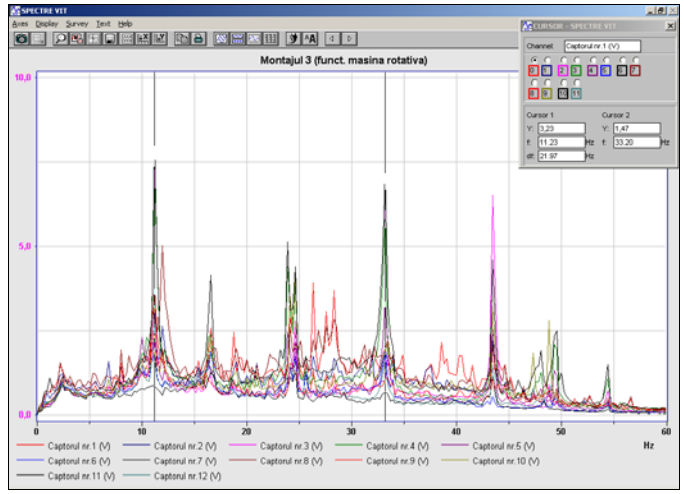


Fig. 25. Printing press operating from 5 to 55 KIPH. Amplitude Fourier spectra; vertical direction; velocities.

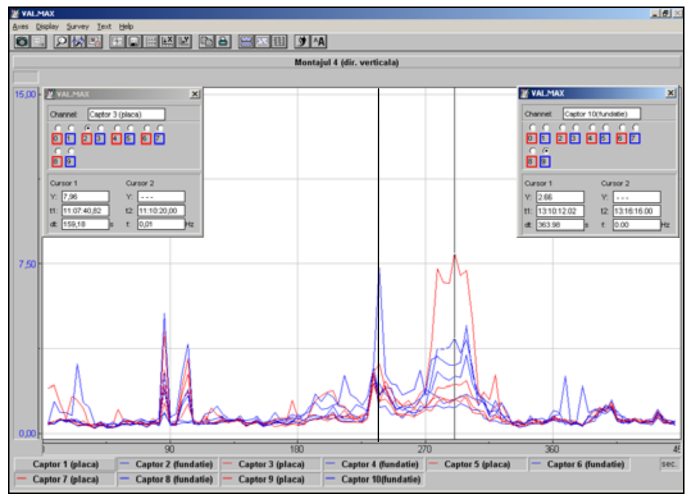


Fig. 26. Printing press operating at 55 KIPH. Sensors location on the mat foundation and on the floor of the industrial building. Maximum displacement values; vertical direction.

After performing the entire program of instrumental investigations a set of useful information was obtained.

Some conclusions

In the present case study, upon a detailed instrumental investigation and evaluation, it was found out that the design of the printing press itself was the source of the occurred vibrations.

The vibrations caused by the printing press operation are due to some of the components of the printing press, which at high speeds generate unbalanced dynamic forces.

The supplier of the second hand printing press did not mention to the publisher the existing possibility that unbalanced dynamic forces could be generated during operation, and the latter did not communicate to the designer of the foundation this information.

During the operation at high speeds, transverse vibrations of the printing pressline have been observed and have alleged difficulties for the press owner. The press manufacturer claimed that there were no unbalanced forces associated with his equipment. No specific criteria exist for tolerable vibrations for these printing presses, except that the paper must pass through the press without tearing, and excess bearing wear must be avoided.

The cause of these transversal vibrations was identified by professor Richard Woods (Woods, 1987) upon detailed questioning of the manufacturer's representatives. It was learned that in the case of "ROTOMAN" printing presses, during operation, the ink is distributed to the printing plates by rollers which rotate about an axis transverse to the longitudinal direction of the press. Some of these rollers distribute the ink to the printing plates from a fixed position and the rest of the rollers slide along their axes in the transverse direction to distribute ink uniformly on the plates (Fig. 27). There are at least three such rollers for ink distribution associated with each group of printing, or half-deck, and each of these rollers weight on the order of 92 kg (1.1 kN).

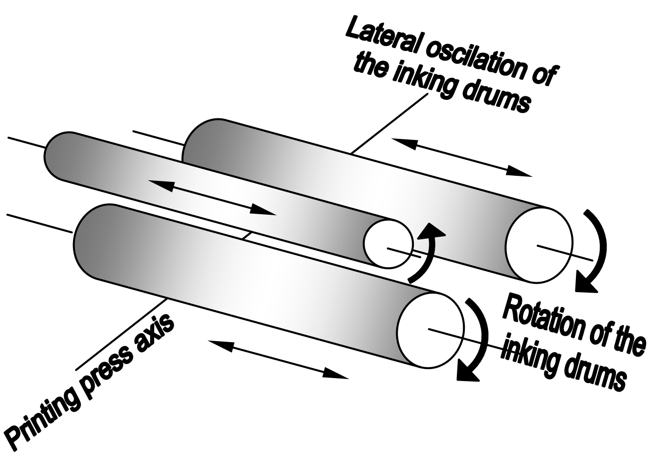


Fig. 27. Graphic representation of the inking drums

In the case of the "ROTOMAN" printing press, whose vibrations are analyzed in the present paper, there are six rollers: three for printing on the top side of the paper and three for printing on the bottom side. "*The rollers spin on their axes at a speed which is associated with the speed of the paper through the press. Their lateral stroke along their axes is adjustable up to 30 mm and is also geared to the speed of the press. The six rollers can be geared so that they produce a minimum unbalanced force but cannot be perfectly balanced. The sliding speed of these inking rollers was measured on many such printing presses and it became obvious that the swaying frequency was exactly the frequency of these inking rollers. As the transverse sliding frequency of these rollers approach the first mode frequency of the press structure, the swaying vibration increased*" (Wood, 1987).

In his paper "*Sideway in offset printing presses*", professor Richard Woods makes a comparison between the transverse frequency of the inking rollers at a given press speed (in KIPH) and the first mode frequency of the press. The ratio of the frequency of the ink roller to the first bending mode of the press structure is also shown in the mentioned paper. The obtained frequencies (for the inkers) for this type of printing press, by instrumental investigations were: 2.22 Hz; 2.25 Hz; 2.64 Hz and 2.95 Hz.

The evidence was clear that the ink distributing rollers generate a transverse excitation which is dependent on the speed of the printing press. As the oscillating transverse frequency of the ink rollers resulted very close to the eigenfrequency of the first swaying mode of the ensemble "printing press – foundation" (2.62 Hz), which resulted after performing the R.N.C.E.E.V. instrumental investigation program, the vibrations on the transversal direction became excessive.

As a final conclusion, the main cause of the excessive vibrations that were generated during the printing process must be localized in the performance of the ink rollers.

Remedial measures

The first proposed solution for the vibration problem was to change the inking rollers gears so that the rollers wouldn't reach a frequency ratio greater than 0.60 (frequency of inkers/ frequency of the first eigenmode). This should correct the problem for the existing facility. The existing situation was created by a state of corrosion on the inside of the cylinders, as well as a non-uniform wear of the plastic layer from their exterior. Definitely, this fact contributes to the amplifying of the dynamic unbalance during working hours.

The second measure, if the first one may be too expensive, is to restrict the speed of the press to less than 40 KIPH.

The third measure which can be taken into account is to clean the foundation's existing rigid insulator material so that an adequate protection screen should be realized between the press foundation and the floor of the industrial building. It is also recommended to insert a plate of expanded polystyrene on the entire protection screen depth.

The intensity of the vibrations that occur on the horizontal direction is not so dangerous for the building's structural system. However, the vibrations that occur on the vertical direction to which the maximum displacements correspond, can lead in time to fatigue phenomena, or can even influence the working parameters of other equipment in the precinct.

THE THIRD CASE STUDY

Short presentation

The object of this chapter is the study of severe vibrations that were generated by weaving looms in an industrial building and of the annoying acoustical vibrations that were induced in the adjoining office building. As it was previously mentioned in paragraph 1.3, when the fabrication process started, severe vertical vibrations were perceived in the industrial building and annoying acoustical vibrations were felt in the office building. Practically, nobody could stay for more than 10 minutes in any room of that floor. In addition, the high intensity of the vertical vibrations affected the operation of sensitive electronic equipment and, as a result, a business center located at the fifth floor closed its activity. This made the owner lose a big amount of money obtained by renting the spaces. The *weaving shed* is of rectangular shape in plane, consisting of four spans of 18 m and seven bays of 12 m. No partition walls existed in the rented area. Between the two buildings there is a small "*connecting body*" (Fig. 28).

Fig. 28. General view of the complex of three buildings.

As the building concrete floor was not in good condition the Italian company decided to cast-in-place a 15 cm reinforced concrete plate above the 22.5 cm existing one. Thus was made an error, which consisted of the inclusion of all bases of the columns in the new reinforced concrete plate. In this way, a huge flat plate, like a general "mat" (37.5 cm) was obtained.

The *office building* is of square shape in plane, consisting of three spans and three bays, 5.40 m each. From the architectural point of view the building has 5 levels (no basement). The first floor is 4.00 m high, the next three levels are 3.30 m high and the last one is 3.70 m high. The structural system of the building is of reinforced concrete moment resisting frame type. In Fig. 29 the horizontal plane section of the industrial complex which is subject of the present paper is presented. Fig. 30 shows a general view of the weaving shed.

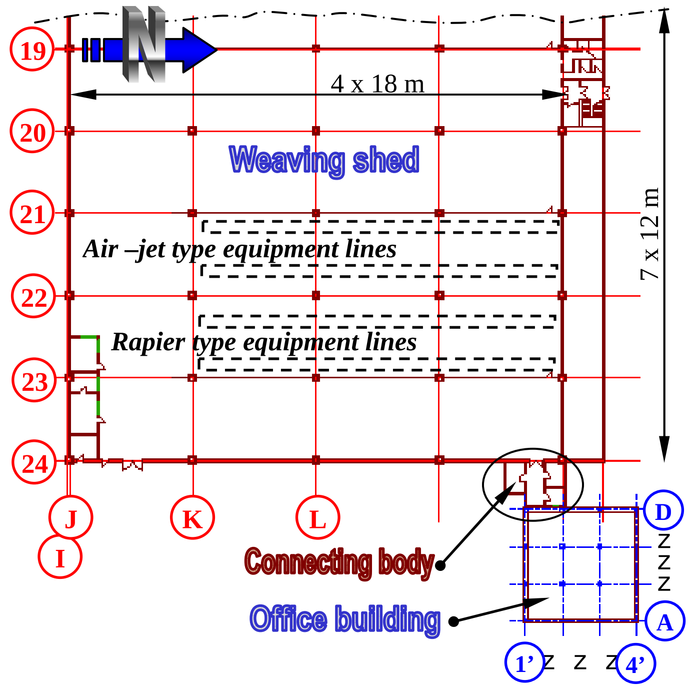


Fig. 29. Overall layout of the industrial and office buildings.

Fig. 30. General view of the rapier type weaving looms.

Instrumental investigations

The instrumental investigations were carried out in two stages, in June, 2006 and June, 2007.

The first stage

In order to identify the source of the annoying vibrations, several configurations for the positioning of the pick-ups were adopted: 5 arrangements in the industrial building and 4 in the office building. A number of SS 1 Ranger seismometers were placed in different locations, in the area of the air-jet type weaving looms, as well as in the area of the rapier type weaving looms. The selection of these locations was decided according to the workers' statements that confirmed that at these points the vibrations were strongly felt. In all the considered configurations vibrations on the longitudinal, transversal and vertical directions were recorded. The *vibration sources* considered were the ambient vibrations and the starting, operation and stopping, under normal working conditions, of the weaving looms. In the following, some of the configurations that were performed both in the weaving shed and in the office building are drafted (Fig. 31÷Fig. 34).

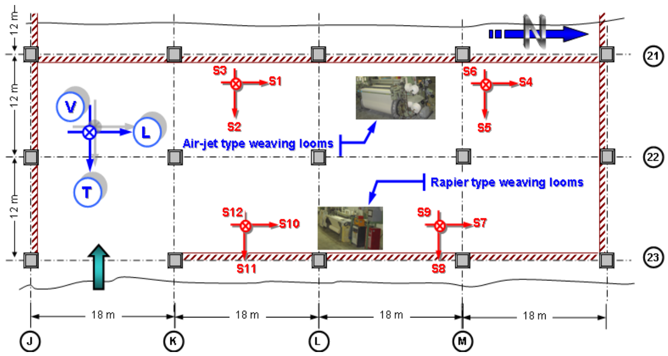


Fig. 31. Weaving shed. Location of sensors (1st configuration).

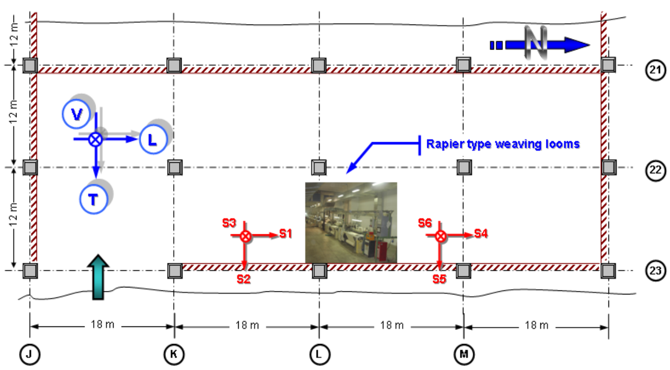


Fig. 32. Weaving shed. Location of sensors (2nd configuration).

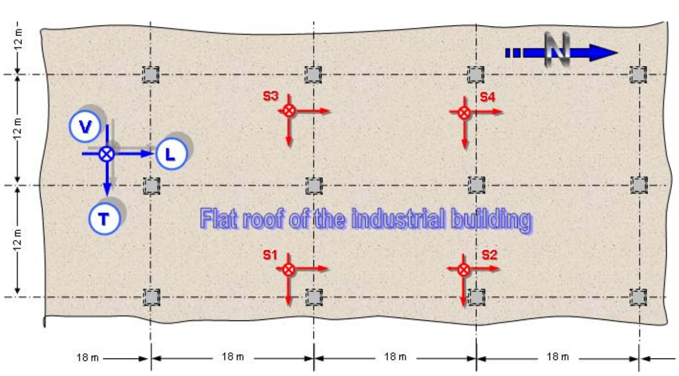


Fig. 32. Flat roof of the weaving shed (3rd configuration).

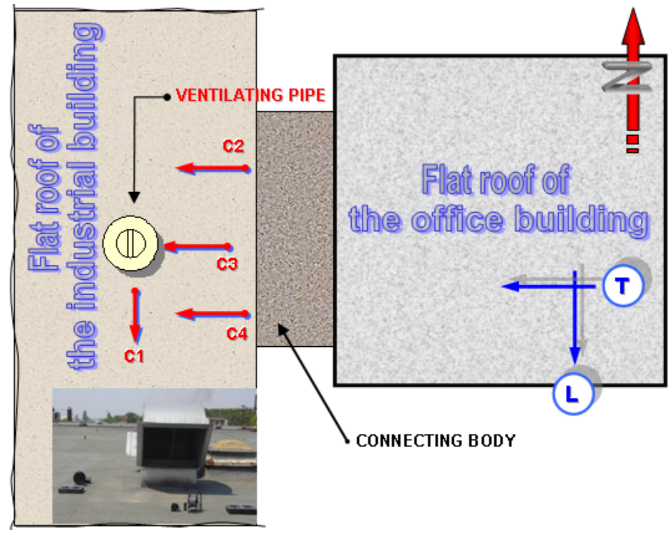


Fig. 33. Flat roof of the weaving shed, the area of the existing "ventilating pipe" where strong vibrations were signaled (5th configuration).

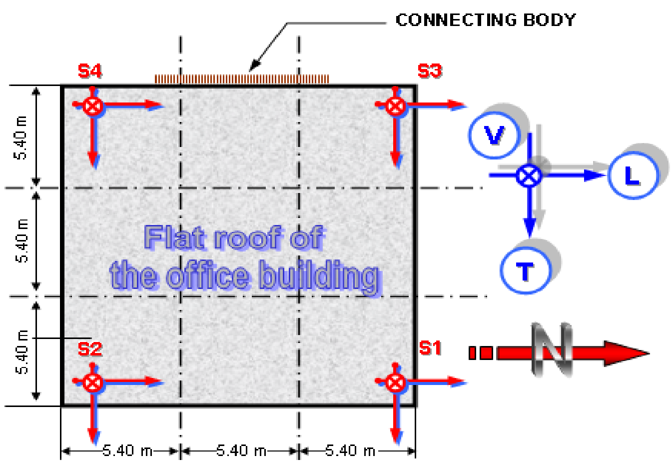


Fig. 34. Office building. Location of sensors.

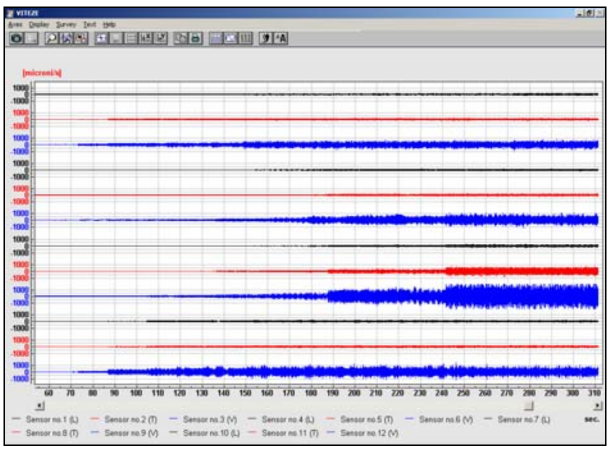
Samples of the outcome of the numerical processing of the instrumental data, recorded during the first stage, are shown in Fig. 35 and Fig. 36.

<u>Some conclusions after performing the first stage of instrumental investigations</u>

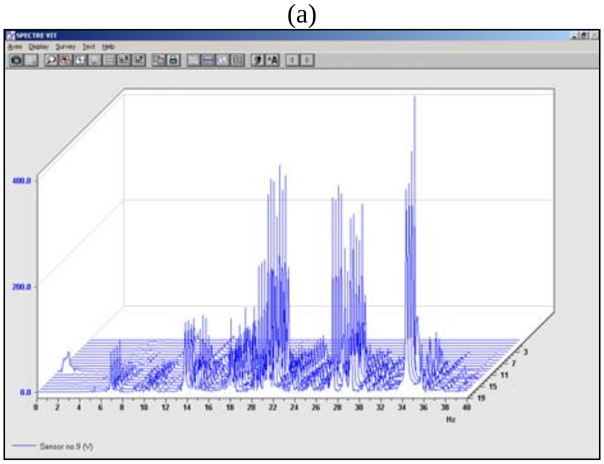
The *conclusions* of the *first stage* of the instrumental investigations that are of interest for the purpose of this paper are:

- despite the fact that the vibrations in the weaving shed were very severe, they were not so dangerous for its structural system; due to the fact that the columns of the industrial building were fixed in the 38.5 cm reinforced concrete plate, the vertical vibrations generated by the weaving looms were transmitted directly to the prefabricated flat roof; their effects could be visible in time at the connections between the structural elements and the nonstructural ones, as a result of the different stiffnesses, as well as of the fatigue phenomenon;

- the strongly perceptible vertical vibrations were due to the rapier type weaving looms, working at a speed of about 420÷450 picks a minute (or frequencies of 7.06...7.50 Hz); for the industrial building the eigenfrequency of vibration on the vertical direction, instrumentally obtained, was 7.04 Hz; it is obvious that the driving frequency is close to the industrial building's natural frequency and the resulting motion is a harmonically frequency modulated vibration, illustrating the phenomenon of "*beats*"; practically, a "*beat*" means a pronounced increase of the dynamic system response;
- the same phenomenon was also present in the office building, whose eigenfrequency of vibration on the vertical direction was 7.3 Hz;
- *only the air-jet weaving looms make that the maxima of the transmitted forces coincide with the operating frequency; for the rapier type machines the maximum occurred at a frequency of higher harmonics.*

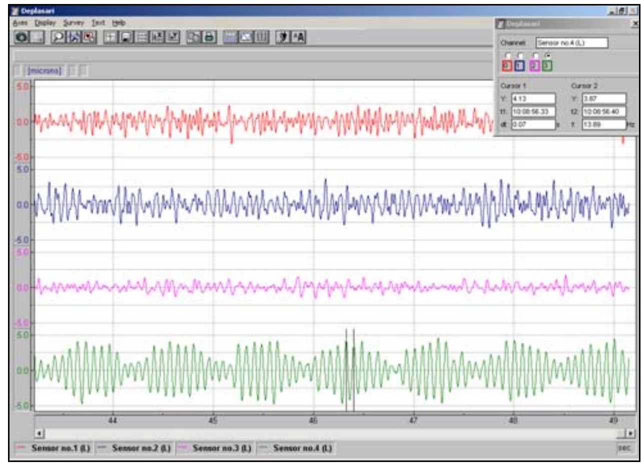


(a)

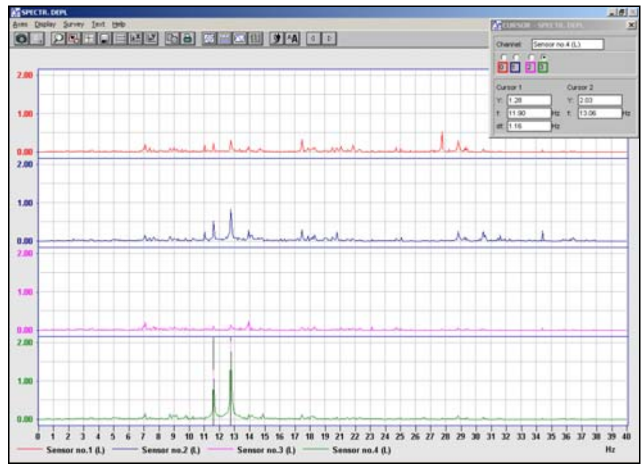


(b)

Fig. 35. Weaving shed. Normal operation of all weaving looms; .velocities [μm/s].
(a) - time domain; (b) - amplitude Fourier spectra.



(a)



(b)

Fig. 36. Flat roof of the weaving shed - third configuration. Normal operation of all the weaving looms). Velocities [μm/s].
(a) - time domain; (b) - amplitude Fourier spectra.

As remedial measures, adequate systems of isolation for all rapier type weaving looms were recommended, but it was also taken into consideration the possibility of intervention on the structural system of the office building.

<u>The second stage</u>

In order to establish the most suitable technical and financial measures, a second stage of instrumental investigations became necessary. This time the vibrations generated by the weaving looms were recorded only in the office building, as there were only two possibilities of intervention to be taken into consideration: to intervene on the source of the annoying vibrations, or to intervene on the structural system of the office building. In this situation, R.N.C.E.E.V. decided to perform a technical assessment of the office building in order to establish the possibility of intervention, together with new instrumental investigations, knowing this time the source of the annoying vibrations (the rapier type weaving looms).

The technical assessment of the office building revealed two surprises: one of them referred to the fact that during its construction the initial structure of foundation had been modified (see paper 2.14) and the other one was that the group of four interior columns with different cross sections at each floor responded with sonorous eigenvibrations. As the intervention on the office building could stop the activity, the owner didn't agree with this measure. That's why all the efforts have been directed on a new system of vibration isolators for the rapier type machines.

In order to be able to give the necessary data and to eliminate any possible mistake, the following instrumental investigations were carried out during the second stage:

- the recording of vibrations on the vertical direction in order to identify the corresponding fundamental eigenfrequency;
- the recording of the vertical vibrations on three columns at the fifth floor, at the intersection of axes B – 3′, B – 2′ and A – 2′ (Fig. 37);
- the recording of the vertical vibrations on three panels of the slab at the fifth floor, in the area with the maximum perception of the noise (axes A – B and 1′ – 4′), in order to establish if the structural system induced waves are refracted by its slab surfaces (Fig. 37);

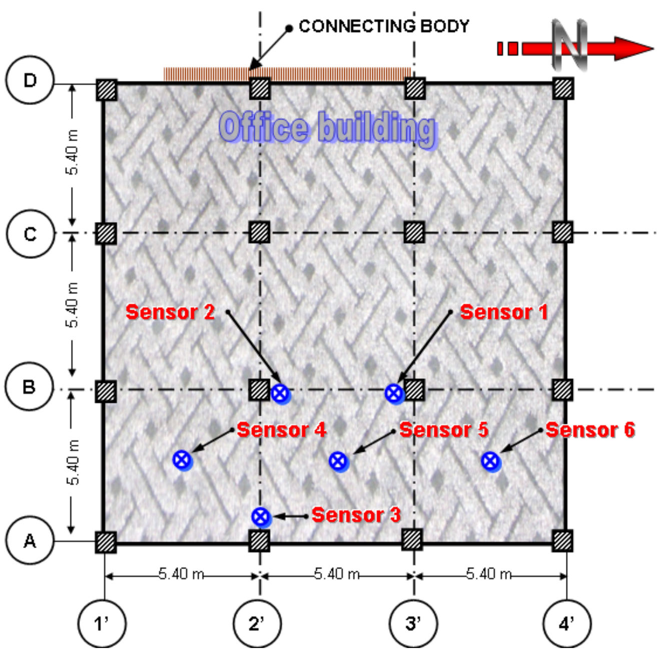


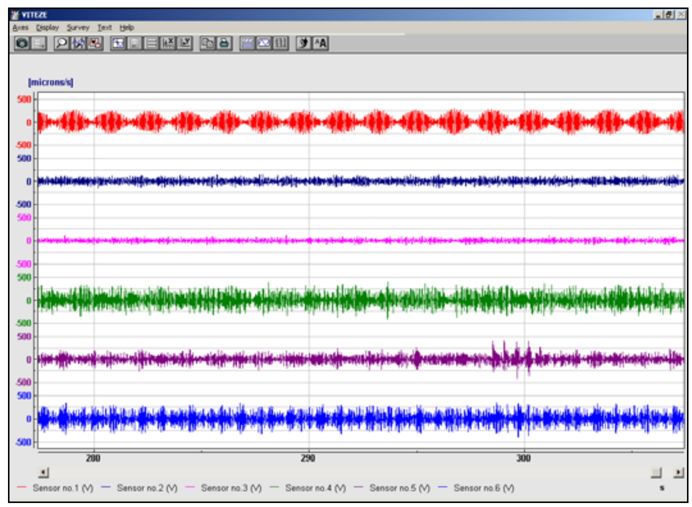
Fig. 37. Office building. Location of sensors at the fifth floor.

- the identification of the starting moment of the perception of the annoying noise, both by instrumental way and by the presence at the fifth floor of the building of four persons of different ages; firstly, the vibrations were recorded in the six locations already specified considering as source of vibrations the ambient vibrations on the site in order to establish the eigenfrequencies of the three columns and of the three panels of the slab; then, the 17 rapier type weaving looms were successively set in operation, one after another, the vibrations thus generated being recorded in order to observe the starting moment of the weaving looms running and their steady state operation.

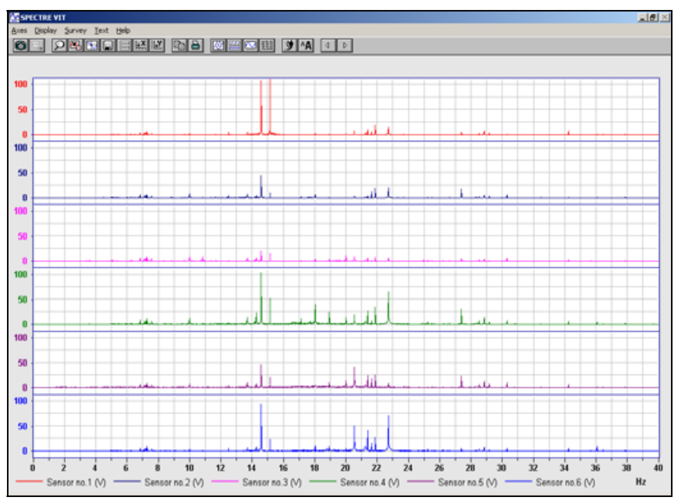
Typical time domain velocities and the corresponding amplitude Fourier spectra are shown in Fig. 38 and Fig. 39.

<u>Some conclusions after performing the second stage of instrumental investigations</u>

Some of the *conclusions* of the *second stage* of the instrumental investigations were the following ones:

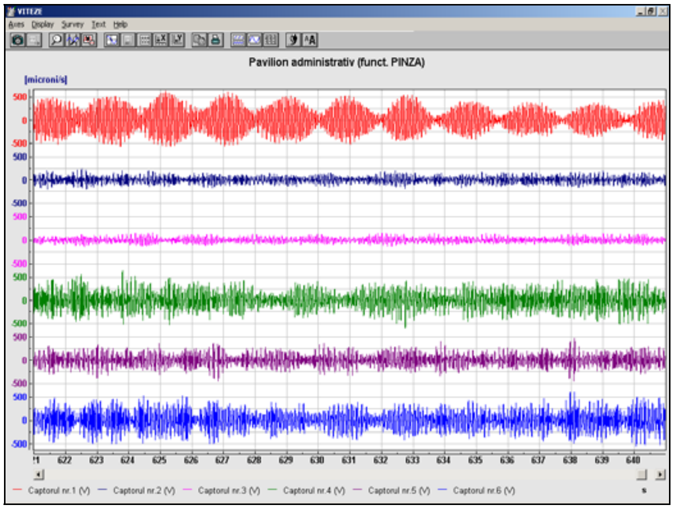


(a)

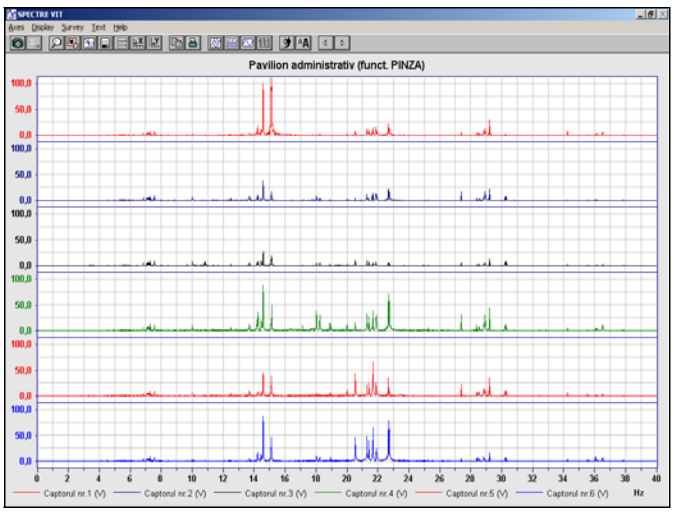


(b)

Fig. 38. Office building. Normal operation of 4 rapier type weaving looms. Velocities [μm/s].
(a) - time domain; (b) - amplitude Fourier spectra.



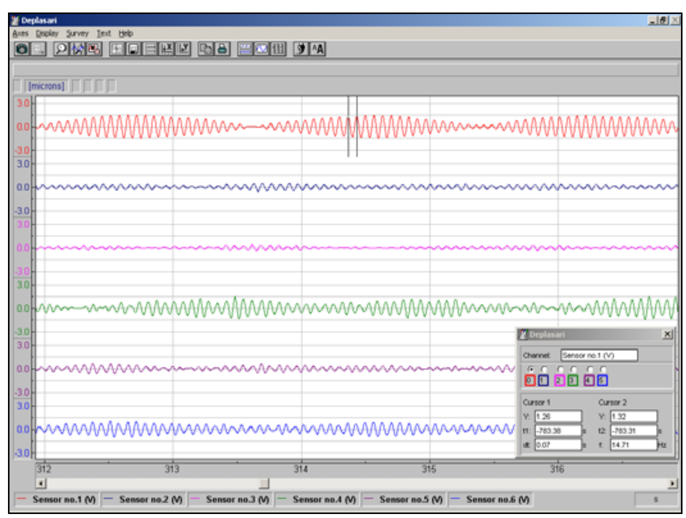
(a)



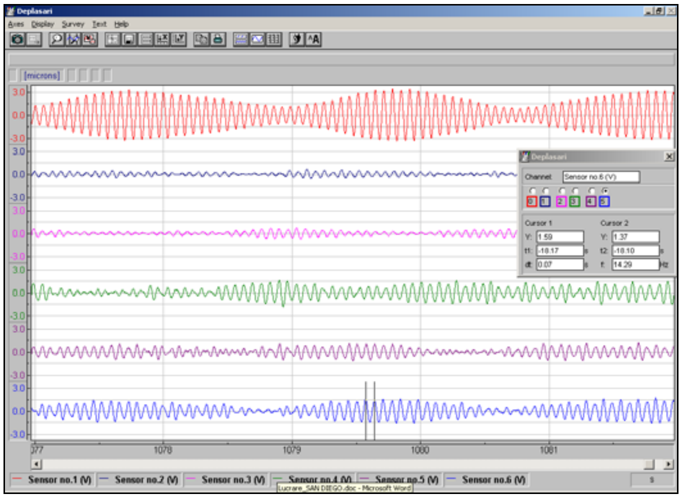
(b)

Fig. 39. Office building. Normal operation of 11 rapier type weaving looms. Velocities [μm/s].
(a) - time domain; (b) - amplitude Fourier spectra.

- the recorded data, both for “free” conditions (ambient vibrations) and for the “forced” ones (the running of the rapier type weaving looms), put into evidence a powerful tendency to a sinusoidal type configuration of the vibrations; this fact led to the conclusion that there existed a “powerful filtration” of these, due to eigenmodes of vibration of the structural system of the office building together with a reduced capacity of damping;
- the peak values of the recorded signals, practically for all time intervals, were reported on the column placed at the intersection of the axes B and 3′, and on the slab panels between the axes A – B and 1′–2′, respectively A–B and 3′– 4′;
- there is a sensitive tendency to non-synchronism of the recorded signals, both for the ambient vibrations as well as for the forced vibrations; this tendency is probably due to the powerful non-classical character of the eigenmodes (complex eigenvectors); it is difficult to consider a systematic character of non-synchronism, especially due to the complex dynamic system represented by this building;
- the study of the Fourier amplitude spectra put into evidence pairs of close marked spectral peaks around the values 7 Hz, 14 Hz, 22 Hz and 29 Hz; this result can be placed on the fact that there is a combination of two sources of vibration with close frequencies of operation (f=7.20 Hz, respectively f=7.50 Hz), which practically coincide with the fundamental eigenfrequency of the dynamic system represented by the office building (the measured frequency on the vertical direction is f_1=7.30 Hz, and the computed frequency on the same direction is f_1 = 7.14 Hz); *this was the case of dynamic system forced vibrations close to the resonance, followed by two levels of the phenomenon of beats*; the most pronounced spectral peaks are placed around the frequency of 14 Hz; thus, for the higher frequency (f = 7.50 Hz) the most pronounced spectral peak was identified for the interior column located at the intersection of the axes B and 3′; for the lower frequency (f = 7.20 Hz), the most pronounced spectral peaks were identified for the interior columns located at the intersection of the axes B and 2′ and for two slab panels (corresponding to sensors 4 and 6); there were also observed marked peaks for columns placed at the intersection of the axes A and 2′ and for the slab panel where Sensor 5 was placed (Fig. 37);
- as one can notice, the most pronounced spectral peaks were placed around the frequency of 14 Hz, in close vicinity of the lower limit of frequencies perceived by the human ear;
- marked spectral peaks were also identified for frequencies of superior order III and IV, at values equal to 22 Hz and 29 Hz;
- the phenomenon of acoustically perceived beats was well correlated with the obvious “beat” character of the records (Fig. 40) in time domain (filtered or non-filtered).



(a)



(b)

Fig. 40. Office building. Normal operation of 5 (a) and 17 (b) rapier type weaving looms. Signal filtered in the interval 14...14.9 Hz. Displacements [μm].

Final conclusions

The instrumental investigations and *in situ* observations revealed that the mechanical vertical vibrations of the column isolated foundations are induced through the columns in the whole building (to its floors, partitions and exterior walls). These vibrations are perceived in the building as "*acoustic waves*", especially at its fifth floor. It is an extremely rare case, when mechanical vibrations transmitted at distance are accompanied by a permanent noise with exceedance of thresholds of high intensity at very short intervals of time.

It must be specified that the cross section of all the interior columns differs from floor to floor, at the last two floors being 0.35 m x 0.35 m. The instrumental investigations of the vertical vibrations performed on the last floor of the office building, with sensors placed directly on the columns, revealed important differences in their response and an independent behavior. At the interior columns, the presence of vibrations near resonance was certified; thus the phenomenon of "*beats*" was present and perceived as an acoustic annoying noise. The waves induced to the structural system were refracted by the reinforced concrete floor and wall surfaces as an "*indirect sound*", unpleasantly perceived, as the people working inside could not localize its source.

As a conclusion, the vertical vibrations generated by the 17 rapier type weaving looms were perceived in the office building, especially at its fifth floor as "*sounds*" that were intercepted as "*dull sound*" (thud), due to the perception characteristics of the ear. At some time intervals the noise was amplified to "*thresholds of feeling*" (of high intensity), which created an extremely annoying sensation. The phenomenon of "beats" acoustically perceived was present in the response of the dynamic system represented by the office building, as a result of the fact that the disturbing source (rapier type weaving looms) had a "*permanent*" character (operating more than 8 hours a day) and the transmitted vertical vibration presented a strong tendency to harmonic type of waves. As a result that this tendency is also present in the "free" vibration conditions (ambient vibrations on the site, road traffic and technological processes in the near vicinity), one can state that this fact is favored by the structural system configuration of the office building and its reduced capacity of damping. The second condition of the presence in the dynamic response of the phenomenon of "beats" is also accomplished, as the frequencies of the sources (f = 7.20 Hz and f = 7.50 Hz for the two rapier type weaving looms) are very close to the fundamental eigenfrequency of the dynamic system on the vertical direction, instrumentally obtained (f_1 = 7.30 Hz), but *not* equal (response in the resonance vicinity).

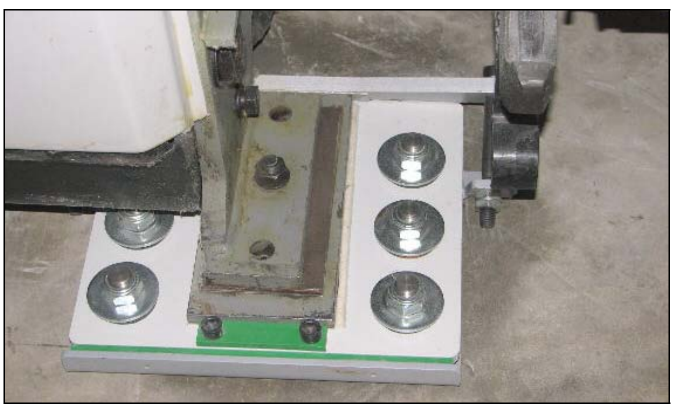
Remedial measures

After performing a complex program of instrumental investigations in two stages, the rapier type weaving looms was found responsible for these. It must be mentioned the fact that these weaving looms were installed in an old industrial building, not designed for such equipment, together with the fact that the supporting soil is of macroporous type, which favored the propagation of the vertical mechanical vibrations. Due to the local conditions, any other solution to stop the transfer of the vibration energy induced by dynamic sources (as an example the use of artificial barriers) was considered difficult, expensive and possibly ineffective; that's why the attention was focused on the "*source*" and on the "*system*".

The technical assessment of the two buildings was also performed in order to establish a solution for avoiding the vibration problems. During this process, faults in the design project and in the construction of the office building were identified. Among them, two structural deficiencies (the structure of foundation and the reduced cross sections of the columns at each floor) were the ones that favored the annoying acoustical vibrations. As the costs for the remedial measures for the five levels office building were high and they were not approved by the owner, an intervention on the vibration source remained as the unique solution. In general, the most effective method is the *reduction* of the energy at the *excitation source*. In this case, the excitation source was treated as an entity, by considering the process of isolation, damping and attenuation with the objective of reducing the propagated vibrations. Thus an agreement was reached by taking the decision to replace the system of isolation of the rapier type weaving looms. The associated phenomena to this intervention being extremely complex imposed the initiation of a costly research program, entirely sustained by the owner of the weaving looms, both in Romania and in Italy. Based on the first stage instrumental investigation results, the Italian manufacturer asked a specialized company from Italy to carry out a "*system of isolation*", capable to avoid the excessive vertical vibrations perceived both in the weaving shed and in the office building.

Two systems of isolations were tested. The first type was set at two weaving looms and the second one was set at two other weaving machines. The results obtained by instrumental investigations were that the level of vibrations in the weaving shed was reduced, but the annoying effects at the fifth floor in the office building still persisted. In this situation, the two systems of isolation were tested in the laboratory of RNCEEV. The obtained results led to the necessity of performing new instrumental investigations in the office building. This was the story of the second stage of instrumental investigations when three sensors were mounted directly on three columns and other three on three panels of the general slab of the fifth floor of the office building. As it was established that the two systems of isolation could offer neither the warranty of reducing the level of vibrations and, more than that, nor the annoying permanent noise at the last floor of the office building, the decision to design a new system of isolation was taken.

An engineer of a specialized company in weaving looms vibrations isolation, together with the owner of the equipment arrived in Romania to evaluate *in situ* the actual situation. Based on the second stage results of the instrumental investigations, a new type of "isolators" was created by the Italian manufacturer (Fig. 41). After setting up these isolators, the level of vibrations in the two buildings was substantially reduced. The permanent noise, but in principal the exceedance of "*thresholds of high intensity*", extremely annoying, which have produced the phenomenon of "acoustical fatigue" have also disappeared.



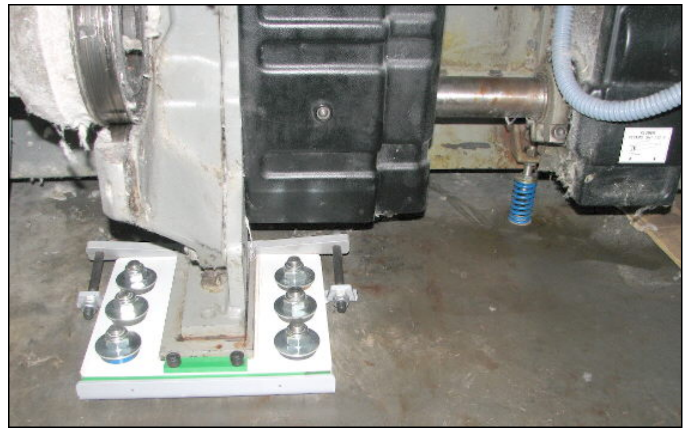


Fig. 41. Photos of the new system of isolation for the rapier type weaving looms.

DEMOLITION BY CONTROLLED EXPLOSIONS

General elements

The team led by the author of this paper has monitored the partial demolition by controlled explosions of the "Lujerului Shopping and Leisure Center", which consisted of three main units, separated one from another by aseismic joints. More precisely, R.N.C.E.E.V. has accomplished the dynamic monitoring of the structural system of the central part named "Body B" (reinforced concrete moment resisting frame type with a special steel structure dome), during the "Body A" and "Body C" (reinforced concrete moment resisting frame type) demolition by controlled explosions. A picture of the complex before the demolition is presented in Fig. 42. The designer was watchful with the process of demolition by controlled explosion in what concerned the behavior of the building that remained after the demolition, the vibrations of the neighboring buildings and the involved risks to people in the zone.

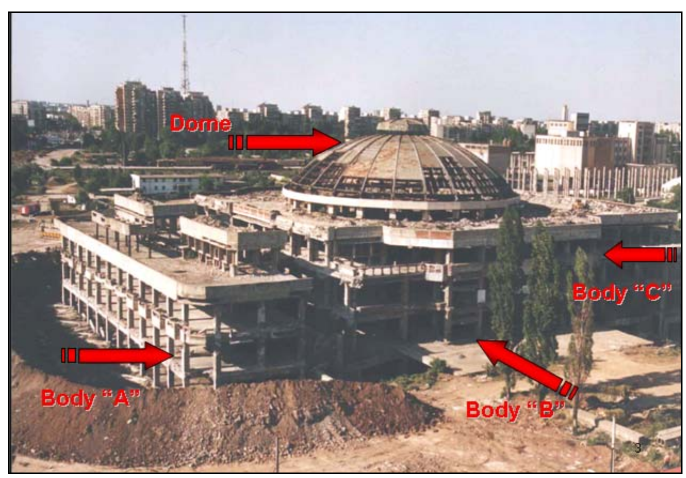


Fig. 42. General view of the complex before the demolition.

Structural monitoring, as part of the experimental process, tried to accomplish the following aspects:

- instrumental monitoring of the demolition by controlled explosions;
- recording of the ambient vibrations of the central part of the "Lujerului Complex", before and after the demolition of the lateral bodies;
- monitoring of the structural response of "Body B", during each blasting for the demolition of bodies "A" and "C";
- getting a comprehensive picture of the deformation of the structure (deformation due to bending of columns and evaluation of the displacements at certain points of the ring supporting the dome);
- providing useful data for the redesign process of the "Lujerului Shopping and Leisure Center".

The commercial complex was placed in a residential area, near the subway line and, for this reason, a *combined method* for the demolition appeared necessary to be adopted. The method consisted of performing a *set of small controlled explosions*, combined with the previous weakening of the cross sections of the vertical structural elements and joints (Fig. 43), by means of *mechanical techniques* (hydraulic cutter).

Fig. 43. View of the lateral wing before the demolition.

Instrumental investigations

The data acquisition system was conceived and developed in order to provide continuous recording of the vibration of the building "Body B" (the records were obtained in real time, continuously, before, during and after one performed the controlled explosions).

The response of the structural components can be determined by suitable choice of measuring points and orientation of the instruments. Consequently, several configurations for positioning the transducers on the building "Body B" were adopted.

There were used 6 SS-1 Ranger seismometers in simultaneous configurations, in order to record the response of the building "Body B" before, during and after the demolition by controlled explosions of the lateral buildings, on May 21st and June 6th, 2003.

The records have been carried out taking into account the following vibration sources:

- ambient vibrations in the "Lujerului" area;
- vibrations induced by the explosions during the demolition of the bodies "A" and "C", on May 21st and June 6th, 2003.

There were performed alternative settings of the pick-ups, two of these being presented in Fig. 44 and Fig. 45, in order to point out the following aspects:

- the motion in certain measuring points, located at equal distances at the level of the dome support (level: +18.20m);
- the non-synchronous motion at the locations of the pick-ups at the extremities of the dome diameter, on horizontal direction;
- maximum displacements at the dome support level, during the controlled explosions for the demolition of the body "Body A" and "Body C";
- frequency content of the recorded signals.

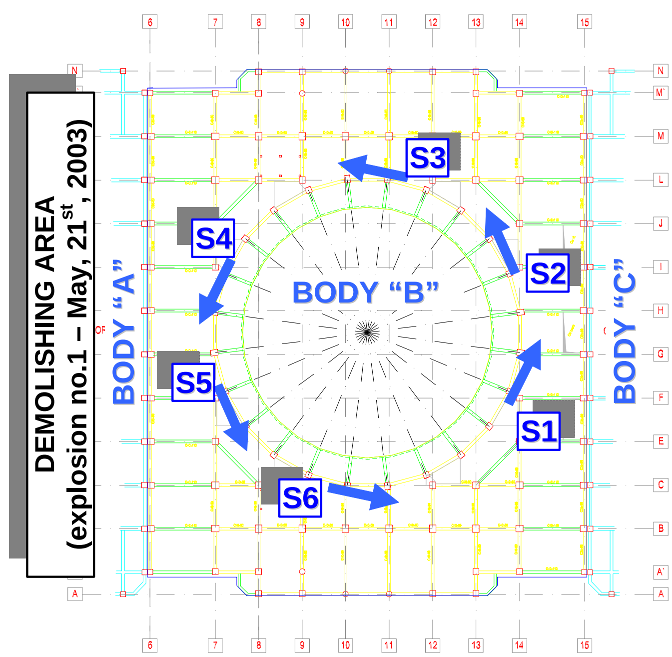


Fig. 44. Location of the sensors at the dome level.

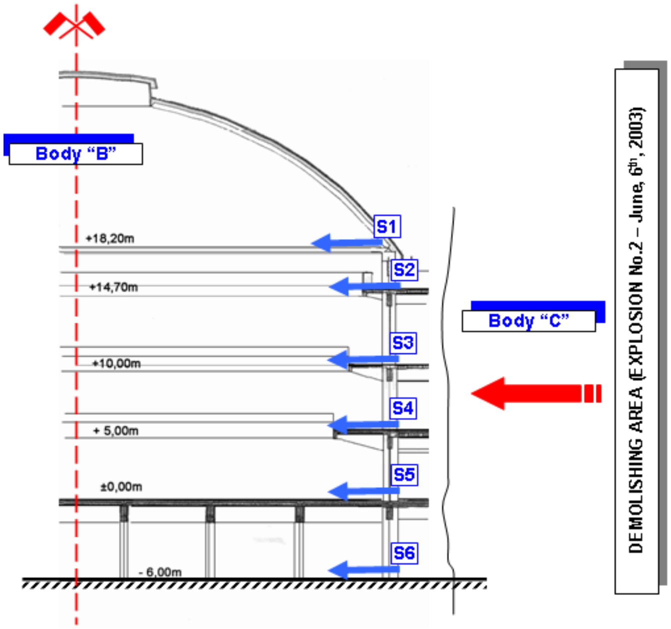


Fig. 45. June 6th, 2003. Location of the sensors in "Body B".

<u>Results of the tests carried on the building "Body B"</u>

Fig. 46 and Fig. 47 present the time domain and the corresponding amplitude Fourier spectra, considering ambient vibrations as source of the vibrations.

Other samples of the outcome of the numerical process are shown in Fig. 48 and Fig. 49 as follows.

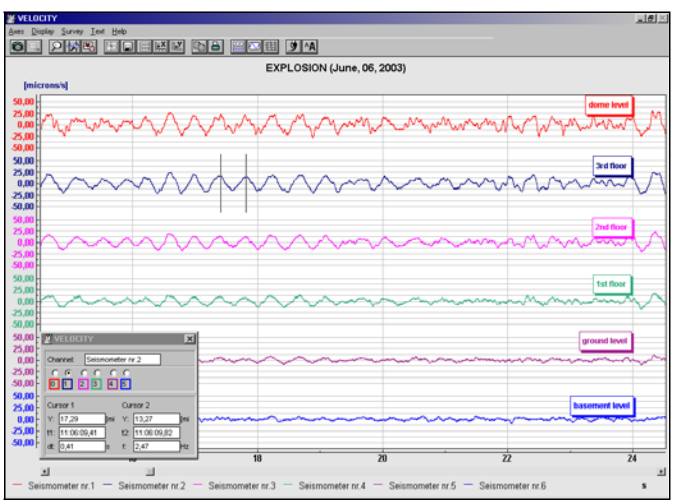


Fig. 46. June 6th, 2003. Ambient vibrations records. Time domain; velocities [μm/s].

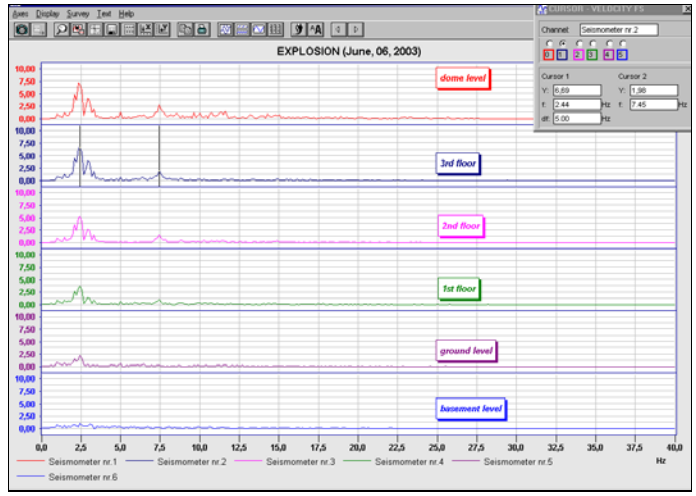


Fig. 47. June 6th, 2003. Ambient vibrations records. Amplitude Fourier spectra; velocities.

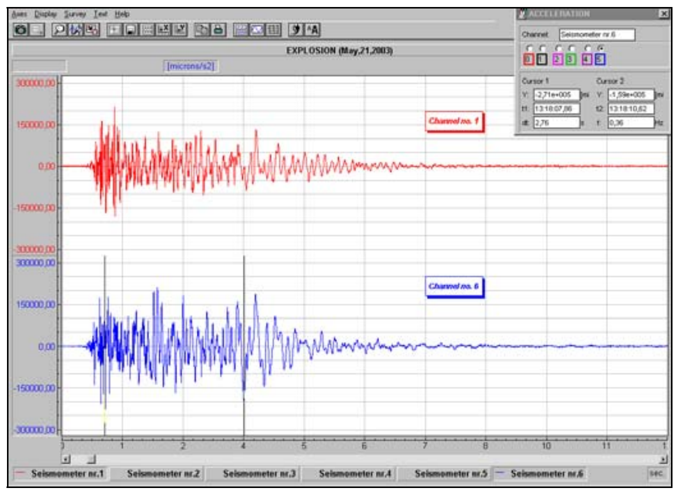


Fig. 48. May 21st, 2003. Demolition of "Body A" [cm/s²].

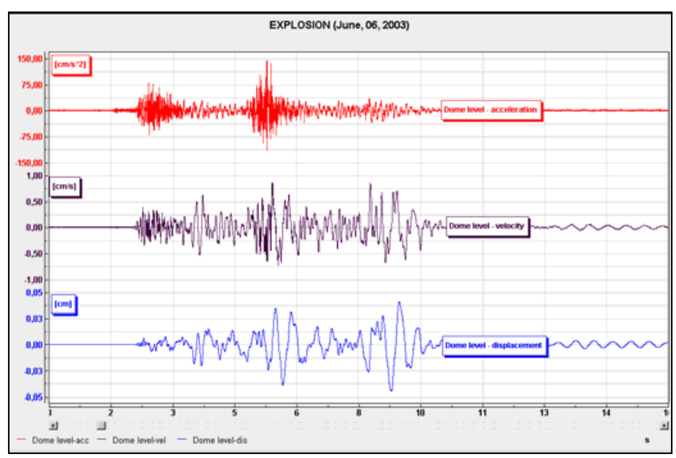


Fig. 49. June 6th, 2003. Dome level: maximum recorded values during the demolition of "Body C".

The Fourier Amplitude Spectra and the auto-correlation functions (Fig. 50) emphasized the frequency content of the recorded motions, as well as the increase of the dominant compounds.

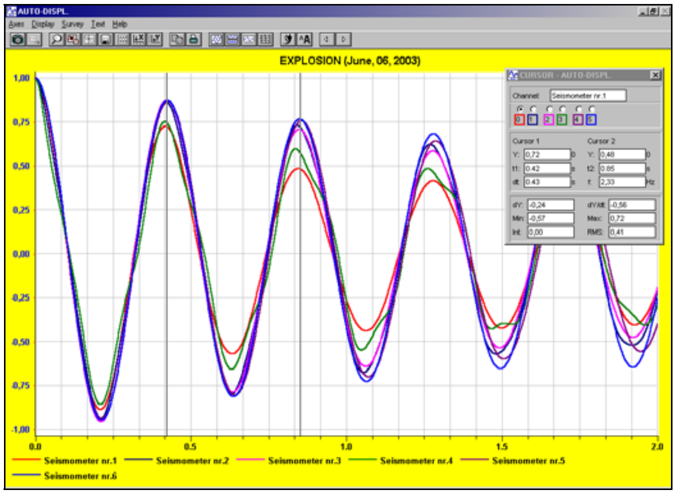


Fig. 50. June 6th, 2003. Auto-correlation functions.

Following the process and the understanding of the experimental data, the fundamental natural periods/ frequencies of vibrations of the building "Body B", within the "Lujerului Shopping and Leisure Center", have been established. These *measured values* are shown in Table 2.

Table 2. Natural periods/frequencies of vibrations of "Body B"

Measured values			
1st Eigenmode of vibration		2nd Eigenmode of vibration	
Frequency (Hz)	Period (sec)	Frequency (Hz)	Period (sec)
2.20	0.45	7.45	0.13

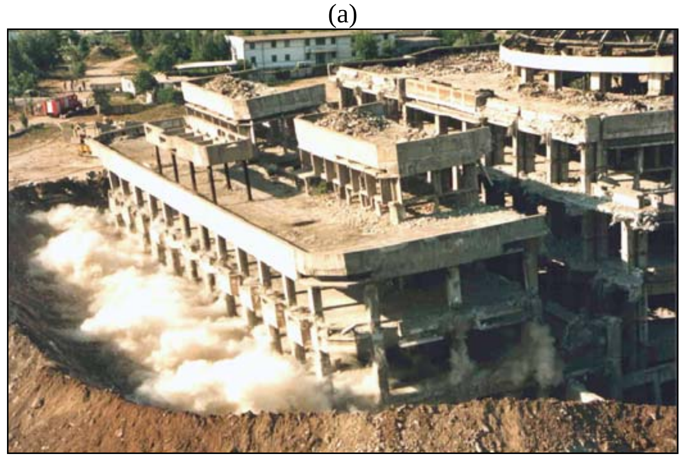
Table 3 shows, by comparison, the maxim values of the kinematic parameters of the motion recorded at the dome ring support, during the demolition by controlled explosions.

Table 3. Maximum values of the kinematic parameters of the motion, recorded at the dome ring support of "Body B"

Dome level (+18.20m)		
Measured parameters	May 21st, 2003	June 6th, 2003
Accelerations [cm/s^2]	57,57	142,6
Velocities [cm/s]	0,71	0,85
Displacements [μm]	500	440

The use of explosives near residential buildings and vulnerable structures was carefully done, in order to prevent injury to persons, damage to public or private property outside the permit area. The maximum recorded ground vibration (0.3cm/s) did not exceed the maximum allowable peak ground velocity (3.18 cm/s), for a distance of 90 m from the blasting site, according to the U.S. Code of Federal Regulations (Sec.816.67 /2003). In Fig. 51, (a)÷(d) and Fig. 52 (a), (b), are shown photos taken during the performing of the two controlled explosions, in May and June 2003.

(a)



(b)

(c)

(d)

Fig. 51, (a)… (b). May 21st, 2003. Photos taken during the demolition of "Body A".

(a)

(b)

Fig. 52, (a), (b). June 6th, 2003. Photos taken during the demolition of "Body C".

<u>Some conclusions</u>

As it was previously mentioned, six high sensitivity pick-ups located at the most vulnerable places of "Body B", in relation to the effects of controlled explosions, were used. These pertained to the zone of support of the dome steel structure by the main loadbearing system of the building, as well as along a vertical axis.

The small controlled explosions had two simultaneous effects:

- the destruction of the gravity loadbering of the structural systems of the lateral bodies, by the collapse of the columns at the basement level;
- the generation of a soil vibration, similar to an earthquake motion.

After each explosion a gravity collapse mechanism was initiated, which was a second shock applied to the soil, having a much smaller intensity and being nonsimultaneous with the explosions.

For the demolition of each lateral unit, 20 small explosions, each of them being delayed with 25 miliseconds (meaning a period of 0.5 sec), were performed. The author considered the action of the set of 20 small explosions as a cumulative action, of seismic shock type, having the duration of 0.5 sec, which is of the same order with the natural period of the remaining building and soil.

The examination of the fundamental eigenvalues derived from records showed that these pertain to a narrow band of frequencies, which made it possible to derive the conclusion that "Body B" shows a homogeneous performance in case of free vibration, along both horizontal directions (there are no noteworthy differences between the values of fundamental natural frequencies along the two principal directions of the building).

The fundamental natural period of the body "B", before performing the controlled explosions, checked after performing the explosions (considering as a disturbing action the ambient vibration, including the contribution of street traffic), had the same value, which puts to evidence the fact that the building "Body B" was not at all affected by the controlled explosions used for the demolition of the bodies "A" and "C". On the basis of auto-correlation functions of the recorded signals, it turned out that the values of the fraction of critical damping obtained on the basis of specific processing pertain to the interval 3…5%.

The signals recorded at the level of dome supports put to evidence non-synchronous motion at the locations of installing the pick-ups at the extremities of a dome diameter. This may be due to the special layout of the body "B".

The visual examination of the supporting zones of the dome by the main loadbearing system did not put to evidence local damage to concrete, or dislocation of the steel supporting systems. Comparing with the mechanical demolition techniques, the major advantages of the used combined method are: short period of the demolition process, limited use for heavy machinery, applicable in case of narrow space and difficult access to the demolition site and cost effective and time saving.

To conclude, one can state that the demolition of the bodies "A" and "C", by means of controlled explosions, had no unfavorable effect upon "Body B" (the modal characteristics of "Body B", before and after the demolition of the lateral wings, remained the same).

CONCLUSIONS

This Special Lecture which honored me was a good opportunity to bring in front of the researchers which attended this international conference three cases of vibration studies, together with an example of safe blast demolition by controlled explosions, that are not so often encountered in the technical literature.

The author was very fortunate when he found the paper of Professor Richard Woods entitled "*Sideway in Offset Printing Presses*" that helped him in solving a similar practical problem of printing press vibrations in Romania. Without the research works made and published by Professor Woods in 1987, a lot of efforts and resources would have been wasted.

Many such case studies were published in the proceedings of the international conferences on "Recent Advances in Geotechnical Earthquake Engineering" and on "Case Histories in Geotechnical Engineering". That's why the author wants to dedicate this Special Lecture to Professor Shamsher Prakash for all his efforts in organizing these two series of international conferences of high scientific level.

ACKNOWLEDGEMENTS

It is a duty of honor to bring the author's gratitude to Dr. Horea Sandi, Chairman of the Division of Civil Engineering of the Romanian Academy of Technical Sciences and to Emilian Titaru, honorary member of the Romanian Academy of Technical Sciences, for their valuable help and involvement during the works. Their support is gratefully acknowledged.

REFERENCES

Hall, J.R. Jr., Editor [1987]. "Use of Vibration Measurements in Structural Evaluation", *Proceedings of a session sponsored by the Structural Division of the American Society of Civil Engineers in conjunction with the ASCE Convention,* Atlantic City, New Jersey

Prakash, S. and Puri, V.K. [1988]. "*Foundations for Machines: Analysis and Design*", Wiley Series in Geotechnical Engineering, John Wiley and Sons, New York.

Richart, F.E., Jr. *et al.* [1970]. "*Vibrations of Soil and Foundations*", Prentice Hall International Series in Theoretical and Applied Mechanics, Prentice Hall, Englewood Cliffs, New Jersey.

Sandi, H. [2009]. Personal communication.

Titaru, E. [2009]. Personal communication.

Vlad, I. [1997]. "Solution Techniques for Eigenvalue Problems of Structural Dynamics of Machinery Foundations. An Accelerated Subspace Iteration Procedure", Scientific Bulletin of T.U.C.E.B., No.2, Bucharest

Vlad, I. [2001]. "Mathematical Modeling and Experimental Dynamic Investigation of an Elevated Foundation Supporting Vibration Machinery", *Fourth International Conference on Recent Advances in Geotechnical Earthquake Engineering and Soil Dynamics,* San Diego.

Vlad, I. and Vlad, M.N. [2004]. "Health Monitoring of a Building during the Demolition of its Lateral Wings by Controlled Explosions", *Third European Conference on Structural Control*, 3rd European Conference on Structural Control, Vienna University of Technology, Vienna, Austria

Vlad, I. [2008]. "Case History of the Malfunctioning of a *Compressor – Foundation – Supporting* Soil System", *Proceedings of the 6th International Conference on Case Histories in Geotechnical Engineering*, Arlington, VA

Vlad, I. and Vlad, M.N., [2008]. "Case Study of Annoying Vibrations Generated by Unbalanced Forces of an Offset Printing Press", *Proceedings of the 6th International Conference on Case Histories in Geotechnical Engineering*, Arlington, VA

Vlad, I. and Vlad, M. [2010]. "Mechanical and Acoustical Vibrations of a Building Generated by Weaving Looms", *Proceedings of the Fifth International Conference on Recent Advances in Geotechnical Earthquake Engineering and Soil Dynamics,* San Diego, CA

Woods, R.D. [1987]. "Sideway in Offset Printing Presses", in *Proceedings of a session sponsored by the Structural Division of the American Society of Civil Engineers in conjunction with the ASCE Convention*, Atlantic City, New Jersey, pp.16-31