ISSN 2176-5480

22nd International Congress of Mechanical Engineering (COBEM 2013)
November 3-7, 2013, Ribeirão Preto, SP, Brazil

DYNAMIC AND STATIC TESTS IN COMPOSITE STRUCTURE SUPERIMPOSED NOT ADHERED WITH ELASTIC SUPPORT

Fábio Raia
Alfonso Pappalardo Junior
Universidade Presbiteriana Mackenzie, Rua da Consolação 930, São Paulo
1097962@mackenzie.com.br

Milton Dias Junior
Universidade de Campinas, Faculdade de Engenharia Mecânica, Campinas
miltondias@fem.unicamp.br

Hugo Heidy Miyasato
Universidade de Campinas, Faculdade de Engenharia Mecânica, Campinas
hugomiyasato@gmail.com

Vinícius Gabriel Segala Misionatto
Universidade de Campinas, Faculdade de Engenharia Mecânica, Campinas
viniciussimionatto@gmail.com

Abstract. *The numerical and experimental modeling of static behavior of composite structures superimposed not adhered is the object of the study of the present work, which seeks to generate a dynamic numerical modeling on a structure, whose characteristic is to own elastic support. The study is based on experimental results conducted on the structure and behavior with respect to dynamic loading, coupled with static loading, it can be served, with the data, for studies of fault under the imposed circumstances. This combination of loads may help to validate the numerical methodology and still generate results of interest about its useful life. The aim of this work is the systematization of experimental data in order to set a numerical process that applies to a real structure for the estimation of the failure and its modal behavior when requested dynamically. It was built on a small and distorted scale, with a flat and rigid geometry, whose structural element, plate, was instrumented with strain, acceleration and displacement sensors. The experiments were performed in a laboratory able to support all the requirements of the experiments. Under these conditions, the hypothesis is that instead of instrumenting a structure in a real scale for removing data, it can be performed the same procedure on laboratory where, controlling certain variables and the possibility of the repetition of tests, the strengthen for appropriate responses for the study of structures supported by elastic means, can be provided.*

Keywords: *dynamic loading, plate, numerical modeling*

1. INTRODUCTION (TIMES NEW ROMAN, BOLD, SIZE 10)

The dynamic behavior of plane structures such as slabs, supported at discrete points or suspended in the form of decks motivate research studying, among other phenomena, the vibrational modes and resort to computing resources that can capture the actual or expected behavior of the structure . When the interaction of the structure depends on the behavior of the lower layers and the dynamic response of these, the numerical study requires more complete data for a coherent and consistent with reality.

This type of structure - plate - which has ongoing support is commonly used in industrial floors, airport yards or road surface, whose activities in those places have characteristics of periodic or impulsive loads. This motivates research aimed at modal behavior and its effects on the structure.

Moreover, unadhered overlapping structures arising in everyday life as a bearing support vehicles or machines. The exposure of the structure to daily events brings the appearance of defects, despite being known, leading experts to conduct specific experiments, in order to obtain more knowledge about them and search refinement theoretical information generated by experiments. This refinement made by the measurement of physical phenomena, through experimental processes, is a good way to study the behavior of the structure facing the stresses to which it will be subjected during its life. Among them can highlight the variations of temperature and deformation. This information has, since then, a key role in setting theory or validations on mathematical models or even confrontation statistical models for forecasting.

A previous literature indicated that in all cases studied, the structures were analyzed in situ under normal environmental conditions. Although this process portray the truth of the behavior of the structure, prevents some procedures may be revised, modified or repeated. Furthermore, it is known that the repetition of tests under the same conditions are problematic and sometimes impractical when there is dependence on environmental factors, not to mention the impossibility of conducting accelerated tests with repeating cycles.

An alternative or a way around these problems was to build a structure inside a laboratory that allowed the application of controlled conditions, whose advantage was the full control over the variables. This allowed the control and manipulation of important parameters such as the intensity of the imposed loads, frequency, deformation, temperature, displacements, accelerations, or even conducting structural studies with different compositions of thicknesses, different compositions of support and the possibility of performing accelerated testing.

To study the internal structure deformations, it has opted for Concrete Construction without frameworks. This facilitated the insertion of modeling and sensors in the laboratory. This material, after curing, has hardness and elasticity characteristics similar to other materials, allowing conclusions extend to other materials. The plate as constructed has the function to resist and distribute the vertical forces, horizontal and tangential as indicated Balbo (2007).

The design of the structure was carried out according to the lower layers, whose duty is to support the loads applicants, for example, bending stresses which depend on the applied load, the contact area of the elastic means on which it rests and thickness . The study of plates was similar characteristics realizad by Westergaard (1926). This study was indicated as critical point, the edge of the plate. It is emphasized that the study by Westergaard, the set of layers composing the structure has elastic behavior linear, and the layers are characterized by the modules reaction "k", an equivalent modulus of elasticity of the material.

The structure - the plate - is defined as a structural laminate which can also be characterized by having a dimension negligible, small, compared to the other two. According to the material it is made, they can be classified as (TIMOSHENKO, KREGER, 1975):

a)isotropic: when the properties are the same in any direction;
b)orthotropic: when the properties are different in two orthogonal directions;
c)anisotropic: when the properties are different in all directions.

The ratio of the thickness *h* by the length *L* classifies board as:

a) thin if it happens the relation: $\frac{1}{100} < \frac{h}{L} \leq \frac{1}{5}$; (1)

b) very thin if the dimensions obey the relation: $\frac{h}{L} \leq \frac{1}{100}$; (2)

c) moderately thick when occur the relation: $\frac{h}{L} > \frac{1}{5}$. (3)

By hypothesis, the structure under study was considered isotropic and due to its dimensions 3,00 m long, 1,78 m wide and 0,15 m thick was classified as thin**.**

1.1 OBJECTIVE

The aim of this work is the systematization of experimental data in order to check a numerical process that is applicable to a real structure, to estimate the modal behavior when requested dynamically.

As specific objectives it has highlighted the study of methodology for control and dimensioning of concrete structures and their static and dynamic peculiarities, when put in a state of repose, isolated from interference of external factors. By hypothesis, this state allows to obtain "clean" data of stresses and strains, as well as, indirectly, present a methodology for accelerated testing in the laboratory, plates, alternating the dynamic state. This justifies the elaboration of this work based on the development of a numerical study setting, with the intention that the confrontation of the data can help to provide a basis for future researches into similar structures.

2 METHODOLOGY

To obtain the static and dynamic data (modal) board was instrumented with accelerometers, displacement sensors (LVDT) and strain sensors. The structural assembly, consisting of three overlapping layers, showed a non-monolithic structure, with the highlight the fact of not being adhered to, have a rectangular geometry and linear scale and distorted[1].

The structure was built on a slab of reaction and under a testing of tension/ compression machine, driven by a hydraulic cylinder and instrumented with a load cell with a capacity of up to 1,5 MN. The dynamic excitation of the plate was initially performed by a motor with unbalanced mass and later by an impact hammer.

The construction process of deformation sensors followed procedures described by Raia (2010), Pappalardo (2006), Sargand, Khory (1999) forming a load cell called inlay cell (EC) or cell strain. This extensometry inlay follows the same considerations and techniques used in extensometry of surface.

[1] In this study the dimensions of length and width are in a range of 1:2, while the thickness has a 1:1 relation. In this situation the scale can be regarded as distorted.

ISSN 2176-5480

The signal conditioning was carried out by a system manufactured by Lynx Technology Ltd, Model 2000 ADS capable of withstanding, without multiplexing, thirty two differential channels.

The interpretation of the signals was performed by a software, developed in the programming language C^{++} provided by the manufacturer, called AqDados and data analysis strain, acceleration and displacement was performed by other software provided by the manufacturer known as AqDanalysis v.7.02.

All data were systematized by the statistical software MINITAB ® and Microsoft Excel(R) spreadsheets. For verification of the natural frequencies in the x, y and z, with greater interest that last coordinate, the plate was instrumented as shown in Fig 1.

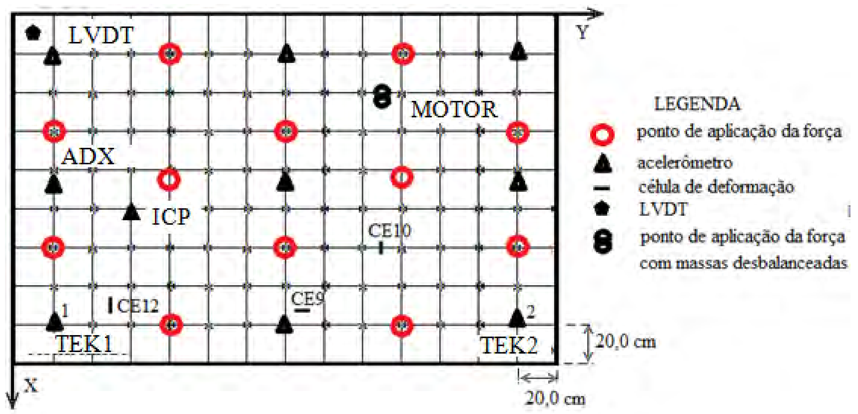

Figure 1. Position of sensors and application point of harmonic dynamic load on the structure of the plate.

Two accelerometers (indicated by 1 and 2) were maintained on a fixed structure, for identification of critical frequencies when the plate was subjected to continuous excitation. The sensors deformation (indicated by EC) indicated the deformation of the inner plate. The displacement sensor (LVDT) was kept fixed at the origin of the system and to indicate displacement of this point. These sensors recorded the behavior of the structure when excited by unbalanced mass and the percussion hammer impact.

The hydraulic structure loaded with 20,0 kN and on this load, the engine driver kept a cyclic load of 700,0 N. The test structure is shown in Fig 2, the cyclic load was applied on one corner plate simulating loading of 700,0 N. The cyclic interval was controlled with a frequency inverter brand Ageon, XF model standard.

Figure 2 Appearance of the structure and the hydraulic machine used in the experiment.

The percussion for the frequency analysis was performed by means of an impact hammer and in the positions determined by the number of accelerometers. Figure 3 shows the positioning of the accelerometers, according to the planning performed in Figure 1.

Figure 3. Placement of accelerometers on the plate.
Marked in red excitation points.

Figure 4 shows the process with percussion hammer impact. It was used seven accelerometers and a system of acquisition of signals in the LMS International, which is shown in detail.

Figure 4. Excitation of the plate with impact hammer and data acquisition system.

The fixation was performed with accelerometer-based cyanoacrylate glue (superglue) on the surface of the plate. As the engine speed with unbalanced masses was performed with digital tachometer ICEL brand, model TC5010.

The numerical modeling used the finite element method using the ANSYS ® software (academic license) used to simulate the modal behavior and spectral structure, which was modeled after real data extracted from the physical model exposed in the laboratory.

The harmonic excitation was imposed according to Eq (4), whose amplitude of force imposed, was 700,0 N.

$$F(t) = F_0 \cdot sen\omega t = 700\ \mathrm{N} \cdot sen(2\pi f t) \tag{4}$$

The analysis was performed using hexahedral solid elements with eight nodes and elements laminar plate with four nodes, for introducing elastic coefficient. Figure 5 shows the mechanical characteristics of the plate, as well as the elements used.

ISSN 2176-5480

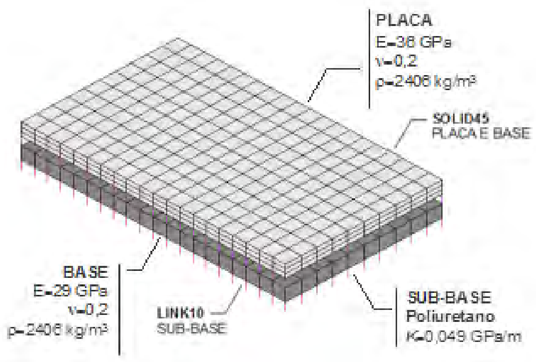

Figure 5. Physical properties of each element of the structure and types of finite elements used in dynamic analyzes the structure (modal, harmonic and impact).

3 EXPERIMENTAL AND NUMERICAL RESULTS

3.1 EXPERIMENTAL RESULTS FOR CYCLIC LOADING

Figures 6, 7 and 8 show the value of the overall level of vibration occurring on the board during testing when it was charged for 2 months cyclically varying frequencies in the range of 400,0 rpm to 800,0 rpm values corresponding to speeds of vehicles or machinery that travels on the structure. Higher speeds were not achieved with the excitation system for unbalanced masses. In the present paper will be analyzed only the condition of 480,0 rpm.

Figure 6 shows the behavior in the cyclic loading of 480,0 rpm seen by accelerometers fixed on the plate surface. The spectrum shows that the frequency of 8,0 Hz, is related to the engine, that is at 60,0 Hz mains interference. Accelerometers were chosen due to the characteristics of sensitivity and response time. One of the accelerometers, ADX, is the type Microelectromechanical systems (MEMS) accelerometer ICP is the common type piezoelectric as well as the other two, and TEK2 TEK 1.

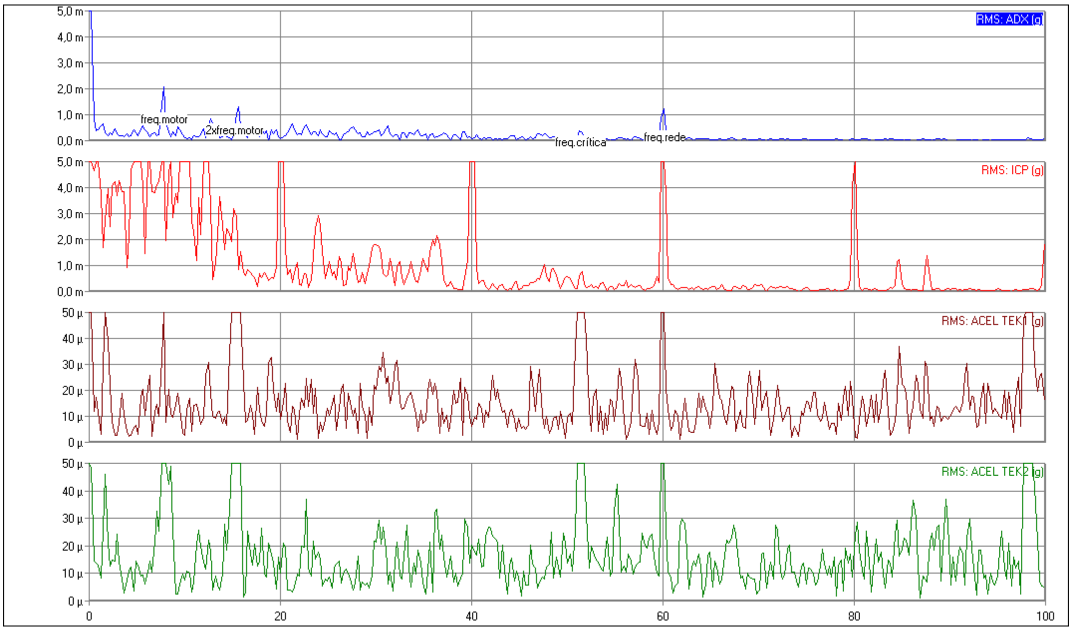

Figure 6. Global spectrum seen by accelerometers ADX, ICP, and TEK1 TEK2
to the excitation frequency of 480,0 rpm

Figure 7 shows the overall response of the sensors CE9 inlay, CE1, CE12 and the load cell. The ECs have similar responses and indicate how the vibrational behavior internal to a board. The load cell indicated the resulting behavior of the relative fluctuations between the test machine and the plate.

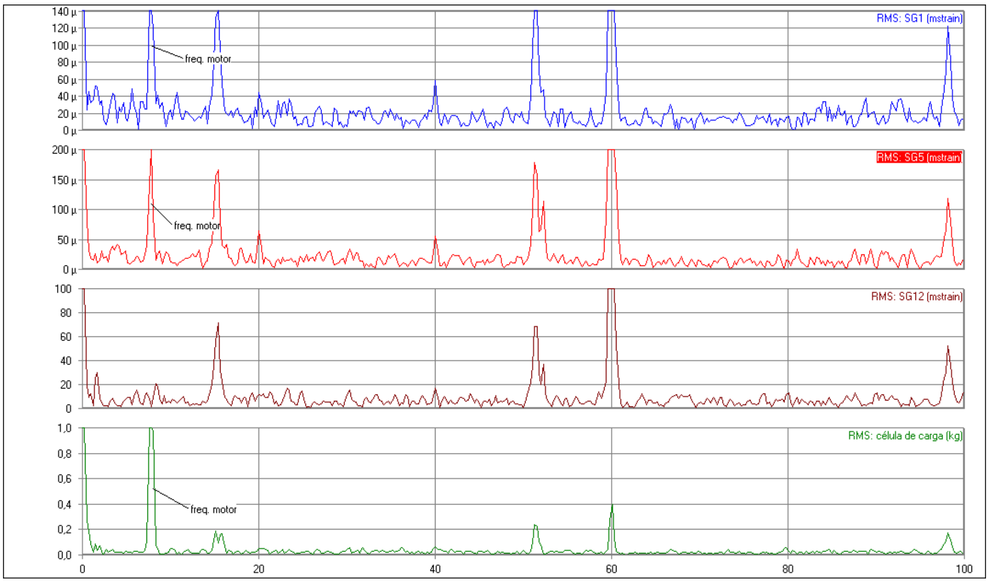

Figure 7. Global spectrum seen by the sensors CE9, CE1, CE12
and load cell for the excitation frequency of 480,0 rpm.

Figure 8 shows how the plate behaves in terms of displacement as seen from LVDT displacement sensor and another similar type potentiometer (POT). The difference between the two sensors is resolution. Nevertheless, it was noted their occurrence frequencies. The vertical scales were not standardized.

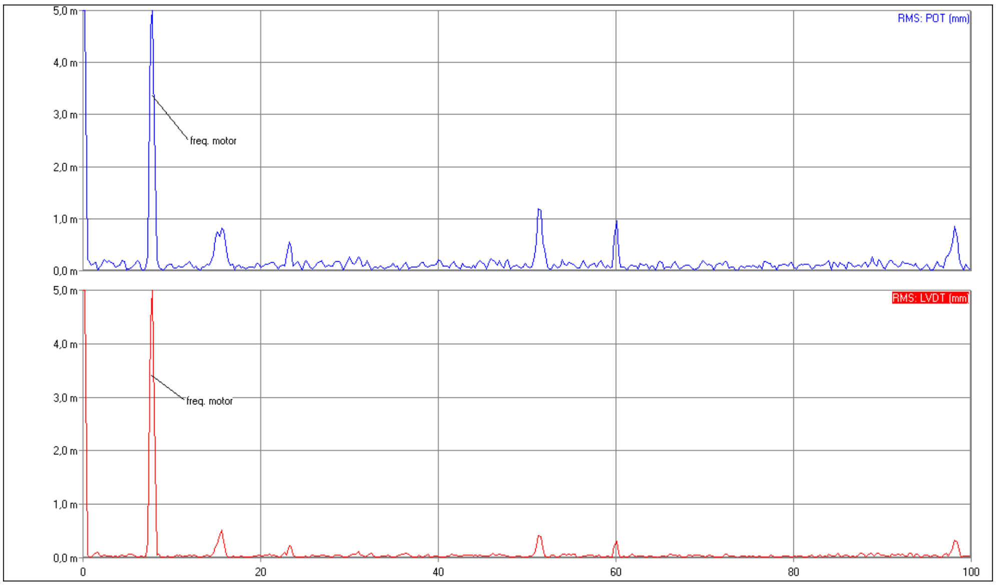

Figure 8. Global displacement seen by the sensors LVDT and POT
to the excitation frequency of 480.0 rpm.

3.2 NUMERICAL RESULTS FOR HARMONIC ANALYSIS

The following, are shown the results of numerical simulation by finite elements relating to the practice performed with motor mass unbalanced. Figure 9 shows a simplified view of responses at each point of the structure by means of numerical simulations, it was possible to excite the structure at a frequency of 480,0 rpm at the same point and collect data as done in the experimental part. The response was consistent, as globally, the frequencies appeared in the same spots seen previously in other words, the simulation was able to capture the same vibration modes**.**

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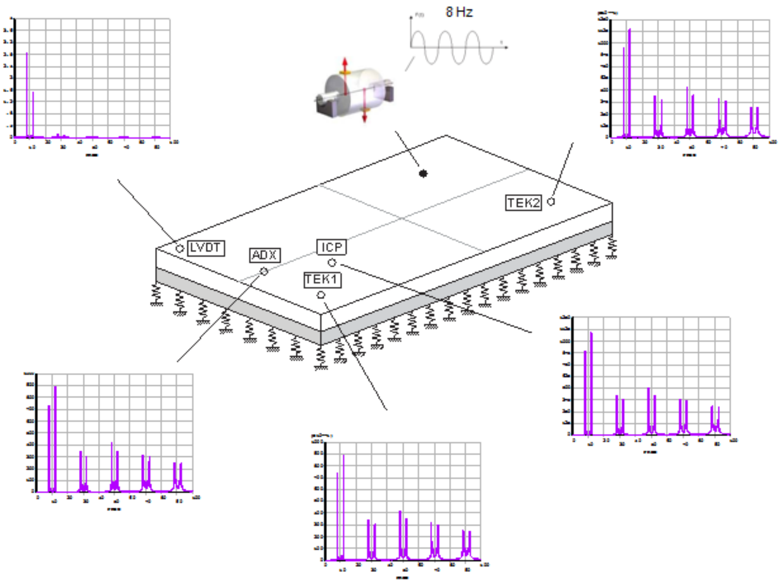


Figure 9. Displacement response spectra (LVDT), and
to the frequency of accelerations forced 480,0 rpm.

3.3 EXPERIMENTAL RESULTS FOR IMPULSIVE LOAD

The impulsive loading was done with impact hammer on the points described in Figure 10. Points 1-15 indicate where the plate was excited, points in red indicate where they were measured accelerations and frequencies. The designations C2 to C8 represent the channels of the acquisition system, which is the same classification used in the frequency response functions (FRFs). Channel C1 represents the excitation force at point 1 (see figure legend). Thus, FRF (C1, C7), for example, shows excitation response at point C1 and C7. Only the graph of Figure 11 with excitation at one point is shown and the related frequency curves corresponding to points 3-9 - 8-7 - 13:15. The analysis was performed with similar data taken at the same points excitedly at point 1-13.

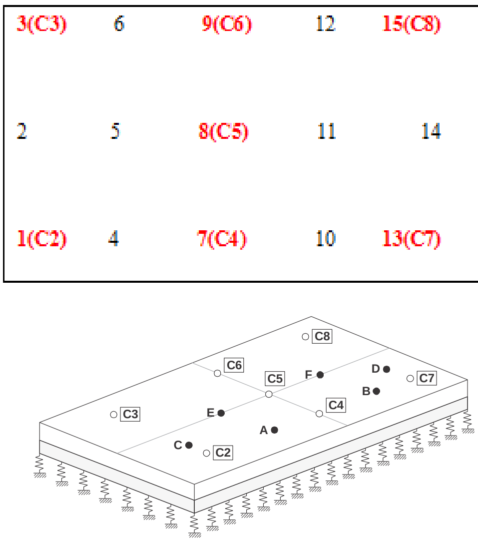


Figure 10. Arrangement of measurement points and excitement run on the plate.

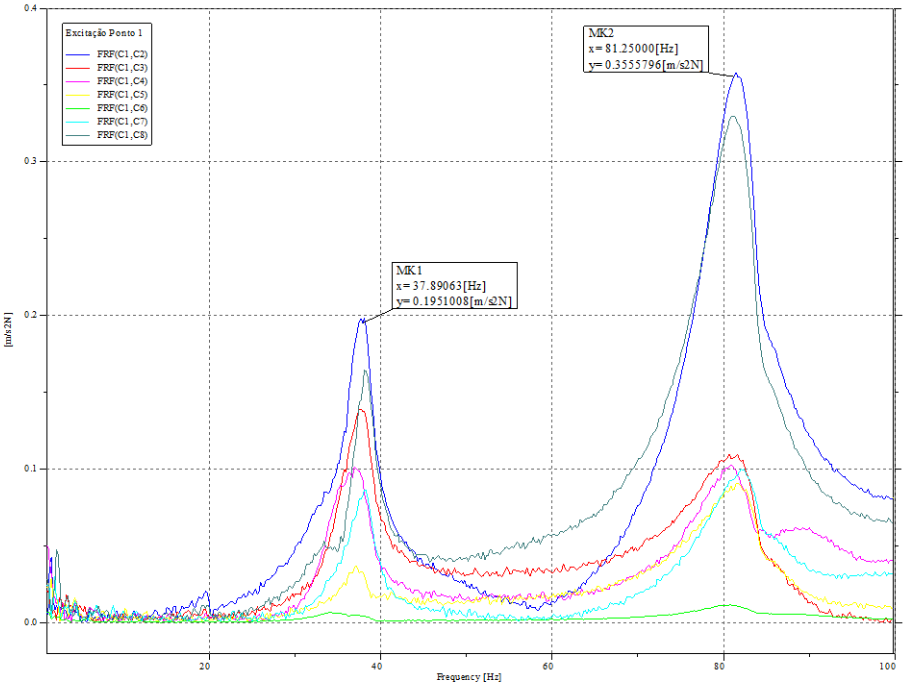


Figure 11. Frequency response with excitation at point 1
with their respective accelerations

3.4 NUMERICAL RESULTS FOR IMPULSIVE ANALYSIS

The following, are shown the results of numerical simulation concerning to the experimental part held with the impact hammer. It was considered for the dynamic analysis, transient time increments of 0.03 seconds to the time of analysis was 100,0 seconds, the weight of the hammer is equal to 10,0 N with a duration of 0.3 seconds without dampening. Figure 12 shows the response time as a result of the simulation by finite element method, with excitement at the same points made above, i.e, only one graph is representative, but the excitations were carried out in sections 3-9 - 8-7 - 13 and 15. The analysis was performed with similar data taken at the same points excitedly 1-13. The graph in Figure 13 shows the temporal response of the excitation point A, corresponding to point 4 of Figure 10. Table 1 shows an illustration of the behavior of the structure with the demands imposed.

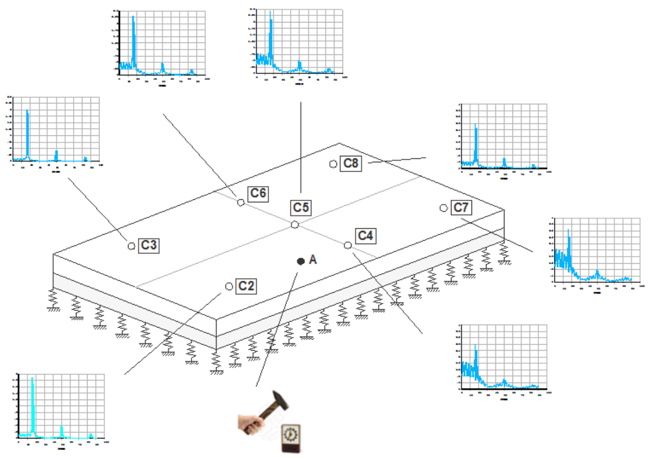


Figure 12. Point of impulsive load application
(point A) and instrumentation points (C2 to C8)

ISSN 2176-5480

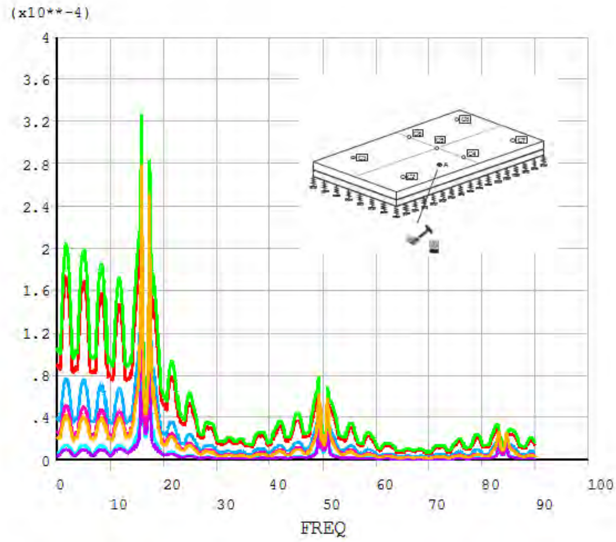


Figure 13. Acceleration response spectra for the points Instrumentation (C2 to C8) for the impulsive load at point A

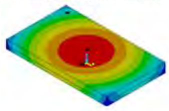
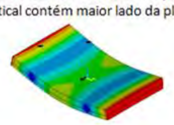
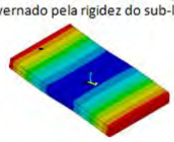
MODO	FREQUÊNCIA (Hz)	FORMA MODAL	MODO	FREQUÊNCIA (Hz)	FORMA MODAL
1	45,5	Deslocamento translacional vertical governado pela rigidez do sub-leito 	3	112,0	Flexão da base e sub-base no plano vertical contém maior lado da placa 
2	79,8	Deslocamento rotacional do conjunto governado pela rigidez do sub-leito 			

Figure 14. Vibration modes of the structure according to the frequencies imposed

Figure 15 indicates succinctly the experimental responses at the points indicated with overlapping numerical results.

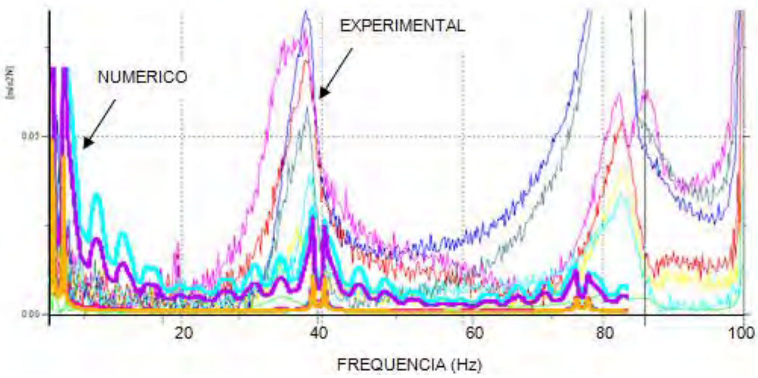


Figure 15. Comparison of numerical and experimental results for point of impulsive load application (point A) in instrumentation points (C2 to C8)

4 INTERPRETATION OF RESULTS

The experimental data obtained in sections TEK1 TEK2 and show how the board behaves with three different frequencies. Figure 6 although not show frequency details, from 0,0 Hz to 10,0 Hz, it can be understand that the plate responds in frequency of 8,0 Hz. Figure 7, which shows the behavior of the internal plate that was captured by the embedded sensors, they show the operating frequency of the motor, as well as amplitudes in the region of 50,0 Hz and one near 100,0 Hz, as mutiplicity it is not presented, it is presumed to be the movement on the base plate. Figure 8 shows the behavior as a function of the displacement of the plate. Although the resolution is small, it can be seen engine response and information between 40,0 Hz and 60,0 Hz. Numerical simulation indicates that the displacement plate has at frequencies 40,0 Hz and 80,0 Hz.

Some streaks do not mean the behavior of the plate, but indicate the unbalance motor, its harmonics and frequency grid. Some are not identified but can represent any sort of shock to the motor board, or the board itself on the sub-base, which, as is known, is not adhered, and this could cause misinformation.

The numerical simulation performed with a harmonic excitation, also followed the same criteria and frequencies of the experimental part. Figure 9 shows that the largest vertical displacement occurs near the frequency of 40,0 Hz and 80.0 Hz, seen by all "sensors", except the internal sensors, these cannot be simulated. Figure 13 facilitates visualization of the behavior of the plate. It can be observed that the plate has a flexural strength of about 110,0 Hz This is interesting because the graphs of the experimental part were already showing the plate responds to this frequency. Although not representing a practical possibility, because it would impose the passage of a speeding vehicle. Situation not observed in practice imposed by the initial conditions, ie vehicles maneuvering patios or industrial floors.

The experimental impulse responses are shown in Figure 11, which shows, as a whole, the plate has the frequency response of 40,0 Hz to 80,0 Hz, which were evident in previous analyzes. The excitation simulated EF shown through Figure 12 and Figure 13, which indicates frequencies can be classified as critical, which are coincident with those obtained in the experimental part. The ripples on the modulated spectrum are caused by numerical process and as far as it is known, there is no control over them.

Figure 15 is crucial to be able to observe the agreement between experimental and numerical results. Although the impulsive testing do not extend above the 100,0 Hz, it is observed that the first mode are in the range of 40,0 Hz to 80,0 Hz.

The exemption of the numerical method does not show the frequency of 60,0 Hz, as previously said, arises from frequency of the power grid.

5 CONCLUSIONS

The main results from the analysis of the proposed study were:

I. Verification of instrumentation functionality in a flat, horizontal structure, ie, the possibility of using internal sensors to it and obtain, with the use of the methodology, the relevant information about the physical phenomena involved in the process.

II. The numerical method is in full agreement with the experimental results. This means that it is perfectly possible to use this procedure to perform analyzes on boards not attached.

III. During the numerical process the foundation structure was sensitive in the production of the results. This cannot be verified in the experimental part. In view of that all tests were performed on a single plate.

IV. The experimental and numerical evidence that the coefficient of elastic foundation, simulating the presence of sub-base, should be a design parameter to be considered during the conception of plates with similar characteristics.

V. Confirmation, through the analysis of the mathematical model, the suspicion that the plates undergo deformations due to the passage of vehicles can excite vibration modes at low and high frequency leading to fatigue and, consequently, premature rupture. As can be seen in the numerical simulations and mechanical tests. The deformation despite relatively small as indicated by LVDT instrument is able to generate jointly applying external loads, the collapse very favorable conditions related to the phenomenon of fatigue.

VI. The results were consistent to those of mathematical models chosen for the proposed problem. However, the differences in results in some situations were generated by idealized mathematical model to the practical model.

VII. The verification of the need for further study and many other tests using a bench built, aiming to increase the database and achieve more robust and comprehensive conclusions on several issues that remain open, including, correlations between the plate-scale and structures in full size.

6. ACKNOWLEDGEMENTS

Mackenzie Research Fund, in the person of its President Dr. José Francisco Junior Hintze and staff Cristiane Alves Macedo, Edivaldo Ferreira Cavalcante, Marli Rosana Tonin and Veronica Farias.
The Engineer Francisco Laconelli from company MAVI - Vibratory Machines that lent the engine unbalanced masses for cyclic loading tests.
Engineer Luciano Ponci, Director of the company TEKNIKAO for the loan of two accelerometers used in the sensing plate.
The company's technical team Lynx, especially to engineer André, who kindly performed spectral analysis of temporal data obtained during the experimental tests.
Technicians of laboratories of machining I, Edson Agostinho da Silva Lima, welding lab, technician Jose Antonio dos Santos Neto and academic Elson Barão Soares.
The maintenance department of the University Mackenzie

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