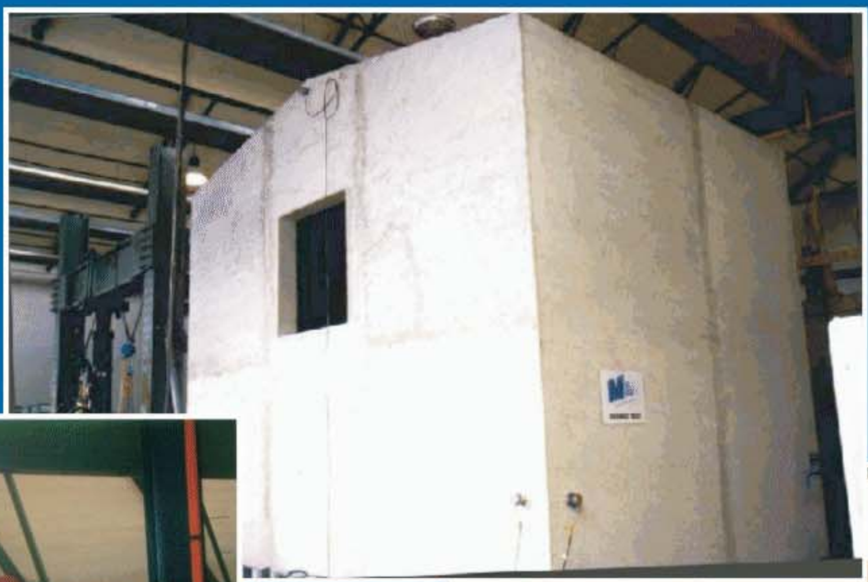
Advanced Building System

M2 EMMEDUE
Advanced Building System

PROVE DINAMICHE

SISTEMA COSTRUTTIVO EMMEDUE



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"PROVE DINAMICHE SUL SISTEMA COSTRUTTIVO M2 EMMEDUE"

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Laboratorio Ricerche e Tecnologie per sistemi Antisismici, strutture e materiali.

DINAMYC TESTS
ON THE
EMMEDUE BUILDING SYSTEM

FIRST PART

Perugia, 24th November 1999

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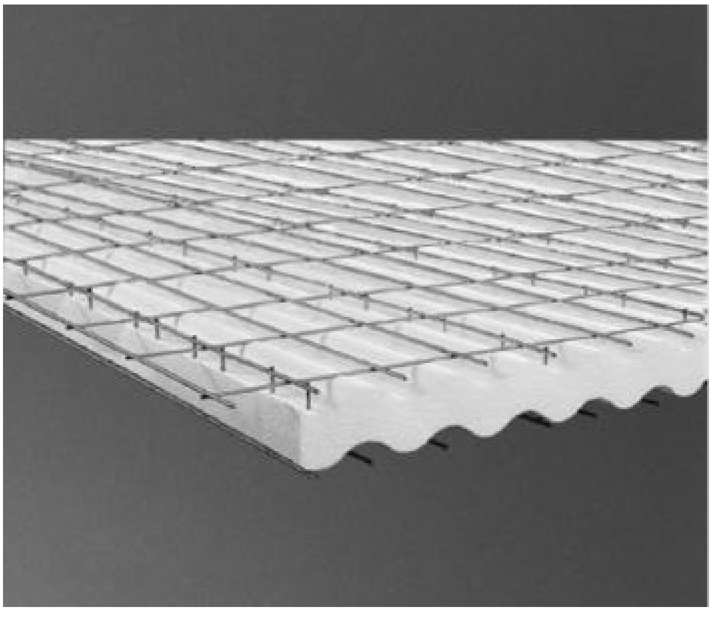
INTRODUCTION

This structural study takes into examination the EMMEDUE building system produced by the company EMMEDUE S.R.L. having premises at Via Treves 7, Bellocchi di Fano (PU), Italy. EMMEDUE is a building system which uses reinforced concrete bearing elements (Picture 1) aimed at answering to the needs of intensive and modular realisation of building units. This system is based on one "basic" element constituted by one panel, manufactured inside the factory, obtained by assembling one electrowelded spatial lattice of high resistant galvanised steel wires with one corrugated foam polystyrene slab having density 25 kg/cu.m. (Picture 2). The "basic" panel, alone or assembled to other "basic" panels, is sprayed with plaster during work in order to realise the different elements of the system: bearing vertical and horizontal elements, external coating and internal partitions. The main target in the study of this building system is the determination of the mechanical and dynamic features of the same structure; therefore the entire schedule of structural surveys carried out from the RITAM Laboratory (ISRIM - University of Perugia - CSM) in Terni, contemplates the following tests:

- no. 1 dynamic test on the prototype erected in the Laboratory of Terni in order to supply the necessary elements for the determination of the dynamic properties of the structure;
- no. 3 axial compression tests centred on vertical panels;
- no. 3 eccentric compression tests on vertical panels;
- no. 3 diagonal crushing tests on vertical panels.

In the present relation the outcome of the dynamic test carried out in the Laboratory of Terni on October 14,99 is reported.

Picture 1 – Building units erected by the Emmedue building system



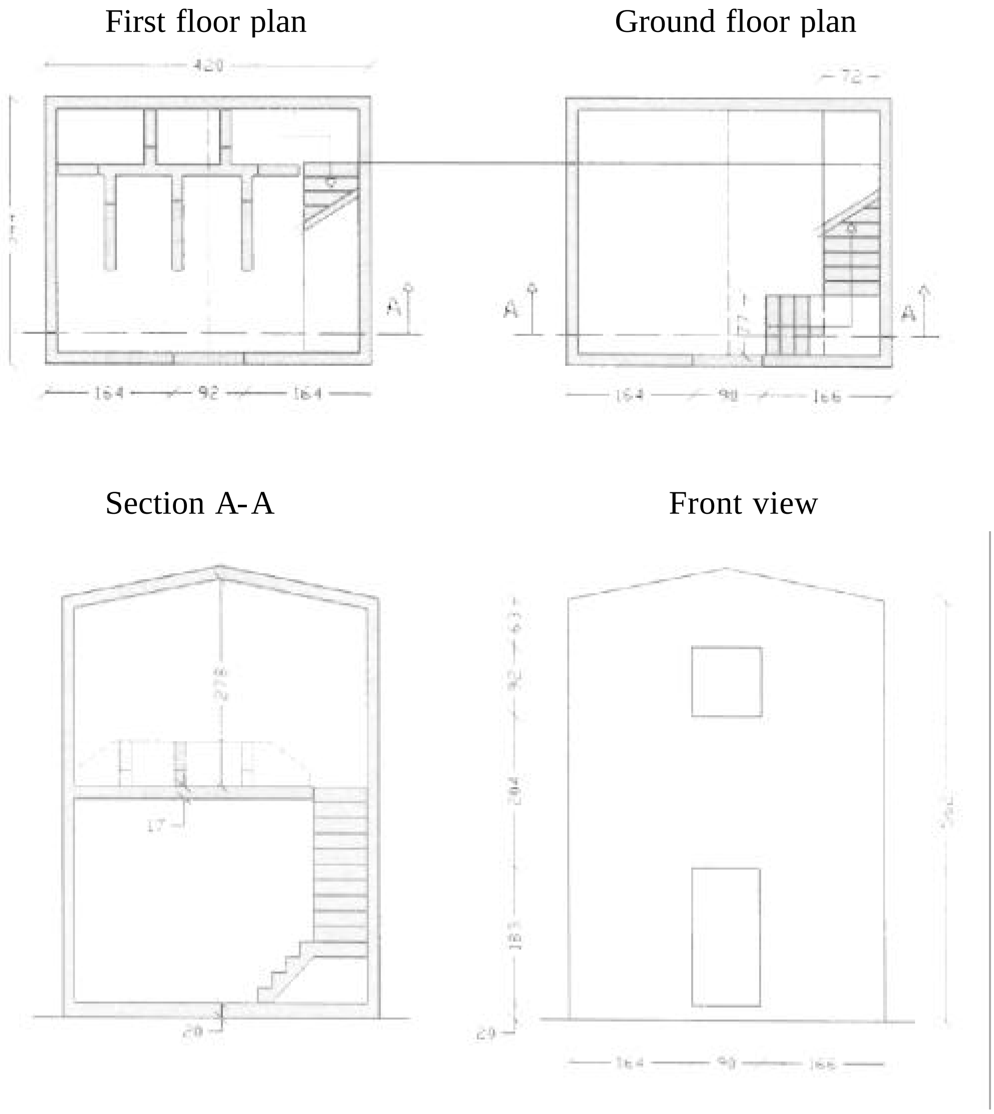
Picture 2 – Emmedue Single panel

1. CHARACTERISTICS OF THE PROTOTYPE

GEOMETRY OF THE PROTOTYPE

For the execution of the dynamic tests one prototype having standard architectural and geometric characteristics has been realised being the EMMEDUE building system, mainly, aimed at answering to the requirements of intensive and modular erection of buildings.
The prototype (Picture 3) is a two storey building, any of which is constituted by a unique room.
The plan has a rectangular shape, with sides respectively of m 4,20. and m 3,44. The access to the building is enabled by one door on the ground floor in the centre line of the longer side; the two storeys are linked each other by an internal staircase always realised by EMMEDUE technology, parallel to shorter side and adjacent to it.
On the first floor one window has been opened in line with the ground floor's door.
The roof is a couple-close type and its ridge line is parallel to the shorter side.
On the first floor's floor one special structure has been realised so as to enable the placement of the Mechanical Exciter machine inside the prototype (Picture3).

The thickness of the panels varies according to whether the loading vertical element or the horizontal elements are considered; these are cm 15.5 and cm 17 thick respectively.
A more detailed description of the panels is shown on the following paragraph.

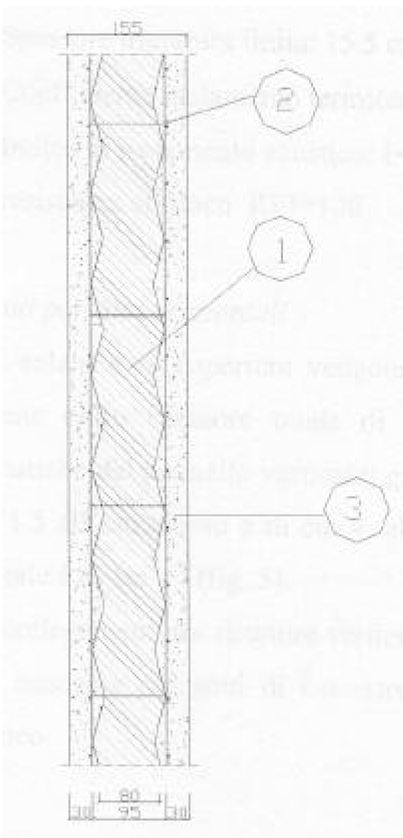


Picture 3 – Plan, front and section of the Prototype

PANELS FOR WALLS AND FLOORS

Load-bearing vertical elements

The load-bearing vertical element, cm. 15.5 in thickness, is obtained by completing with a double layer of plaster the “basic” panel made up of one corrugated polystyrene slab coated by galvanised electrowelded net. In such a way we obtain one wall sprayed with two external layers of reinforced concrete, 3 cm. in thickness, linked together by horizontal stitching wires being part of the galvanised steel wire spatial lattice used as covering of the inner polystyrene. The total thickness is cm. 8 (Picture 4).
The spatial lattice is constituted by horizontal wires Ø 2.5/13 " and vertical wires Ø 3.5/7.5”.



Picture 4 – Vertical wall

The elements constituting the panel have the following features:

- Virgin, non-toxic, self-extinguishing and chemically inert polystyrene, density 25 kg/cu.m. shaped in slabs of the average thickness of cm. 8.
- Galvanised steel net, drawn, with low carbon content, welded by electrofusion, whose resistance to tensile strength is approximately 6000 kg/cm^2.

  Vertical wire: diameter 3.5 millimetre.
  Horizontal wire: diameter 2.5 millimetre.
  Wire for connectors: diameter 3 millimetre

- Micro-beton plaster (cement concrete whose particle size ranges from 0 to 7 millimetre) sprayed by Spritz-Beton method with double coating and resistance equal to minimum 200 kg/cm^2.

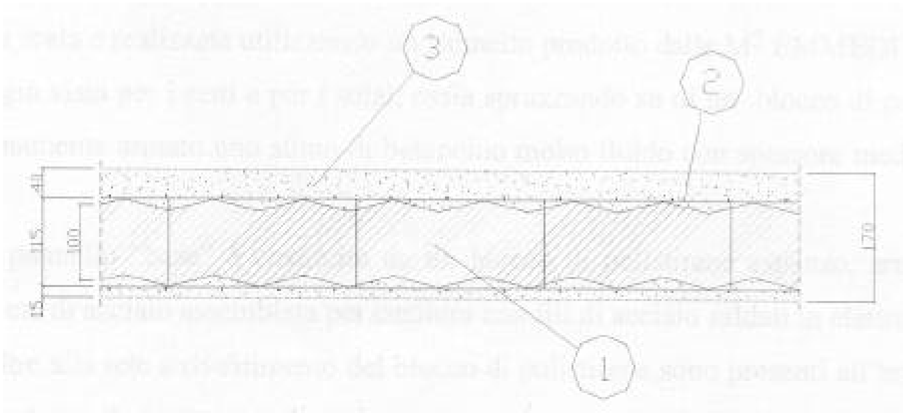
The panel obtained in such a way has the following characteristics:

- Final thickness of the masonry: 15.5 cm.
- Heat insulation coefficient K=0.425 Kcal/h ° C m^2
- Soundproofing index: I=38 dB at 500 Hz.
- Fire resistance REI=120

Horizontal load-bearing elements

The floor and the covering are realised using a "basic" panel made up of polystyrene slab, total thickness cm. 11.5, and spatial lattice with the same characteristics of the vertical panel; the layers of sprayed micro-beton size cm. 1.5 in thickness at the intrados and cm. 4 at the extrados. The total thickness of the horizontal element is cm 17 (Picture 5).

The connections among vertical and horizontal structures are always made up of steel bars plunged into the concrete castings which enable the realisation of monolithic joints.



Picture 5 – Floor panel

The elements constituting the panel have the following features:

- Virgin, non-toxic, self-extinguishing and chemically inert polystyrene, density 25 kg/cu.m. shaped in slabs of the average thickness of cm. 11.5.
- Galvanised steel net, drawn, with low carbon content, welded by electrofusion, whose resistance to tensile strenght is approximately 6000 kg/cm^2.
  - Vertical wire: diameter 3.5 millimetre.
  - Horizontal wire: diameter 2.5 millimetre.
  - Wire for connectors: diameter 3 millimetre

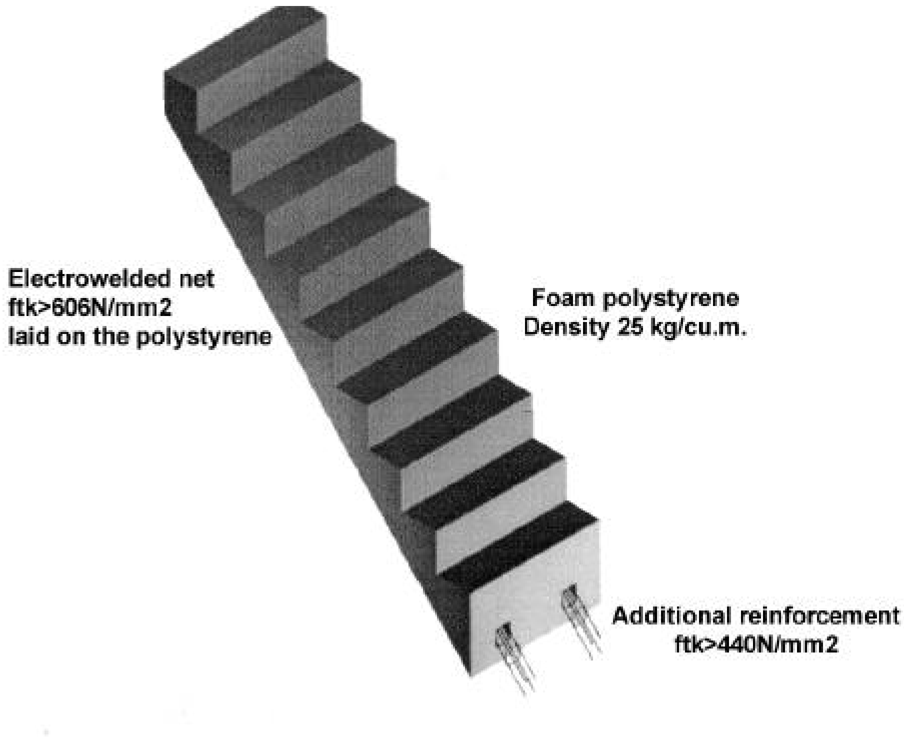
- Micro-beton plaster (cement concrete whose particle size ranges from 0 to 7 millimetre.) sprayed by Spritz-Beton method with double coating and resistance equal to minimum 200 kg/cm^2.

The panel obtained in such a way the following characteristics:

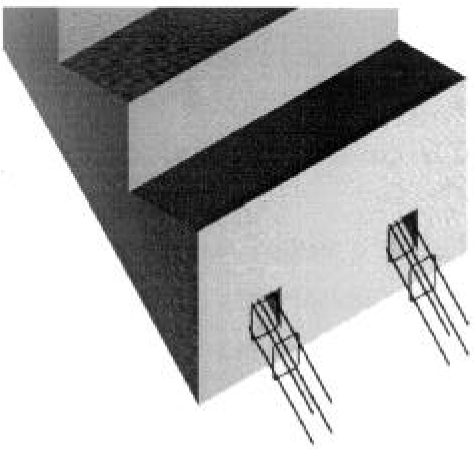
- Final thickness of the masonry: 17 cm.
- Heat insulation coefficient K=0.435 Kcal/h ° C m^2
- Soundproofing index: I=38 dB at 500 Hz.
- Fire resistance REI=120

THE STAIRCASE

The staircase has been realised by using a panel manufactured by the company EMMEDUE with the technique already shown for the walls and floors, that is spraying on a polystyrene block duly reinforced one layer of very fluid micro-beton with an average thickness of 2,5 cm.
The "basic" panel is made up of one foam polystyrene block, reinforced by a double steel wire net connected by sewing with steel wires welded by electrofusion. Further to the net which covers the polystyrene block, two rectangular section ribs are inserted inside the same panel. Said ribs are reinforced by one frame of bars with improved adhesion which are successively filled up with concrete having maximum particle size < 12mm and minimum mechanical resistance R_{ck} > 250 dN/cm^2 (Picture 6).



Picture 6 – Staircase panel



Picture 7 – Staircase panel – detail on the reinforcement

Picture 8 – The staircase inside the prototype

The elements constituting the panel have the following features:

- Foam polystyrene, density 25 kg/cu.m., shaped in slabs whose dimensions are subject to the length and width variations of the flight of stairs as well as to the measurements of the tread and riser.
- Galvanised steel mesh, drawn, with low carbon content, welded by electrofusion having the following mechanical features:
  - F_{yk}= 606 N/sq.mm. (yielding stress)
  - F_{tk}= 681 N/sq.mm. (breaking stress)
  - Vertical wire: diameter 3.5 millimetre.
  - Horizontal wire: diameter 2.5 millimetre.
  - Joint steel wire: diameter 3.0 millimetre.

Reinforcement of the ribs constituted by 2+2 Ø 6 mm bars for each of them and by Ø 6/30" stirrups.

2. METHOD OF TEST

In order to determine the dynamic features of the prototype erected by “Emmedue single panels” (see the previous paragraph) an experimental campaign has taken place by stressing the structure with the use of horizontal forces variable in time and measuring the answer in the most meaningful points, in order to supply the values of the peculiar parameters of the dynamic behaviour of the same structure.

USED INSTRUMENTATION

In this paragraph we want to supply a short list of the main equipment used for the dynamics test. The list includes one synthetic description of the features of the each equipment and, in the next paragraph, gives some indications referred to their specific applications.
The description takes into consideration (according to a logical pattern referred to the different phases of the dynamics survey) the equipment for the excitation of the structure under test constituted by the mechanical vibrator with counter-rotating masses, the instrumentation of measure of the physical magnitudes found (seismic accelerators, laser vibrometer), the systems for the test data input and storage and their subsequent processing (WorkBench, VibSoft, Excel, MatLab.).

- ***Mechanical Exciter***

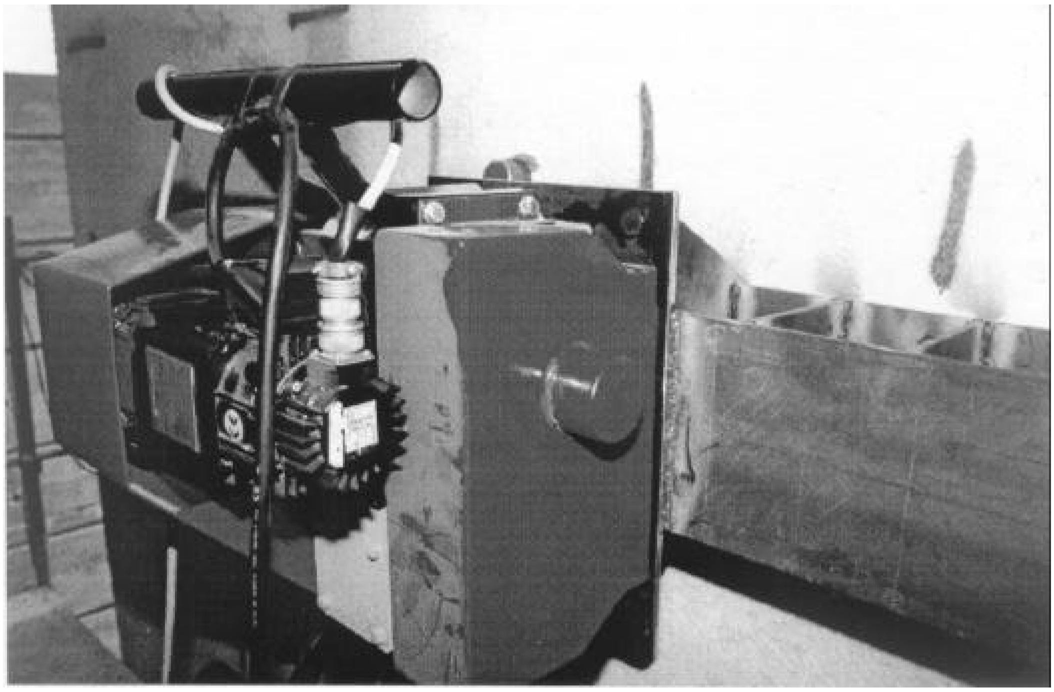
The dynamic system of vibration is constituted by one excitation unit (Mechanical Exciter), by one manual controlled feeding station and one Personal Computer, equipped with proper software, being able to carry out dynamic tests in automatic way (automatic scansions in frequency, special sequences of vibration). The excitation unit is made by two counter-rotating eccentric masses and by one engine in order to transmit the motion to the same masses able to generate a maximum unidirectional sinusoidal force of approximately 13 kN.

The feeding and control station of the excitation unit is placed in one container inside which the servo control electronics and the engine’s power feeding for the dragging of the eccentric masses have been placed. The data input system, constituted by one Personal Computer and its relevant software, enables to control the Mechanical Exciter automatically and to manage the special structural tests (i.e. maintenance of one frequency, dynamic swepts, fatigue tests, etc.).

The unidirectional mechanical excitation unit is essentially constituted by two counter-rotating trees, equipped with eccentric masses. The rotation of the two trees is synchronised through one couple of toothed wheels in order to originate unidirectional oscillations whose force is perpendicular to the ideal axis of connection of the two trees. Each mass has three holes, where additional lead moulds can be inserted in order to increase the maximum load applied by the shaker. The main features of the Mechanical Exciter are the following (Picture 9):

- Minimal frequency: 0 Hz
- Standard frequency: 16.6 Hz to 1000 rev/min.
- Frequency max.: 16.6 Hz to 1000 rev/min.
- Weight: approximately 130 kg with engine, carter, handles for transport
- Dimension: approximately 600x500 mm., height 500 mm.
- The control electronic part of the Mechanical Exciter allows to set up the revolutions of the engine by means of an external signal or by precision potentiometer (millesimal).
- The engine's revolution number is controlled by one encoder with resolution 1000 impulse/revolution encoder (very high precision in frequency and in the counter-reaction of the engine in order to maintain the vibration frequency stable).
- The vibrating system is assembled on one steel slab whose dimensions are 480x350 millimetre, with a perforated template for the fastening to the floor or to the wall sizing 420x290 millimetre.
- External tension + / - 7.8 Volt c.c. for the remote control of the engine
- TTL compatible signal exit proportional to the engine's revolution number.

From the characteristics evidenced turns out clearly that the Mechanical Exciter does not require external structures of reaction; the application of the supplied force is simply obtained by rigorously restraining the frame of the Mechanical Exciter to the structure under test.



Picture 9 – The Mechanical Exciter

- ***Seismic Accelerometers***

The seismic accelerometers are constituted by extremely stable quartz sensors having a very good thermal stability to low frequencies. These sensors are feeded by a simple signal conditioner at constant current and are incorporated in systems with high precision and low impedance systems having sensibility in fixed tension, high resolution tension exit, intrinsic self-diagnosis. The conversion between high impedance current and low impedance tension signal, carried out through the electronics equipment, allows the transmission of the signal also for remarkable lengths without any appreciable decrease of the sensibility and the quality of the signal.

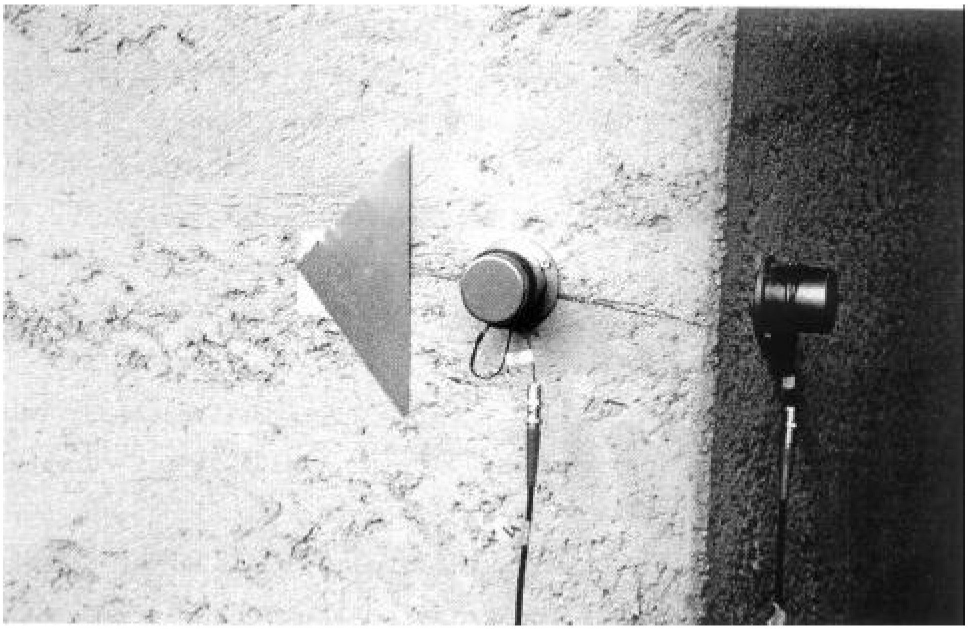
The input accelerometric system used is made by no. 7 PCB piezoelectric accelerometers PCB (Picture 10), low disturbance cables, 20 m. connection coaxial cables, DS-EXP input module complete with connection valves for piezoelectric sensors, software for Windows for the input, the control and the storage in real time of the experimental data.

Features of the PCB piezoelectric accelerometer in use:

- monoaxial;
- quartz type;
- measure interval ± 2,5g
- nominal sensitivity 1000 mV/g
- field of frequency from 0.01 to 1200 Hz
- hermetically sealed lateral connector 10-32
- size: 59.7x57.2 millimetre, weight 1 kg

Features of the DS-EXP/CE input module:

- 16 analogic differential entries
- intervals from +/ - 10 V
- resolution 12 bit + the sign
- maximum conversion speed 100 kHz
- DSP with reduction noise algorithms
- Data transfer through parallel interface



Picture 10 – The two accelerometers used

- ***The Laser Vibrometer***

The laser vibrometry uses optical techniques for the measurement of displacements and speed. The optical techniques bring several advantages compared with the traditional techniques of measurement as they are not intrusive and give an optimal answer as for frequency. Laser vibrometers use the luminous waves' doppler effect, consisting in the variations of frequency of one luminous radiation due to the source's and/or the receiver's speed differing from zero. Measuring the frequency variations that the laser beam endures when it hits the object in motion (in the case taken into consideration) it is possible to calculate the speed of the object.
The main advantages given by this instrument are:

1. Measure without contact;
2. Easily locatable measures (that is measures taken on a precise point);
3. Intrinsic calibration;
4. Wide dynamic range of measure;
5. Easy transport and use on the spot.

The vibrometer used, model OFV-303 Single Point Interferometer, measures the movement of surfaces from far positions in the direction of the laser beam using the interferometric technique. The source used is an He-Ne laser with polarisation oriented to 45' on the horizontal plan. Such instrumentation introduces a separation between electronic and optical members:

- the control processor that contains the electronic part;
- the interferometer;
- the fringes PC-counter card;
- the PC with related Software for the input and the storage of data.

The electronic part has 3 main functions:

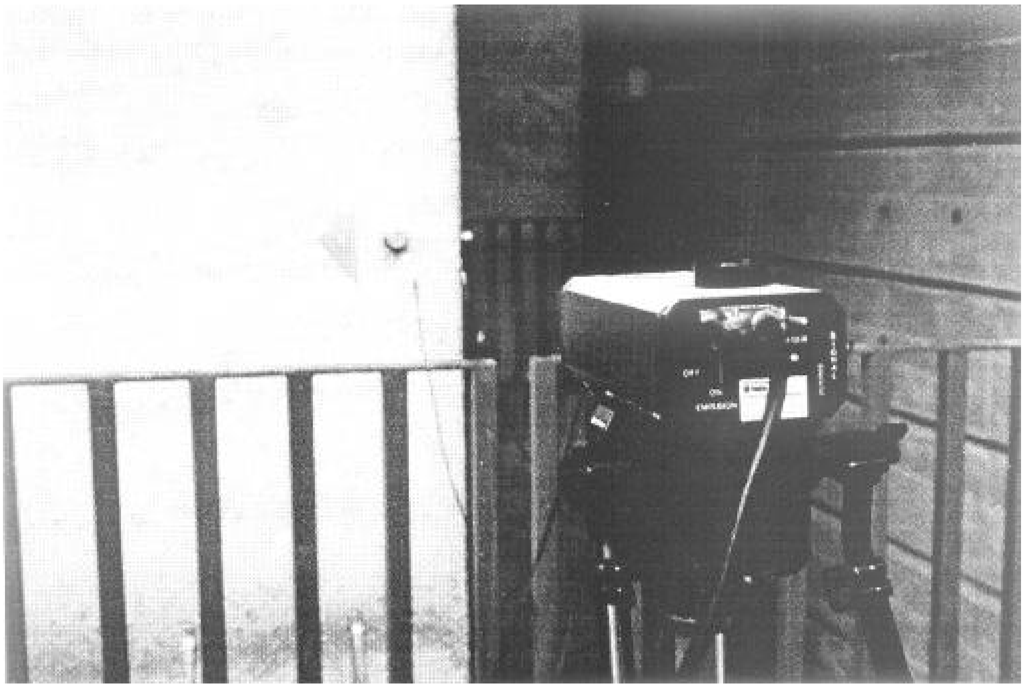
a. it supplies power and gives the RF Drive Signal to the interferometer;
b. it develops the information of measure supplied by the interferometer;
c. it gives the possibility of controlling the parameters of measure by means of the computer.

The optical part is formed by the interferometer that, in the case of our vibrometer, operates as for the principle of Mach-Zender interferometer.
The fringes PC-counter takes very accurate measures of great movements and therefore it extends the range of measure. The counted impulses coming from the vibrometer are directly derived from the passage light-dark. The fringes counter-PC consists of a sampling system to 32 bit similar to a digital analogic converter having

on the output a good reading counter instead of analogic values variable during time.

The main characteristics of such system are:

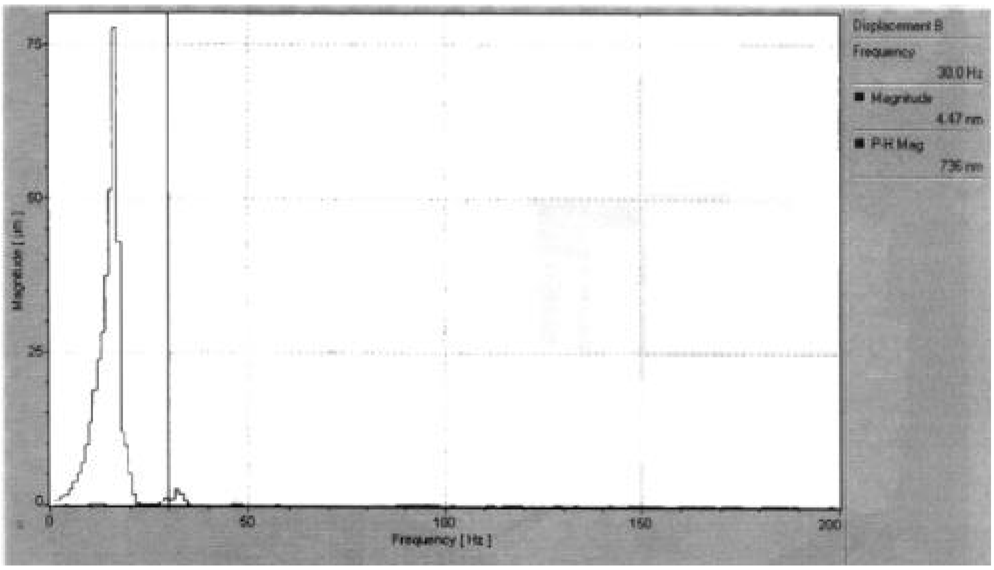
- Speed measure instrumentation, range of frequency from DC to 1 MHz, dynamics ± 10 m/s;
- Displacement measure instrumentation, with interference fringe calculation system, dynamics ± 4x10 m peak-to-peak;
- Minimal sensibility in speed 0.3 μm/s, in movement 2 nm.
- Optical head with optical from 50 millimetres and remote-controlled and motorised focusing.



Picture 11 – The laser vibrometer

The use of the vibrometer has allowed to compensate possible deficiencies of the accelerometers due to the incapacity of the same ones to find signals higher than the possessed level of resolution (0.0001 g [m/s^2]). Under such value, instead, the vibrometer guarantees an optimal answer, evidencing the fundamental frequency to

12 Hz (Picture 12), that the accelerometer only evidenced once reached an upper level of excitation of the structure.



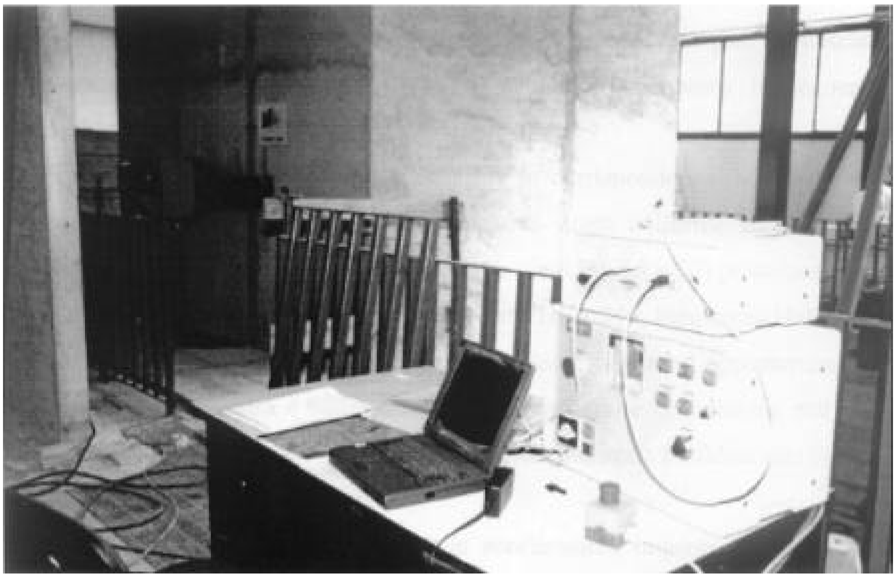
Picture 12 – Laser vibrometer diagram

Software for data input

Each one of the three equipment used is provided with a program of data management like, for instance, VibSoft for the vibrometer and WorkBench for the accelerometers. Such programs allow, further to the formulation of the information related to the single instruments, the input of the data, the visual control through diagram of the measured magnitudes and the data storage in the most appropriate format for then being processed through adequate programs.

Software for data processing

The data stored in such a way are then processed using Windows programs Excel type or MatLab. The obtained diagrams show the variation of the magnitudes observed directly during the tests and/or the variation of derived magnitudes in order to obtain an analysis in time and/or in frequency.



Picture 13 – Comp uter for the Mechanical Exciter's control

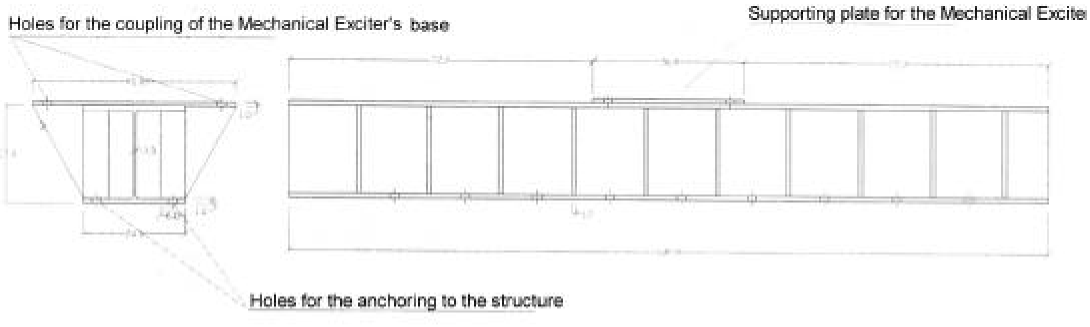
Picture 14 – Computer for data input

Disposition of the instrumentation

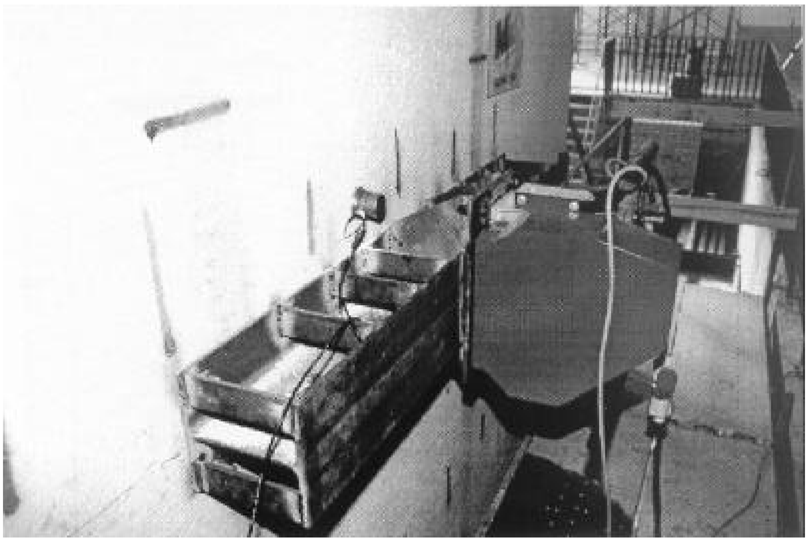
The instrumentation of measure illustrated above has been placed upon the structure taken into examination keeping in mind the pursued goal; to such aim, as it can be easily determined through the diagram shown in Picture 15 and 16, the following disposition of test has been arranged:

- *The Mechanical Exciter:* used for the excitation of the structure, placed in correspondence of the 1st floor's floor. In order to apply the force in a nearly uniform way on the floor the Mechanical Exciter has been connected to one metal slab (see Picture15 and 16) placed on the north side. The slab is constituted by one HEA 240 beam, 1800 millimetre of length, with wings reinforced by some plates, 10 millimetres of thickness, opportunely distanced. The slab is connected to the structure through bolting. On the bolting's opposite side, in correspondence to the centre line, one plate has been welded to which the vibrometer has been anchored.
- *The accelerometers:* for the survey of the accelerations given to the structure on the points of greater interest so as to get a general view of the movement of the structure.

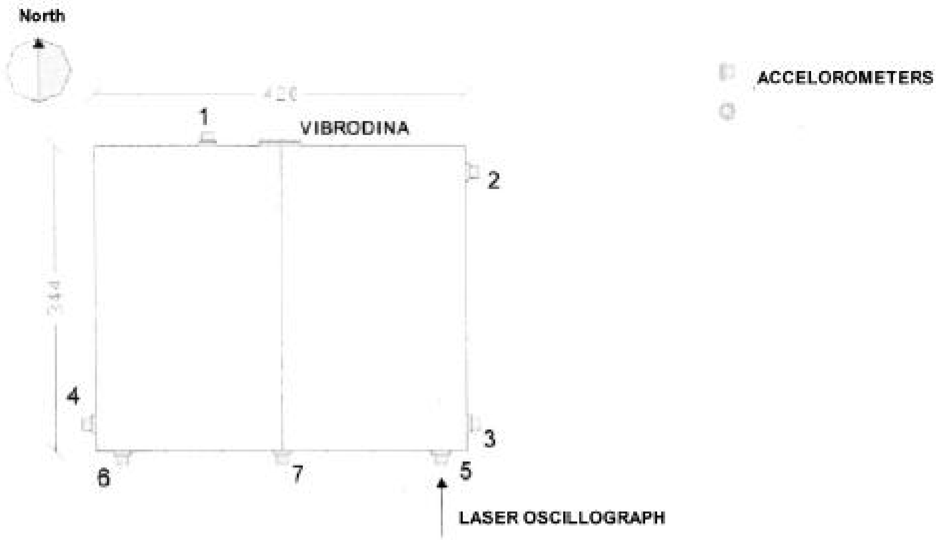
  The accelerometers' relative positions are shown at Picture 17, 18 and 19.
- *The laser vibrometer*: for the survey of the displacements suffered by the structure in consequence of the given accelerations.



Picture 15 – Mechanical Exciter's anchoring structure



Picture 16 – Mechanical Exciter and plate



Picture 17 – Disposition of the instrumentation on plan