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Development of a compact, experimentally testing system for active control algorithms of building vibration

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ABSTRACT: A new compact testing system, which has been developed at Osaka university, is presented. The main purpose of this system is to evaluate various active control algorithm under the same condition. In order to assure the reproducibility, responses of a shaking table of this system are examined for harmonic excitations and typical earthquake excitations. And also a simple active mass control algorithm is examined as a preliminary test. Through these examinations it appeared that the proposed system is useful for testing the active control algorithm and the quasi-inertia control forces worked well to reduce the response of the modelled structure.

1 INTRODUCTION

Active control is a well known technique in aeronautical or mechanical engineering. However, it is relatively new in civil and architectural engineering. Various active control systems for reducing building vibrations are proposed. Three types can be identified according to the way of using data: closed loop control, open loop control and open-closed loop control. Those are usually based on optimal control theory (J.N.Yang et al (1987), R.K.Miller (1988), T.Hatada et al (1989) and J.N.Yang et al (1990)). and, in a few cases, fuzzy control theory (L.A.Zadeh (1965) and B.Creamer et al (1991)). Control forces are generated by active mass dampers or active tendons (or cables) equipped with servo-controlled hydraulic devices or electromagnetic devices. A large amount of experimental results for each control system have been presented. But it is very difficult to evaluate them or to compare with each other, because those experiments are performed by using different models under different conditions, and furthermore output data are chosen from different view points.

In this paper a new compact testing system, which has been developed at Osaka university, is presented. The main purpose of this system is to evaluate various active control algorithm under the same condition. Basic concepts are based on the following four items. 1) Generality: Most type of control algorithm can be tested. 2) Reproducibility of displacement: Displacement caused by external excitations and control devices can be reproduced exactly. 3) Compactness: Size of the whole system is small enough to handle in a wind tunnel. 4) Good cost performance: Operation and maintenance should not be expensive.

2 PROPOSED COMPACT TESTING SYSTEM

A configuration of the proposed compact testing system is shown in Fig.1. A whole size of the testing system (shaking table + structural model) is 114(cm) long, 165(cm) high and 41(cm) wide. These sizes are small enough to operate in a wind tunnel.

Two tables are prepared as supporting frames. The lower table is used for earthquake excitations, and the upper table for active base isolation control. If the two tables move in the same distance in the opposite direction at the same time , the structural model will not move with reference to the absolute coordinate. Usually, these two tables are fixed together or sometimes connected with inserted rubber isolators.

In order to produce a precise displacement, stepping motors are adopted in this system to generate both earthquake excitations and active control forces. The motion of the shaking table are controlled by electric pulse signals calculated by computers. One pulse signal makes a stepping motor rotate at a precise small angle causing the screw bar to rotate at the same angle, and thus changing into axial movements. The axial movement of one rotation of the screw bar is 0.5cm. The precise small angle is changeable at 0.72° or 0.36°.

As can be seen in Fig.1, a three-story model is adopted as an objective structure that will be controlled. This model does not mean a practical three-story building. This model can represent the first three modes of multi-story buildings. The stiffness of the columns were designed very flexible. Owing to this flexibility, an amplitude of vibration is magnified and the efficiency of active control can be observed visually. The sensitivity of the sensors also become relatively improved.

An active mass damper type, an active tendons type

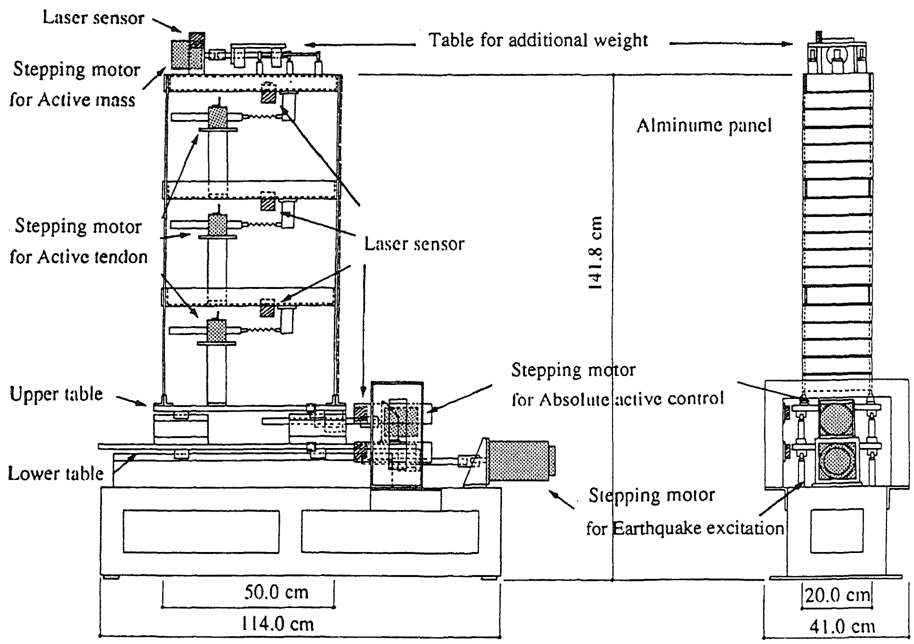


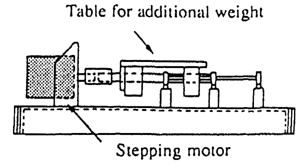
Figure 1. Configuration of testing apparatus and structural model.

and an active fin type can be adaptable easily by changing devices. These are also driven by stepping motors. The variations of the devices are shown in Fig.2(a,b,c).

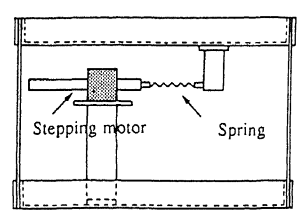
All displacements at the assigned points are measured by laser sensors (gauge length = ± 4cm). No additional forces act on the structure by those sensors.

The system is controlled by five desktop computers. One is a master computer managing the whole system, and the other four computers (called slave computers) are used for driving the motors. BASIC language and C language are used as the control program. The flow diagram of the system is shown in Fig.3.

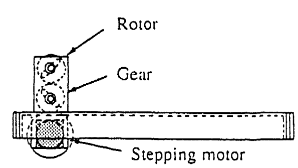
The master computer and the slave computers are linked by GPIB interface. All information from sensors are monitored by both master and slave computers via A/D converter. Two different kinds of calculations are needed to control the stepping motors. One is a calculation of the number of pulse according to the active control algorithm. And the other is a calculation of the pulse rate (the number of pulse in a unit time interval). In order to avoid putting too much load on each slave computer, four pulse control modules (represented by PC in Fig.3) equipped with own cpu are used with each slave computer in this system. If a number of pulse is given from the slave computers the module calculates the pulse rate. Operations of the pulse control module are executed according to two patterns in a short time interval Δt. These two patterns (shown in Fig.4) are



(a) Active mass



(b) Active tendon
(or variable stiffness)



(c) Active fin

Figure 2. Typical variation of adaptable control devise.

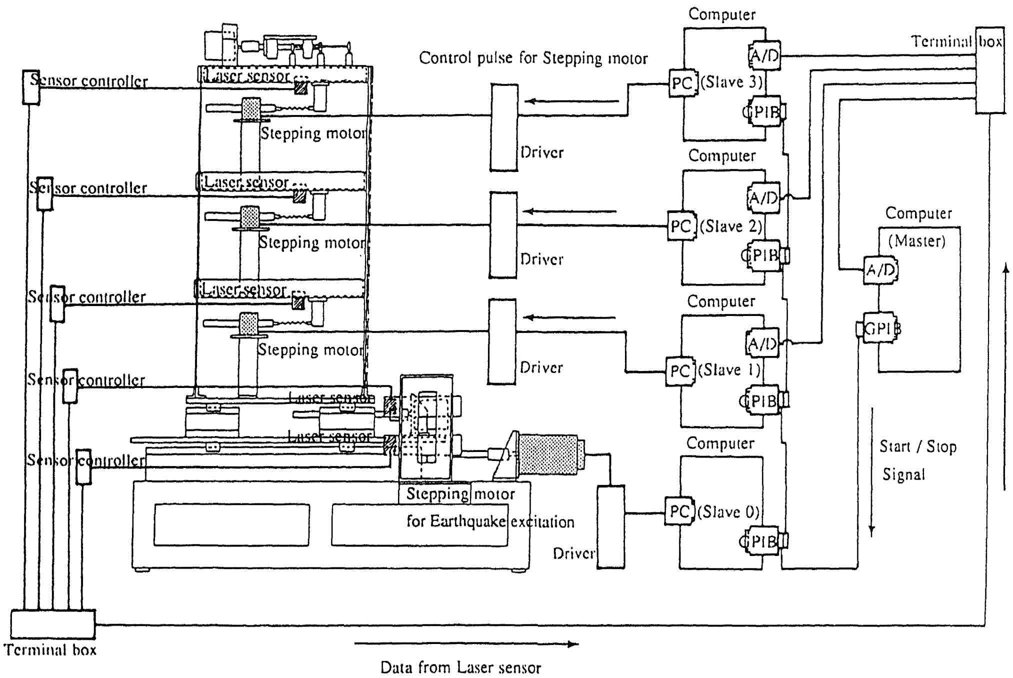


Figure 3. Flow diagram of control.

called as rectangular mode and trapezoid mode, respectively.

If the number of pulse informed from the slave computer is small, then the rectangular mode is selected. If the number of pulse is large the trapezoid mode is selected. Each area of rectangle or trapezoid is corresponding to the given number of pulse. However, by the mechanical limitation, the upper limit of pulse rate is set *a priori*.

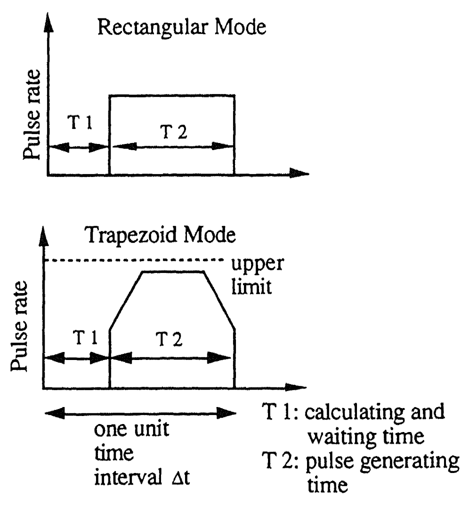


Figure 4. Rectangular mode and trapezoid mode.

For the case of quick movement of motor, several amount of the number of pulse is cut off. This cut-off pulses may cause a drift of the displacements which should be generated.

In this testing system, the slave computers always counts these cut-off pulses and fill up them as early as possible when the pulse rate decreases under the upper limit.

3 REPRODUCIBILITY OF HARMONIC EXCITATION AT THE SHAKING TABLE

In order to know the reproducibility of excitations, responses of the shaking table for harmonic excitations are examined. Considering the interaction of the shaking table with the structural model, this test was done with the structural model. Total weight of the structural model was 29.26kgf, and the natural frequencies $f_1 \cong 1.0$Hz, $f_2 \cong 3.1$Hz and $f_3 \cong 4.6$Hz. These natural frequencies were measured by a spectrum analyzer.

As harmonic excitations, sine waves $u(t) = A \sin(\omega t)$ were used. By changing the amplitude A and circular frequency ω, the reproducibility of harmonic excitation was examined. Two typical results are shown in Fig.5 and Fig.6.

The frequency of 1.0 Hz(Fig.6) is chosen to accord with the first natural frequency of the structure. As can be seen from Fig.5 and Fig.6, the reproduced wave shows considerably good accordance, even when the frequency of the excitation was nearly equal to the first natural frequency of the structural model.

However, a noise with about 10 Hz can be observed for both cases. This was mainly owing to the one unit time interval Δt which is shown in Fig.4. The value of Δt was set as about 0.1(sec). Though these noise were higher than the third natural frequency(4.6Hz) of the structural model, it should be decreased smaller.

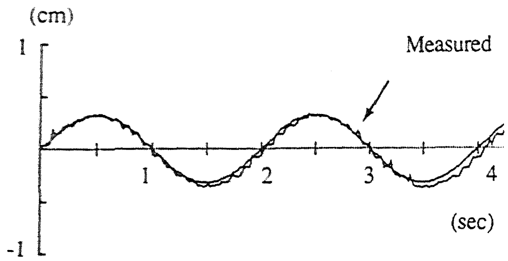


Figure 5. Comparison of measured displacement of shaking table with input harmonic wave of u(t) =A sin(ωt) (A= 0.3cm , ω = π rad/sec).

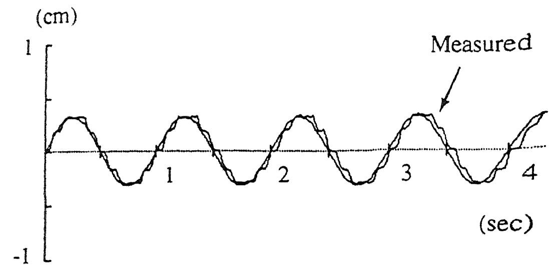


Figure 6. Comparison of measured displacement of shaking table with input harmonic wave of u(t)=A sin(ωt) (A= 0.3cm, ω =2π rad/sec).

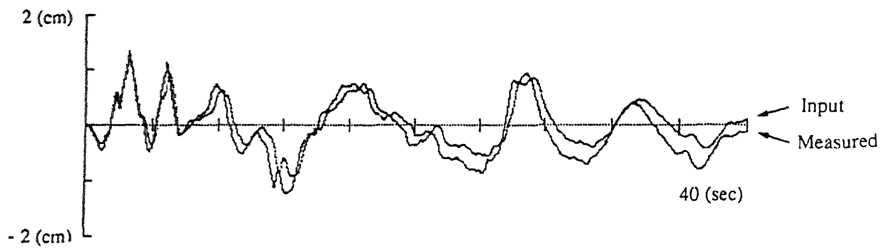


Figure 7. Comparison of measured displacement of shaking table with input displacement data (integrated from velocity data of El Centro NS).

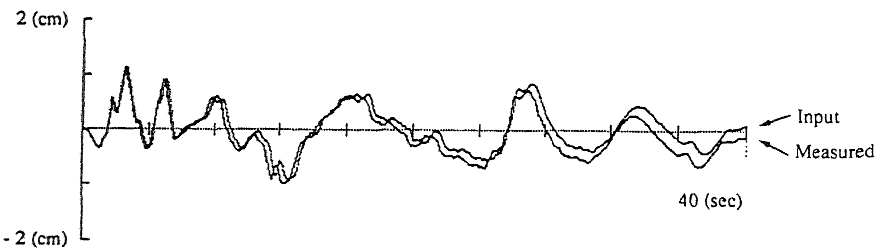


Figure 8. Comparison of measured displacement of shaking table with input displacement data of El Centro NS.

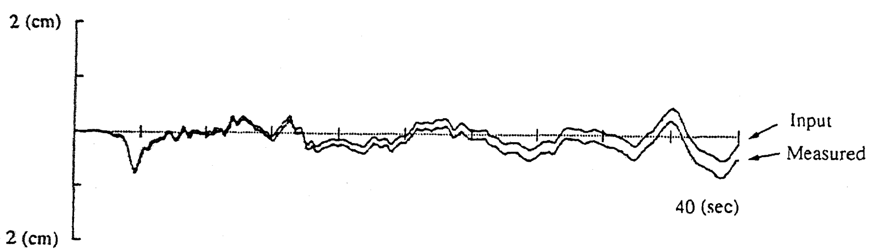


Figure 9. Comparison of measured displacement of shaking table with input displacement data of TAFT NS.

4 REPRODUCIBILITY OF THE EARTHQUAKE EXCITATION

Three different earthquake digital data were chosen: The velocity data of El Centro NS, the displacement data of El Centro NS and the displacement data of Taft NS. Comparisons of displacement of input digital data with the actual movement of the shaking table are shown in Fig.7 to Fig.9. A small discrepancy were observed for all cases. This may be caused by the mechanical limitation in stepping motor.

5 PRELIMINARY TEST OF ACTIVE CONTROL

5.1 Active mass control for free vibration

A simple active mass control algorithm is examined as a preliminary test. Control force was given by the active mass (using the device shown in Fig.2(a)) at the top floor of the structural model.

Let X^* be a displacement of the active mass M^*. This displacement is generated by a stepping motor and a screw bar using the device shown in Fig.10.

If the value of X^* is given proportionally to the displacement of the third floor; $\alpha X_3(t)$, an inertia force of $(1+\alpha)\ddot{X}_3(t)M^*$ acts to the top floor. So, by this operation, an active control force of $\alpha\ddot{X}_3(t)M^*$ is generated. In other words, we can get the same effect as if the active mass is changed from M^* to $(1+\alpha)M^*$ regarding to the horizontal direction. According to the theorem concerning to natural period (E.Tachibana (1986)), an exact value of the additional mass is given explicitly that makes structural model have asigned natural periods. So we can control easily the natural periods of the structure by this way. (An optimal control method based on this idea has presented by S.Tono et al (1989))

In this preliminary test, an effect of the value of α is examined. At first, the structural model is in free vibration by fixing $\alpha=0$, then α is changed to 1. This value may not optimal one, but reductions of amplitudes can be expected by changing natural periods of the structural model.

Figs.11(a) and (b) show the comparison of the absolute displacement of the top floor for free vibration in no controlled case and controlled case. Fig.11(c) shows relative displacements between active mass and the top floor. The point t_{st} means the beginning of control (the value of α is changed to 1.0).

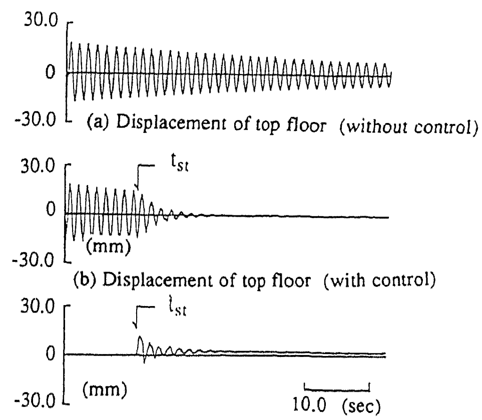


Figure 11. Effect of control for free vibration

A considerable effect of control can be observed from Fig.11(b). By analyzing these two responses, it is pointed out that it could increase equivalent nominal damping ratio of the structural model to 7.5% from 0.4%. As can be seen from Fig.11(c), the behavior of the active mass are seemed to move smoothly and it stops after 10 seconds from the beginning of control t_{st}.

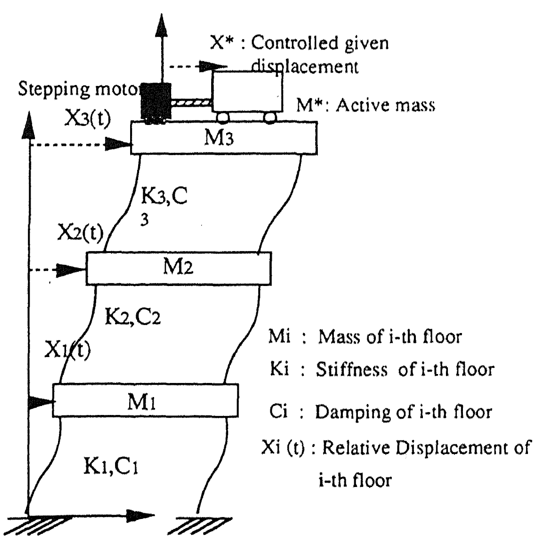


Figure 10. Structural model

5.2 Active mass control for wind-induced vibration

Using the same algorithm in the article 5.1, the active control is examined for the case of wind-induced vibrations. Fig.12 shows a testing system located in a wind tunnel.

Fig.13(a) shows absolute displacements of the top floor. The relative displacement between the active mass and the top floor are shown in Fig.13(b). The average wind speed is nearly 10 m/sec.

Considerable effects of control can be seen from Fig.13(a). The motion of the active mass is also seemed to be smoothly.

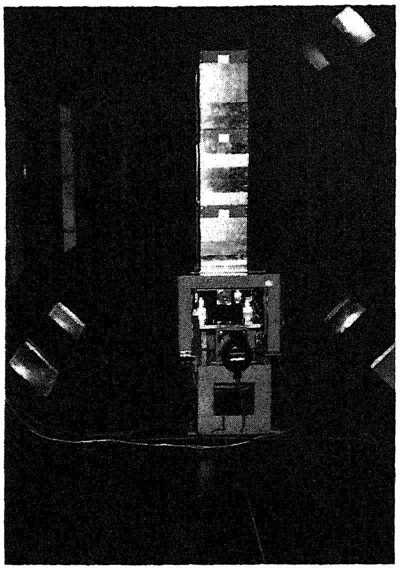


Figure 12. Testing system in wind tunnel.

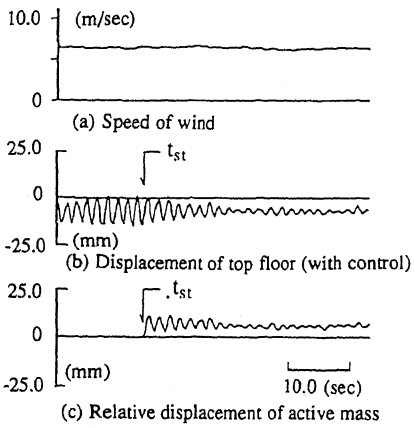


Figure 13. Effect of Control for wind-induced vibration.

6 CONCLUDING REMARKS

As concluding remarks, this experimental system is useful for testing the active control algorithm. The reproduced displacement of the shaking table shows considerable good accordance with input original ones. Some problems concerning with the noise at the neighborhood of 10 Hz still remain. The noise level may be decreased by refining the pulse control modules to more effective ones for the active control.

Through the preliminary test presented in this paper, it appeared that the quasi-inertia control forces worked well to reduce the response of the modelled structure both for the free vibration and wind-induced vibrations.

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A one-well device for dynamic soil testing

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ABSTRACT: The one-well harmonic device is designed for obtaining in-situ dynamic shear properties of soils under severe seismic actions. This device has been design for avoiding difficulties encountered in seismic reconnaissance, due to the impossibility of testing the soil behind the casing at high strain levels. The prototype is under experimentation in a test area in 200mm diameter holes. A special casing can provide a lateral expansion and alternative vertical movement. An excitation probe is used to apply the special casing to the soil and make it vibrate vertically. Accelerometers, pressure gauges and thermal gauges are forced into the soil behind the special casing from the surface for shallow depths. For greater depths, they are placed from inside the well by robots drilling the casing and forcing gauges into the soil. Surface apparatus provides 12 Kw power, monitors robots and records the measurements.

1 OBJECTIVES

The one-well harmonic device presented here has been designed in order to record in situ dynamic shear properties of a soil under severe seismic actions. This device has been proposed to avoid the difficulties encountered in seismic reconnaissance, which are mainly due to the impossibility of testing the soil behind the casing at high deformation levels. The one-well harmonic device has been designed for reconnaissance wells of around 6" in diameter. The principal equipment is described below.

2 TEST SITE (Figure 1)

An alluvial site was chosen for the tests. A 8m-thick silty layer covers a detritic formation of limestone boulders mixed with clay, with marl substratum at a depth of 12m.

A 2mx3m concrete slab receives all the apparatus necessary for the 6 possible well heads. At the moment, two wells 200 mm in diameter have been drilled; one is 6m deep and the other 12m deep.

Undisturbed samples have been taken for soil identification tests and complementary laboratory tests on the dynamic triaxial apparatus and the resonant column.

Several 76mm diameter holes installed around the test area are essentially used for classical cross-hole tests.

These preliminary tests exhibit values of

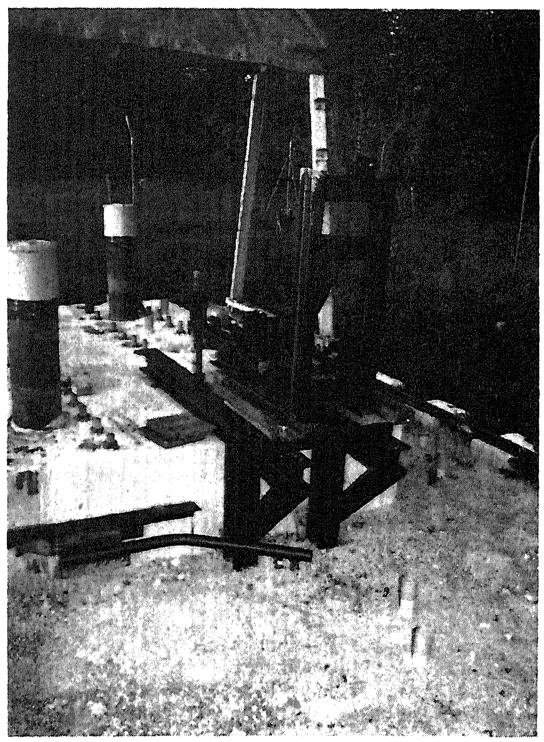

Figure 1 Test slab and well heads

the equivalent elastic modulus of 10 Mpa near the surface up to 1000MPa at a depth of 8m.

During drilling of the two main holes, Measurement While Drilling registration was performed by the Impasol procedure. It shows a high correlation with the cross-hole tests, indicating a soft homogeneous material down to 8 m and then very heterogeneous soil.

3 SPECIAL CASING (Figure 2)

The reconnaissance holes are protected by a standard casing with 160mm inside diameter. However, at each level where measurements are to be made, a special casing is placed between two standard casing sections.

The special casing is a passive part of the device:

- It makes it possible to transmit to the soil a lateral expansion, of a maximum value of 2 cm, with a pressure which can be monitored to balance the initial horizontal stress in the soil.
- It then makes it possible to transmit to the soil an alternative vertical movement, creating shear vertical deformations around the well.

Special casing sections are 1m long and consist of a standard pipe with longitudinal holes to push external mobile pieces against the soil. These mobile pieces possess external notches to prevent sliding between the excitation device and the soil. A special rubber membrane allows all the mobile parts of the system to return to the initial retracted position along the pipe and to an average vertical position.

At the moment, one special casing section is installed at a depth of 1.70m in well No.1. A second special casing section is placed at 6m deep in well No.2.

4 EXCITATION PROBE (Figure 3)

An harmonic probe can move the mobile pieces of the passive special casing section. This probe can be described as follows:

- A central bar, with possibly additional masses, is the inertial piece of the whole system.
- A vertical movement of this mass is possible, under the action of hydraulic vertical jacks and rubber springs.
- Through a system of lateral jacks, this system can be clamped to the standard casing.
- A connecting piece allows the moving mass to be connected with the moving pieces of the special casing.
- Maximum 12 Kw power is delivered to the jacks by an hydraulic circuit with capacity of 200 bars.
- The alternative movement is created by an electrovalve which performs various functions.

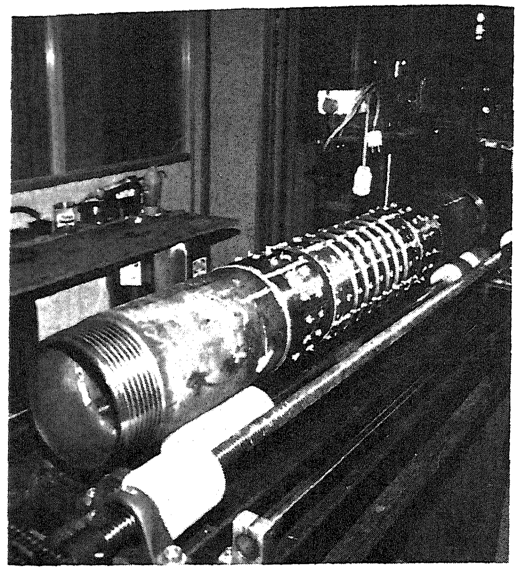

Fig. 2 Special casing

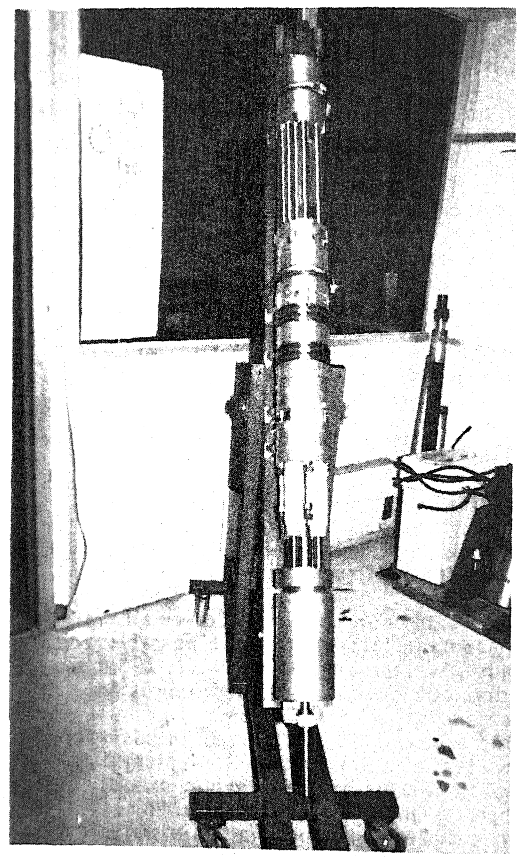

Fig. 3 Excitation probe

5 PLACING GAUGES INTO THE SOIL

5.1 Gauge installation from the surface

At shallow depths, accelerometers or other gauges such as pressure and temperature gauges, are installed in the bottom of small vertical holes, drilled from the surface. Such an installation was realized around preliminary holes 100mm in diameter, situated in the close vicinity of the test concrete slab.

5.2 Gauge installation from the well

At greater depths, placing gauges around the well will be performed by down-the-hole robots.

A first robot drills the casing and small inclined lateral holes into the soil.

Another is designed for placing accelerometers in these inclined lateral holes, with the help of a column of small casing sections. Robots are shown in Figure 4.

6 MEASUREMENT DEVICE (Figure 5)

Gauges and their preamplifiers are placed in a protecting cell which is forced into the soil through the small inclined drillings.

Measures are sent by radio to the main hole and then transmitted to the surface installation.

6 SURFACE INSTALLATIONS

Surface installations provide power and monitor the excitation probe and the down-the-hole robots.

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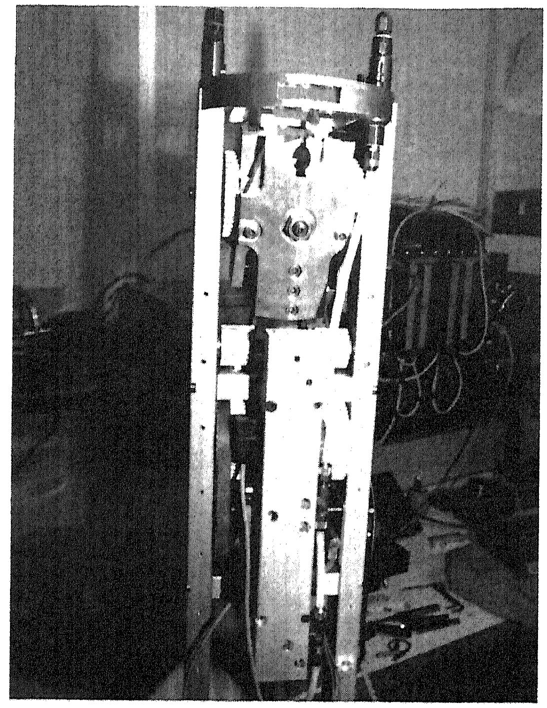

Figure 4 Down-the-hole robots

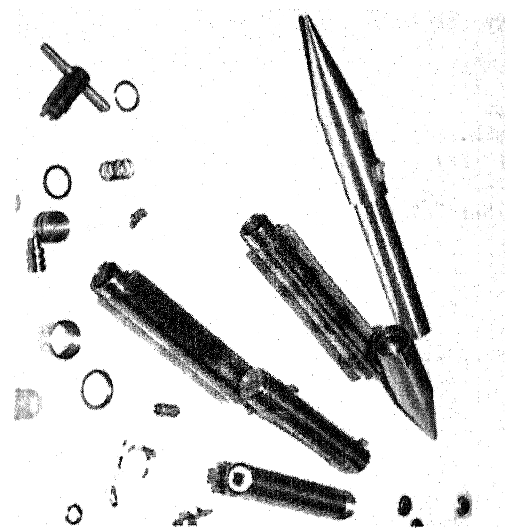

Figure 5 Gauge cell and accessories