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The use of 'bounded fluid' preloading cells for the foundation piles of a viaduct on the high-speed freeway in Naples

A. Bellini, R. De Domenico, L. Gagliardi & P. Polenghi
Engineering Department of Presspali SpA, Milan, Italy

ABSTRACT: This paper describes the use of preloading cells, which have been conceived and designed as "bounded fluid cells" by Dr. P. Sembenelli, Eng. These cells have been installed and pressurized at the base of foundation piles with a diameter of 1200 mm, at a depth of 30 m.

The piles in question represent the foundations of the piers of a viaduct on the new high-speed freeway being built in Naples in the area around Corso Malta.

The preloading cells were designed to reduce the settlements that may otherwise have resulted from the statically indeterminable structure of the viaduct and the nature of the ground, which consists chiefly of the pozzolana typical of the Naples area.

Their design took account of the need for ease of installation and working and they took the form of a membrane that could be expanded by means of the injection of cement mixtures after the concreting of the piles.

Special materials were used in order to achieve optimum performance during the graduated injection operations for preloading the bearing surface of the piles, the base of which had to support most of the load.

The paper also describes a series of load tests carried out on piles with preloading cells and gives an interpretation of the results obtained.

SOMMARIO: Nella memoria si riferisce sull'impiego di celle di precarico, concepite e progettate a "fluido contenuto" dal Dr. Ing. P. Sembenelli, che sono state poste in opera e messe in pressione alla base di pali del diametro di 1200 mm, alla profondità di 30 m.

I pali costituiscono le fondazioni delle pile di appoggio del nuovo asse viario a scorrimento veloce di Napoli, nella zona di Corso Malta.

Le celle di precarico sono state realizzate allo scopo di ridurre i cedimenti data l'iperstaticità della struttura del viadotto e data la natura del terreno, costituito dalle caratteristiche pozzolane del territorio napoletano. Sono state studiate tendendo ad una semplicità di messa in opera e di esercizio e concepite come un involucro dilatabile mediante l'iniezione di miscele cementizie, dopo l'esecuzione dei pali.

Particolari materiali sono stati sperimentati per ottenere un optimum di comportamento durante le operazioni di iniezione graduata per il precarico del terreno di appoggio sui pali, destinati a portare prevalentemente di base. Si riferisce anche su alcune prove di carico condotte sui pali dotati di celle di precarico, fornendo i risultati ottenuti ed illustrando quanto necessario per una interpretazione del lavoro eseguito.

1 GENERAL INFORMATION

This paper deals with the foundation piles of a viaduct on the high-speed freeway in Naples, from Via De Roberto to Corso Malta (Lot C), carried on in the years 1988-1989.

The piles, which were 1200 mm in diameter, were sunk to an average depth of 30 m. At their base preloading cells were installed, designed to reduce the settlement that may otherwise have resulted from the poor bearing capacity of the ground. Large differentiated settlements were not allowed because of the statically indeterminable nature of the viaduct.

The construction of the high-speed freeway was commissioned by Naples City Council, engineered by INFRASUD PROGETTI SPA of Naples, and carried out by COGEFAR SPA of Milan.

2 PRELIMINARY SURVEYS, EXPLORATORY DRILLING AND THE NATURE OF THE SOIL

Prior to the start of the work, exploratory drilling was carried out down to a depth of about 50 m and the samples thus taken were analyzed in the laboratory in order to determine particle size and the physical properties of the soil. In addition, SPT sounding was performed during the exploratory drilling as well as static sounding to a depth of over 50 m.

The stratigraphic sequence of the soil can be summed up as follows:

various types of filling, down to a depth of 4-5 m, followed by pozzolana dislocated by natural events and argillated, with peaty pozzolana in the lower part of the banck to a depth of 10-15 m. From here down to the depth of the piles and beyond, we find non-dislocated, sandy/slimy pozzolana with lapilli and pumice, typical of the area around Naples.

3 TYPE OF PILE USED

The 1200 mm diameter piles were made with rotary equipment, by means of static bentonite mud, in groups of 9 or 6 according to the dimensions of the rectangular plinths, for the main highway and the approach and exit ramps respectively.

Bucket drills were used to cut the holes, with teeth suitable for cutting through loose pozzolana.

The piles were driven to a depth of 30 m, so that they were sunk at least 12 m into the formation of non-dislocated pozzolana deposits unaffected by surface water and atmospheric agents.

Preloading cells were installed at the base of the piles, as described below.

4 DESCRIPTION OF BOUNDED FLUID PRELOADING CELLS

The preloading cells, which have been conceived and designed as "bounded fluid cells" by Dr. P. Sembenelli, Eng., were realized and patented specifically for the job on hand and consisted of:

A) A circular metal plate welded to a metal cylinder, acting both as a base and a protection for the pile.

B) Wire netting beneath the plate to support the granular material inside the box thus formed.

The granular material was highly permeable in all directions.

C) A membrane made of special, highly expansible, plastic stuff, closing off the bottom of the box and covering the sides.

D) Two metal pipes, one leading into the box and the other leading out, enabling injections to be made into the space between the box and the membrane at the required pressure, thus causing the membrane to expand and compress the ground beneath the base of the pile.

E) The pipes described in paragraph D) rose to the surface, where they were fitted with valves and gauges enabling the injection pressure to be controlled.

Many special materials, such as waterproofing resins, adhesives and metallic strips, were used in the design, construction, assembly and testing of the preloading cells.

Prototypes of the cells were tested and re-tested over considerable lengths of time.

5 OPERATION OF THE BOUNDED FLUID PRELOADING CELLS

The bounded fluid preloading cells serve three main purposes:

- to pre-compress the surface of the bottom of the hole evenly, thus strengthening the ground beneath the base of the pile;
- to box in the area around the base of the pile;
- to prevent uncontrolled leakage of the grouting fluid to areas away from the base of the pile.

These goals can easily be achieved by adjusting the composition of the grout, the injection pressure and the setting time.

After grouting, the weight of the pile in the semi-fluid state will rest on the bottom of the hole, through the non-pressurized preloading cell. When, however, the grout has set and the cell is pressurized, the pressure of the load in the cell will stress the bearing ground as much as the ultimate, total skin friction bearing capacity of the pile being pushed upwards by the cell will allow and the cell pressurization limit is defined, consequently.

The preloading action carried out by the cell and the resulting settlement of the ground at the base of the cell prevent the possibility of further settlement of any importance at the safe design load. The ultimate bearing capacity at the point of the pile will thus be at least equal to the cell pressure multiplied by the section A of the pile;

$$P_{\text{ultimate bearing capacity at the point}} = p \times A$$

and if the pile reaches its upward lift limit by overcoming the ultimate, total skin friction bearing capacity.

$$P_{\text{ultimate, total skin friction bearing capacity}} = p \times A$$

so that:

$$\text{ultimate bearing capacity of pile} \leqq 2\ P.$$

Since it is unsafe to reach this limit, a reduction factor is applied to the preloading pressure.

With regard to the work to be carried out on site when using preloading cells, the following points should be made:

- cells made in the workshop are welded to steel reinforcement of the pile and inserted into the hole with it. Care must be taken to lower the cell very slowly so that the pressure balance in the hole is not disturbed by the bentonite mud motion.
- when the cell has been put into position, the concrete is poured through che concreting pipe which is almost in contact with the cell on its circular metallic plate.
- the grouting mixture consists of water and cement, plus a delaying additive in case the grouting process takes place in several stages.
- in the coarse and fine formation, the total substitution of the bentonite mud is necessary, as this one has a trend to thicken because of the suspension of the fine material and it doesn't allow the cell to go down into the hole.

In this particular case, the grouting pressure used for the preloading cell reached an average of 10 atm, with the pressure and the flow rate of the mix coming from the mixing equipment being controlled by means of the gauges and valves on the pipes.

6 RESULTS OF LOAD TESTS

The following tables and curves show the result of the load tests carried out on some of the foundation piles for the viaduct of the freeway. The tests were performed by means of the conventional system of hydraulic jacks contrasted by the ballast consisting of concrete blocks.

As can be observed, the settlement caused by the operating load of 223 t and the maximum testing load of one and a half times the operating load was in the order of a few millimeters.

Preliminary calculations had estimated that the bearing capacity at the point of the piles would result in a settlement of several centimeters, and this was obviously incompatible with the requirements of a statically indeterminable elevated structure such as the viaduct in question.

By comparing the results of the load tests with the theoretical elastic settlement of the piles with no surrounding soil, it is possible to affirm that the cells provided a firm bearing base. Further proof of this is given by the figures relating to the rebound curves with its good percent of the elastic returns.

TABLE SUMMARIZING THE RESULTS OF THE SETTLEMENT AT THE PILES HEADS

TEST Nr	Settlement at the maximum operating load of 223 ton.	Remaining settlement at the end of the unloading	% of the rebound	Maximum settlement at 1.5 times the operating load of 332 ton.	Remaining settlement at the end of the unloading	% of the rebound
1	1.71 mm	0.25 mm	85	2.97 mm	0.74 mm	75
2	1.50 mm	0.38 mm	75	2.97 mm	1.03 mm	64
3	1.35 mm	0.28 mm	79	2.53 mm	0.70 mm	72
4	1.90 mm	0.31 mm	84	3.97 mm	1.02 mm	74
5	2.34 mm	0.22 mm	90	5.48 mm	1.77 mm	68
6	1.16 mm	0.13 mm	89	2.00 mm	0.41 mm	79
7	1.44 mm	0.24 mm	83	2.59 mm	0.61 mm	76
8	0.95 mm	0.13 mm	86	1.69 mm	0.40 mm	76
9	1.19 mm	0.23 mm	81	1.87 mm	0.52 mm	72

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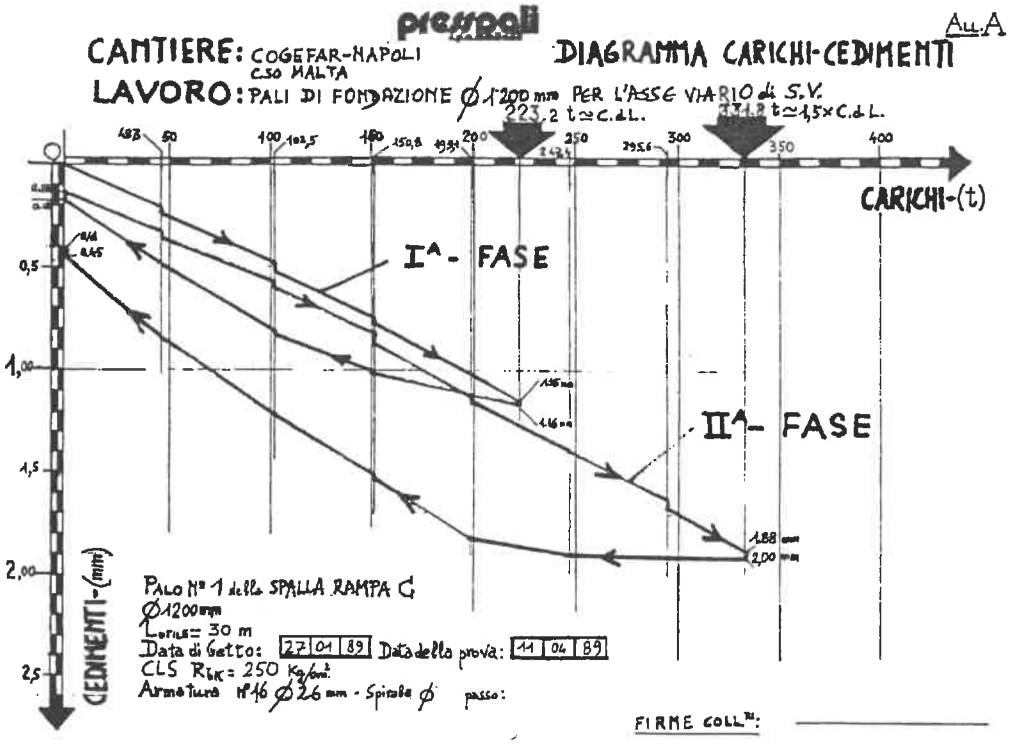

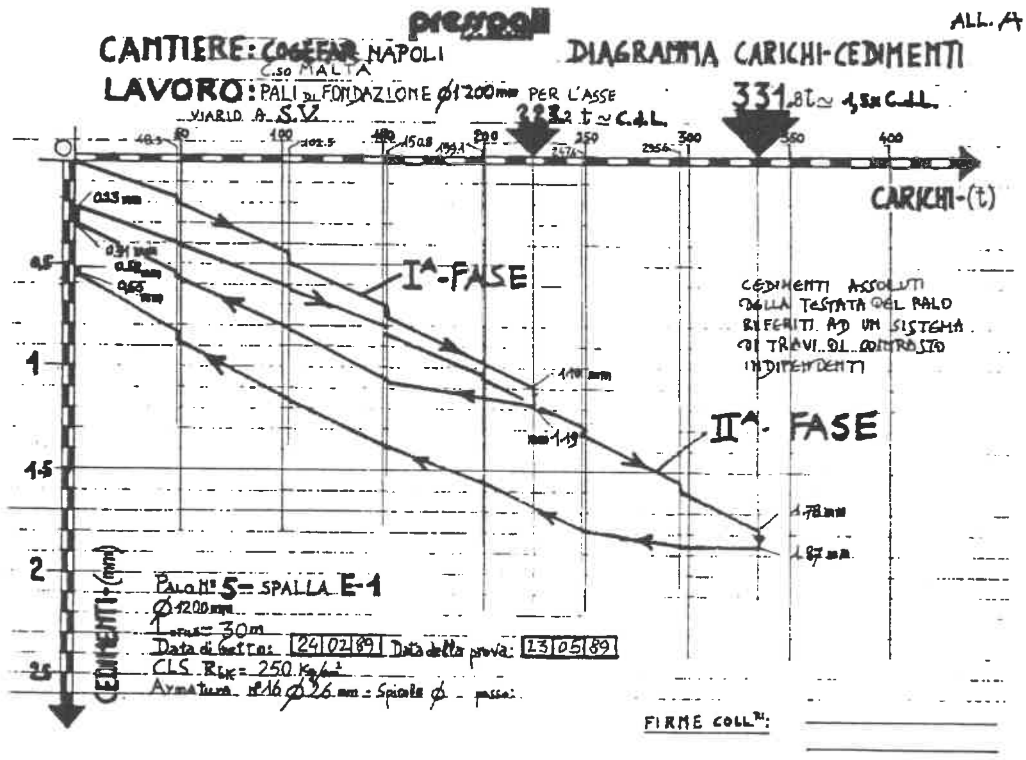

Original load-settlements diagrams concerning two load tests, which have been summarized on the prior table.

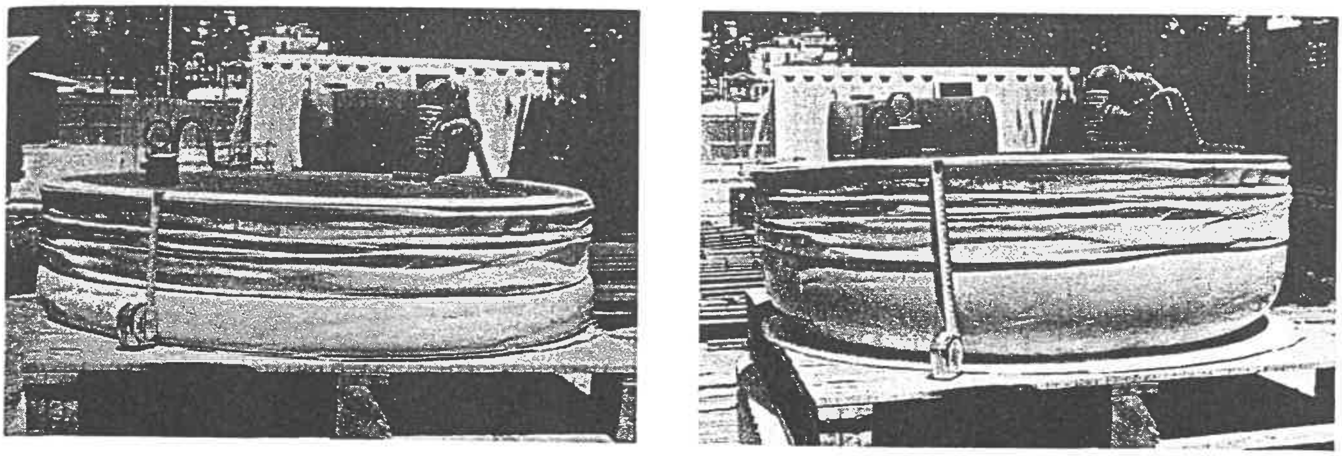

Fig. 1 - 2 Testing of a preload cell: view of a cell at zero pressure and at the beginning of the mix injection.

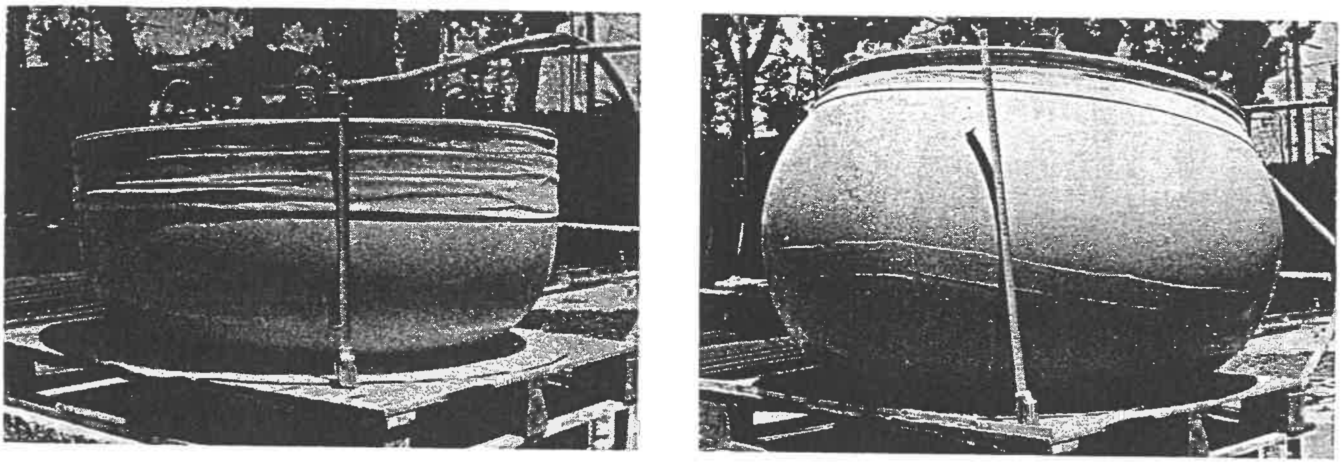

Fig. 3 - 4 Testing of a preload cell: on injecting the cell with the fluid at increasing pressure, the cell is becoming almost half-spheric.

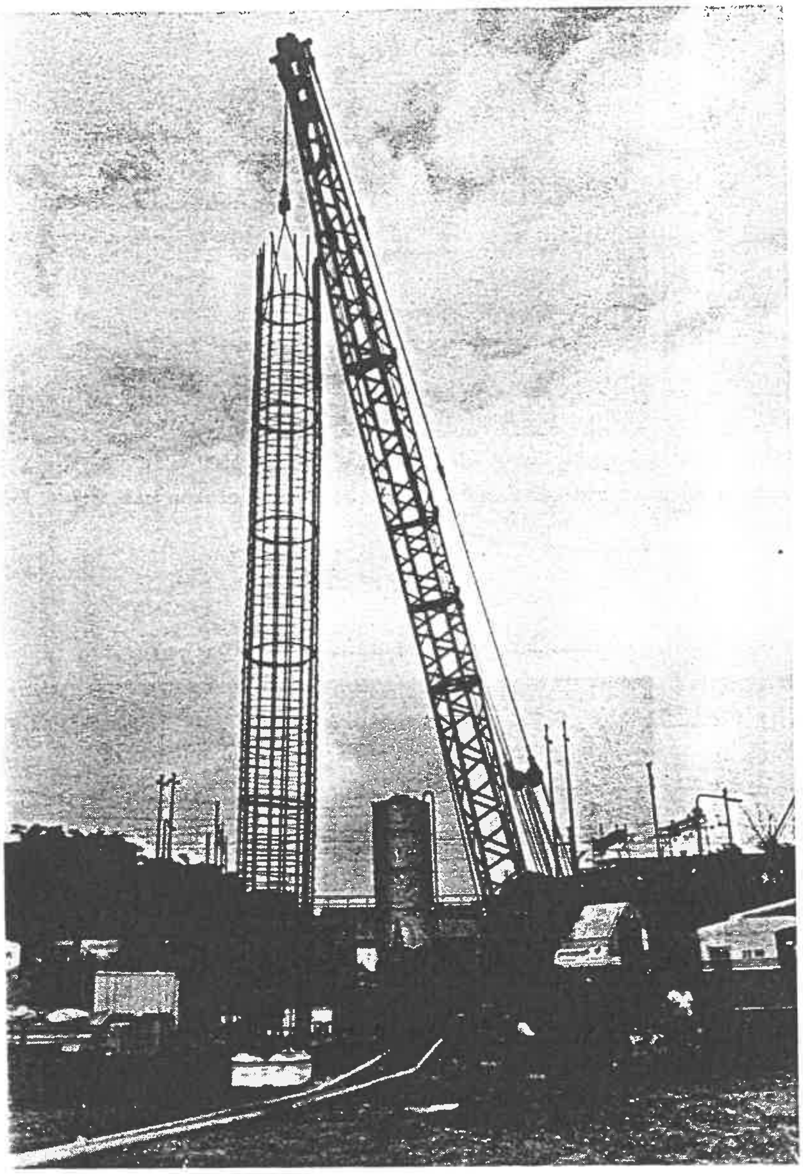

Fig. 5 - View of the setting in operation of a preload cell, which is jointed to the steel reinforcement.