Pressure Cushions to Correct Tilting of High Buildings

Coussins de Pression Evitant le Penchement des Tours

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SYNOPSIS For the foundation of a 130 m high-rising building founded on "Frankfurt Clay", a central loading of the subsoil could only be achieved by means of a void area beneath the foundation slab. In addition, pressure cushions had to be installed beneath the void area in order to avoid varying eccentricities during the constructional phase of the building. 22 cushions made of glued soft rubber plates were selected, with an area of 3 x 5 m each. By changing the pressure of the cushions for only 2 % of the load of the building it was possible to stop the tilting. The centre of gravity was displaced for only 0,5 m, i.e. 0,8 % of the slab width. The result of measurement proves the sensitive reaction of clayey subsoil to eccentrical loading. It also reveals, however, that corrections of tilting may be achieved by means of minor additional forces. After the normal initial difficulties an unusual technical system has given satisfactory results.

INTRODUCTION

In the city of Frankfurt (Fig. 1) a bank building of 130 m height is presently under construction. The limits of the premises as well as architectural and functional aspects only allowed for an eccentrical loading of the subsoil. The "Frankfurt Clay" reacts sensitively to eccentrical loading (Fig. 2). Several cases of tiltings happened in the past. G. Leonhardt (1972) reported on subsequent corrections of settlements by means of ballast. The following gives a survey on a new system.

Fig. 1 High-rising building

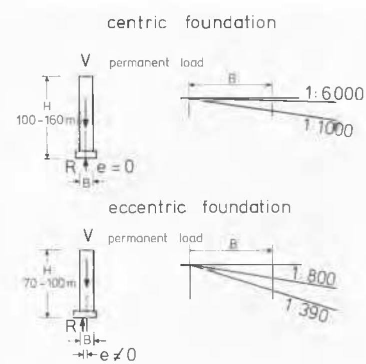

Fig. 2 Tilting of high-rising building in Frankfurt/Main

SUBSOIL

The Frankfurt Clay is overconsolidated. Its consistency varies from stiff-plastic to semi-solid with a water content of 35 %, a plastic limit of 40 % and a liquid-limit of 70 %. Its average unconfined compressive strength is 0,3 MN/m^2. Locally, banks of limestone are embedded, forming up to 10 % of the layer depth subject to settlements which increases the sensitiveness for tilting.

PROBLEM UNDER CONSIDERATION

Experience being presently on hand necessitated the development of a system to center the loads of the high-rising building. Counterweights could not be considered due to the great load of 1700 MN. In addition, a foundation with one side being suspended or joints were not practicable because of structural and utilization purposes. Therefore, a void between 4 m thick foundation slab and the subsoil was chosen (Fig. 3). The eccentricity was eliminated by means of a diagonal void area of 330 m^2, i.e. about 10 % of the total foundation area. However, during the constructional phase of the high-rising building, load eccentricities occurred in the direction of the void area. In order to avoid tilting also in this phase, pressure cushions were installed under the area (Fig. 4), the pressure of the cushions being adjusted according to the progress in construction. Later the cushions will have lost their function. The following gives a report on the preliminary investigations of the pressure cushions, their installation in situ and their effects on the construction. F.G. Gravert (1975) und H. Sommer (1976) already reported some details of this system.

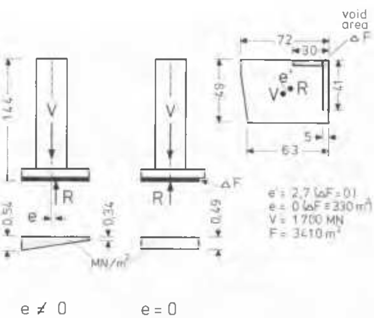

Fig. 3 Centering of the foundation by means of a void beneath the foundation slab

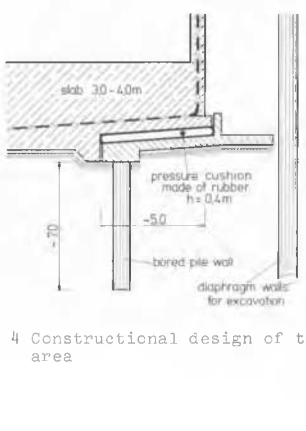

Fig. 4 Constructional design of the void area

DEVELOPMENT OF THE PRESSURE CUSHIONS

The design of the pressure cushions was planned in such a way that the failure of single cushions would not affect the performance of the entire pressure cushion system. For the required void area single cushions of approx. 3 x 5 m proved to be adequate. As there had been no experiences available concerning the reliability of the cushions, 6 trial cushions were tested in a pressure cell specially designed for this purpose at the Materials Testing Institute of the Technical University of Darmstadt (Fig. 5). Cushions of about half the size of the required final cushions were chosen, i.e. approx. 1,5 x 2,0 m. If larger cushions had been selected, the scheduled test pressure of up to 0,75 MN/m^2 - which means an approximate safety factor between 3 and 4 in comparison with the final working load - would have entailed uneconomic test equipment.

As a material for the cushions soft rubber plates of a thickness of 3 mm, a shore hardness of 50 and an ultimate strain of 600 to 650 % were chosen. The plates were rectangular with rounded-off corners. They were glued together, the thickness of the joints being 6 cm. Inside, a reinforcing tape of 10 cm width was glued. In the middle, a twin-walled filling and venting stud of 2" diameter was glued. As a safeguard against mechanical damage a highly expandable coating (Meycopren) of 7 mm thickness was sprayed on the cushions.

Fig. 5 Trial cell for testing the pressure cushions

Similar to the working principle of a car tire with inner tube, the cushions (inner tube) only had the function to remain impermeable. The inner pressure was directly imposed upon the cell wall (tire). A material suitable to fill the space between the rectangular cell and the rounded-off cushion had to be found. After the fillings had been tested, not only the variation of the pressures but also the alteration of the cell height gave satisfactory test results when loosely filled-in sand with bevels at the

Fig. 6 Sand layer above the pressure cushions in the trial cell

corners. Fig. 6 shows the sand layer above and aside the cushions before the lid was placed. In addition to short-period tests with varying pressures and cell heights, a cushion was tested over a period of 6 weeks, applying a pressure of 0,75 MN/m^2. The changing inner pressures of the cushions as well as the variation of the cell height were necessary to imitate the expected settlements of the high-rising building and the scheduled decrease of the pressures.

INSTALLATION IN SITU

22 cushions were installed. Because of the necessary heavy counterweights, no remarkable trial pressure could be imposed to determine the impermeability prior to placing the cushions. In spite of this, several leakages of the glued joints were observed and eliminated. Fig. 7 shows a check of impermeability by means of air pressure.

Fig. 7 Trial filling of the cushions by means of air pressure

Each cushion was placed in a single cell of steel concrete and separated on the sides by means of steel plates (Fig. 8). Due to the slight slope, the unhandiness and the sensitiveness of the cushions, the installation proved to be difficult and a careful scheduling of the operational procedure was

Fig. 8 Preparation of the cells in the site

Fig. 9 Placement of the cushions in the cells

necessary. Fig. 9 shows the placement of a cushion into the prepared cell (on the right side). Fig. 10 demonstrates the mounted form work of the cantilever arm construction above the cushions. In front, the subconcrete for the insulation of the foundation slab was already concreted.

After having concreted the cantilever arm of the foundation slab with the pressure cushions beneath, the assembly locks of the cell were loosened. Now - according to schedule - the contact between the cantilever arm and the subsoil was only effected by the water-filled cushions. Leakages occured after the water pressure inside the cushions had reached the programmed value of 0,15 MN/m^2. These leakages are supposed to originate from the glued connections. The gluing work will have to be improved in the future. Subsequent efforts to seal these leakages did not success with larger leaks. By increasing the pressure, however, the neighbouring cushions were able to compensate the failing ones.

Fig. 10 Shuttering for the construction of the cantilever arm, installation of the filling studs

SOIL MECHANIC EVALUATION

The cushion pressures were regulated in such a way that no eccentrical loading occurred during the construction of the high-rising building. Thus tiltings did not occur. The successful performance of the system, however, and the direct reaction of the clay to eccentrical loading could be observed during an intermediate stage. A pressure being temporarily too high resulted in a tilt in the direction opposite to the cushions. A slight angular turn of 1:4200 of the basement storeys arose from a settlement being mainly central at first (Fig. 11). By means of reducing the cushion pressure by 16,2 MN, i.e. 2 % of the building load at this phase, the tendency to tilt was temporarily stopped. This caused a shifting of the centre of gravity amounted to e = 0,5 m, which is only 0,8 % of the width of the foundation slab. This result of measurement once more proves the fast reaction of the Frankfurt subsoil to eccentrical loading, it also demonstrates, however, how little additional force is required to correct tilting.

At present, the total tilt of 1:8000 of the high-rising building in section a-a is practically insignificant and rather low for the conditions in Frankfurt.

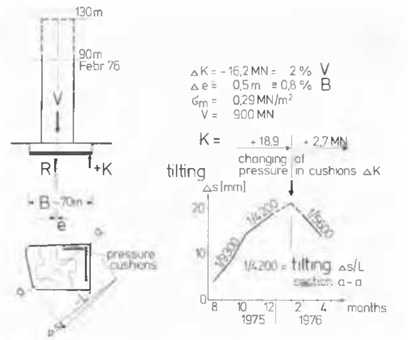

Fig. 11 Pressures of the cushions, reaction of the clay

CONCLUSIONS

By applying the pressure cushion system, a possibility has been tested to control arising tilting of a high-rising building founded on clay. After having passed the tests in a trial cell, the water-filled pressure cushions made of rubber could be approved for installation in situ. In spite of initial difficulties with the installation and in spite of leakages it may be stated that the new pressure cushion system stood the test.

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