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## Repair of a Building Damaged by Foundation Settlement

Réhabilitation d'un bâtiment endommagé par des tassements différentiels  
Sanierung von Gebäudeschäden infolge Setzungen

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### SUMMARY

The paper describes a simple and practical solution used to compensate for settlement caused by different foundations at the same building. Fix supports were replaced by moveable ties on sand jacks that descended periodically in accordance with the settlement measured between the blocks. The whole device, the basic control elements, the operative sequence for load transfer, the problems raised and the solutions given are presented in this paper.

### RÉSUMÉ

L'auteur décrit une solution simple et pratique pour compenser les tassements différentiels se produisant dans un immeuble comportant divers types de fondations. Pour ce faire, des supports fixes ont été remplacés par des tirants mobiles posés sur des presses à sable, qu'il faut descendre périodiquement en fonction des tassements mesurés entre les différents blocs. L'article fournit de multiples informations sur l'ensemble du dispositif, les éléments fondamentaux de commande, l'ordre opérationnel de transfert des charges, les difficultés rencontrées et les solutions correspondantes.

### ZUSAMMENFASSUNG

Der Beitrag beschreibt eine einfache und praktische Lösung, um Setzungsdifferenzen infolge unterschiedlicher Fundationsarten innerhalb desselben Gebäudes auszugleichen. Feste Auflager wurden dabei durch bewegliche Zugbänder auf Sandpressen ersetzt, die periodisch entsprechend den zwischen den Blöcken gemessenen Setzungen nachgelassen wurden. Die gesamte Vorrichtung, die grundlegenden Steuereinrichtungen, die operative Reihenfolge bei der Lastumlagerung, die auftretenden Problemen und ihre Lösung werden behandelt.



## 1. INTRODUCTION

One building that is a medical center in Recife, Brazil, started having cracks due to foundation settlement soon after the end of its construction. It was a reinforced concrete structure with two types of foundation. The central block is an eight floors tower having deep foundation of steel piles near 40 m long. The outer block has three floors in spread foundation at the depth of 0.85 m with columns spaced 6m per 5m and takes 90 % of the ground area. The blocks are separated by a joint but the beams of the lower block were set on consols at the columns of the tower. Figure 1 shows the general lay-out.

Damage was concentrated at the spans next the tower where the differential settlement was larger. The rest of the building had a satisfactory behavior. Cracks started at the masonry walls and soon reached the structural beams showing the need of repair to overcome the design error.

Soil tests were made to predict the settlements that were found to be not less than 150 mm. The excessive cost of underpinning of the spread foundation by the use of deep piles postponed the execution of this solution. Then it was necessary to extend the lifespan of the structure until the definite repair was made. It was decided to relieve the structure using a settlement-control device by moveable ties hung from the tower. The ties allow to compensate the settlement already occurred as well as the settlements that may occur later on. The paper outlines some features of the solution.

## 2. BASIC CONCEPTION OF THE SOLUTION

The basic conception of the temporary solution is to compensate the settlement due to consolidation of the 18 m thick layer of soft organic clay. The solution implies on some procedures as to predict and measure settlement regularly, to loose the outer block from the tower where it is supported replacing the original fix supports of the beams by moveable ones and to descend the lower structure from time to time, according to the settlement occurred in the meantime. Figure 2 shows the succeeding phases of construction that was followed. Phase 1 is the initial situation. Phase 2 is the construction of consols in turn of the tower's columns at the 4th floor, above the roof level of the lower block. Phase 3 is the placement of moveable ties hung from these tower's consols, resting over sand jacks and supporting the three level's beams of the outer block. After the load transfer, the primitive consols are cut off giving way to the descent of the beams.

However the success of the solution depends on having control over the value of some data, as load and settlement, and the performance of some elements as the structure and the conceived devices.

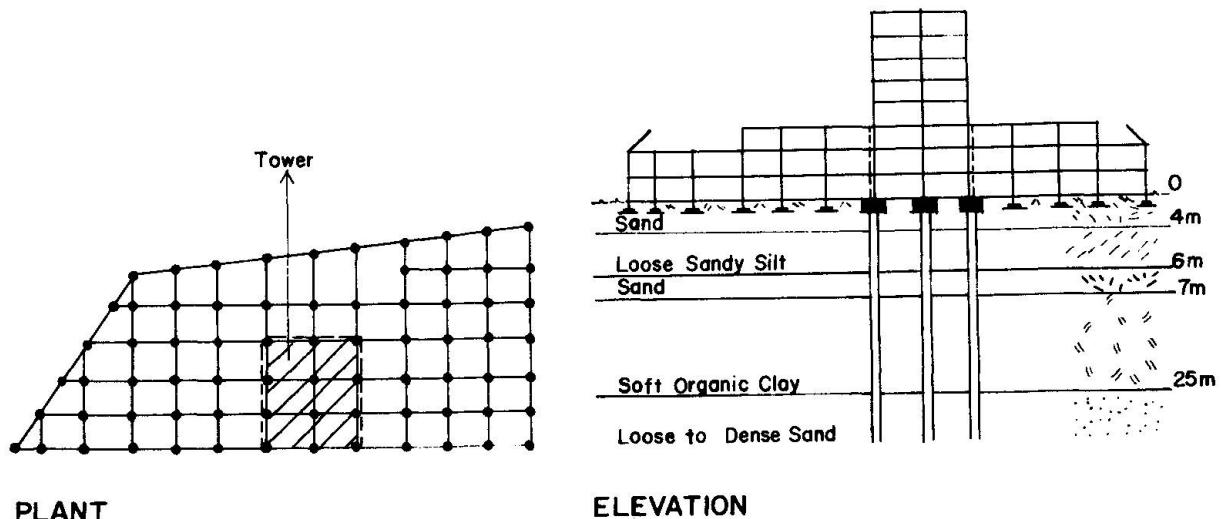
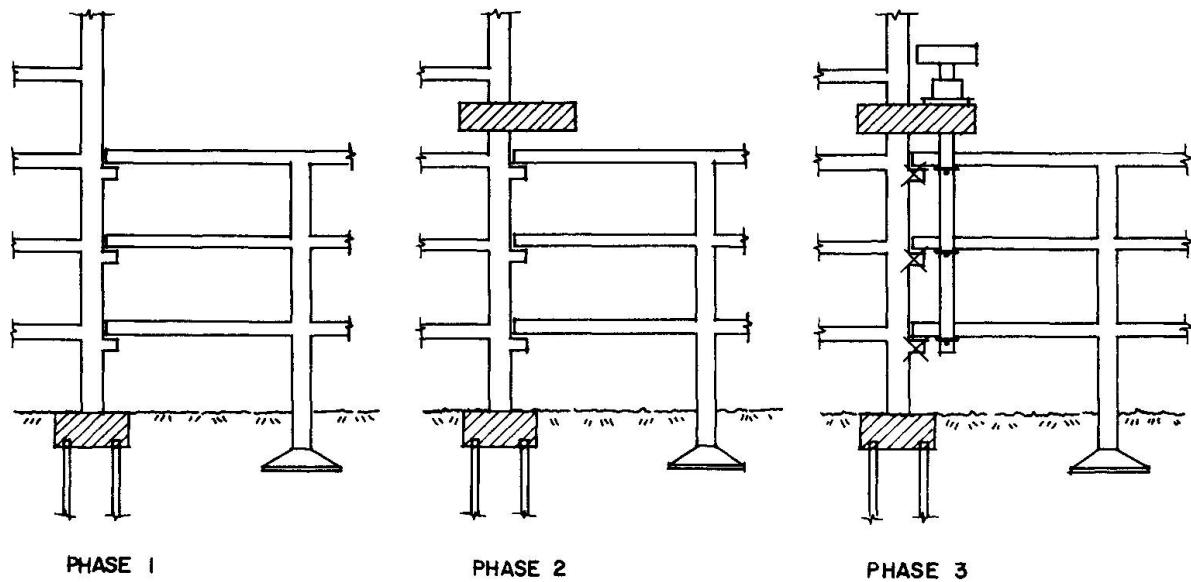


Fig. 1 Lay-out of the structure and foundation conditions

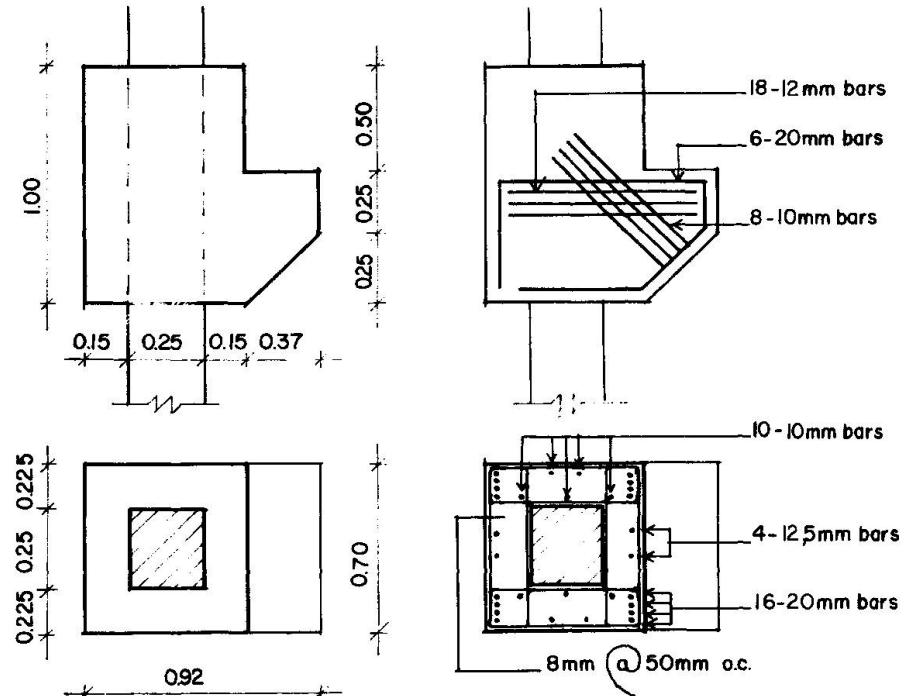


**Fig 2** Construction sequence of the solution

### 3. ANALYSIS OF THE SOLUTION

#### 3.1 The tower structure

The principal effect of the solution is on the reinforced concrete frame of the tower. The structure system should be able to resist to the new load distribution with safety. The maximum tie load is 266 kN. Loads are applied symmetrically to the frame at the 4th floor, when originally they are distributed along the lower floors. The structure was calculated to this new stage of loading and found adequate to support it. The new consols in turn of the tower's columns were designed using the provisions in the Reinforced Concrete Brazilian Code (1) to  $f_{ck} = 15$  MPa. Epoxy was used to bond the external encasement and the surrounding concrete. A summary of the detail is given in Figure 3.



**Fig. 3** Dimension and reinforcement of the consol



### 3.2 Settlements

Loads of columns in front of the tower varied between 500 to 700 kN using spread footings to transmit the pressure of 100 kPa to the soil at 0.85 depth. Since the first notice of damage, pins were fixed at these columns and the settlements started to be measured. At this time, the settlement already occurred and causing masonry and structural damage was evaluated larger than 20 and 40 mm respectively, by the distortion criterium of Skempton and Mac Donald (2). Once taken the decision of compensating settlement, the solution relied as much on the measured settlement as on the predicted ones. The total settlement was predicted to be higher than 150 mm by laboratory tests on soil samples. It was also used the early part of the time-settlements curve as the only datum for its extension, and the rest of it as a check of the prediction to the remaining settlement (3). This method was applied to the lectures of settlement made at different times. The results were dispersed, but the prediction was maintained.

A total of 28 settlement lectures were made along 9 years at interval of 3 to 6 months. The annual average settlement was 15 mm. Settlement was compensated when it reached a maximum of 20 mm or less to release the structure.

### 3.3 Sand Jacks

Sand Jack is much used to descend strut of reinforced concrete form. Should this jack be used at the tie device, it had to work lowering the beams under control in order to compensate the settlement measured.

Figure 4 gives detail of the sand jack. Its 160 mm diameter piston should get out an extension of 150 mm which is the settlement predicted to be compensated along time. The cylinder below has an internal diameter of 180 mm. It is filled in by fine sand of quartz with uniform grain-size and pre-loaded to 350 kN. This load is higher than the maximum one to be transmitted by the tie system. The device has two little holes at the bottom. The sand takes out smoothly using a thin steel pointer through them. Two lateral deflectometers measured the descent up to the value of the settlement to be compensated. Laboratory tests permitted to define the procedures to assure an even lowering of the piston. The field operations proved to be the sand jack a practical, simple and safe device to lower the conceived system.

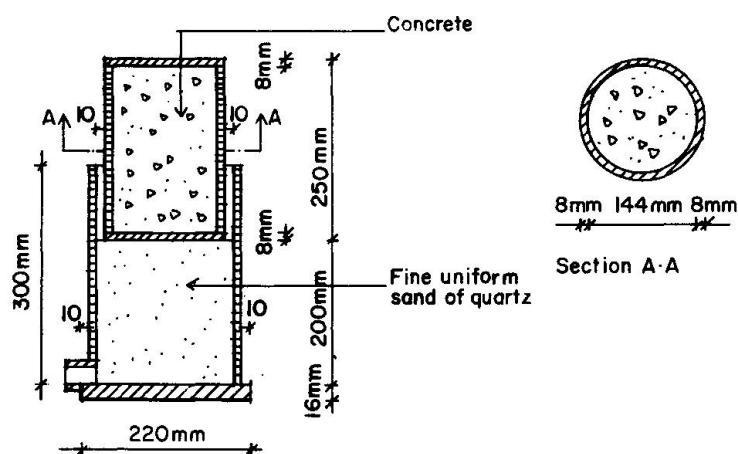


Fig. 4 Detail of the sand jack

### 3.4 Moveable Ties

Rigid ties were used instead of cables having intermediate supports to receive the beams. The transfer of the beam's load from the fix consols to the tie should be made by parts, starting from the top beam to the one down, with the use of inflate jacks put at the contact between the beam and its support in the tie. Epoxic resin was used as fluid. In each level, the load transfer was made symmetrically in order to assure the load equilibrium at the central tower.

The system is shown in Figure 5. All parts of it as splice, hook, bolt, welding, connection, etc. were tested to failure. The system's details should facilitate the anticipated construction sequence, including provisions for its erection and descent, installation through openings made at the existing structure, change of the sand jacks, space to operate them and the placement of inflate jacks to support the beams. Finally, load test made at each installed tie system determined the load transferred by each beam using strain gages fixed on the ties.

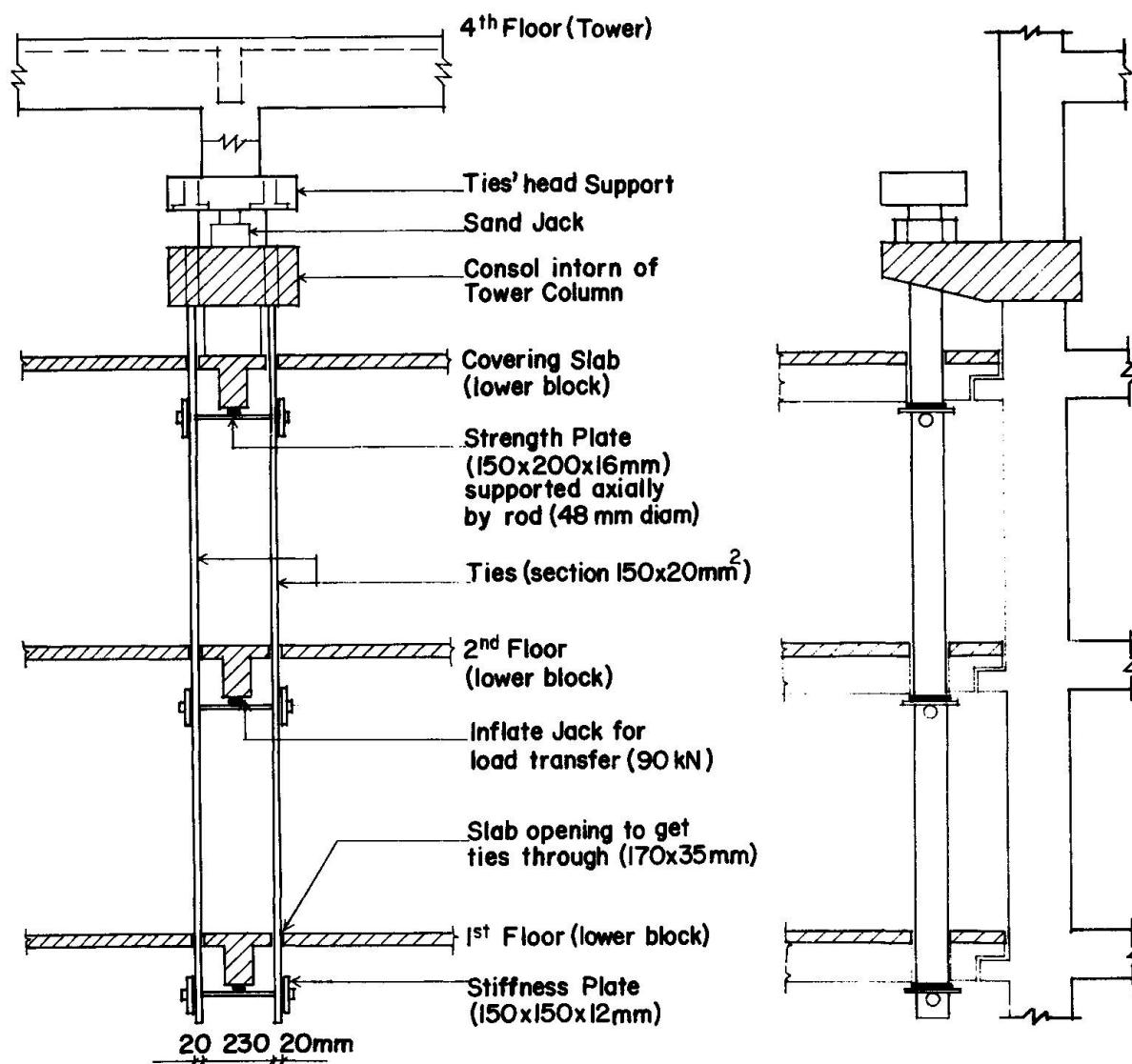


Fig. 5 Tie device to compensate settlement



#### 4. RESULTS AND DISCUSSION

The following sequence was set up to the construction: 1. consols in turn of the tower; 2. openings at the slab to descend the tie system; 3. moveable tie system laid down over the sand jack; 4. placement of the inflate jacks below the beams; 5. instrumentation; 6. load transfer; 7. break of the original consols; 8. structure relaxation by the sand jack lowering the whole device as much as the measured settlement to be compensated.

The load transfer is a delicate operation guided by instrumentation. The process starts with the toric jack applying 90 % of the dead load at the support. In the case of adhesion between beam and its fix support, the jack needs to apply an effort higher than the beam reaction. When the deflectometer indicates movement, one stops to pressure the jack, the load is recorded and the register is closed. Then the fix support is broken and the beam is free to descend. Operation is repeated to the beam at the level below.

The criterion adopted for structure relaxation was to proceed a maximum descent of 5 mm per tie in each round with a timelag of 24 hours between the descents. The first relaxation compensated 60 mm of settlement. Sometime on, when the settlement measurement neared 20 mm, it was compensated to release the structure. The total settlement was more than 100 mm, in average, along seven years of work on the direction of the Author.

In the meantime, the sand jacks were removed once. In some jacks, their pistons had got the final course. In others, the strong confinement of the sand avoided its remotion during relaxation. The jacks were repaired and turned back to the tie system.

The difference of level between the blocks was overcome using flexible by-pass for pipes and cables as well as moveable ramps at the doors. Ties were encased in each floor, together with the corresponding tower's column, having enough space to move inside without being seen.

When the settlement reached 200 mm it was decided to drive piles at all columns and the tie device was disactivated. It had extented the lifespan of the structure for more than 10 years.

#### 5. CONCLUSIONS

A simple and practical device was used to compensate settlements of one building having two different types of foundations. Moveable supports have the advantage to compensate settlements and to release the structure rapidly. The cost is low and construction procedures are quite simple. Otherwise, blocks remain with different level and periodical correction is needed, causing some disturbance to the users of the building.

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