FRACTURE GROUTING FOR CORRECTING BUILDING SETTLEMENT

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Fracture Grouting for Correcting Building Settlement

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ABSTRACT A 10-storey building supported by a mat foundation experienced a maximum settlement of 100mm and a tilt of 1/110. Fracture grouting under the foundation with cement and sodium silicate was applied to the underlying sandy soils to correct the settlement and the tilting of building. Evidence found from this case history indicates that a critical injection pressure which is related to the load of the foundation, is required for the uplifting process.

摘要　由筏式基礎支承之一幢 10 層建物，遭受最大 100 mm 之沉陷及 1/110 之傾斜量。經採用水泥及矽酸鈉材料於基礎下方之砂土層進行劈裂灌漿後，建物沉陷及傾斜已獲矯正。本案例顯示導致建物隆起之臨界灌漿壓力與建物基礎載重有關。

INTRODUCTION

The use of fracture grouting for correcting building settlement has been reported by researchers such as Samol and Priebel(1985), Raabe and Ester(1990). However, this technique appears to be experimental since the grouting parameters, the injection pressure and the volume to be injected shall be determined by field trials or to be adjusted according to actual field conditions. This paper presents a case history of correcting a 10 storey building which suffered from settlement of 100 mm. Details of grouting such as injection pressure and injected volume were closely monitored. Analysis of the grouting data enables a simple interpretation of the response of heaving to fracture grouting.

A CASE STUDY

Building A, a 10-storey building located in the central area of the Taipei Basin, suffered from maximum settlement of 100 mm at the southeast corner and tilting of 1/110 in

TABLE 1. Summary of Grouting Parameters

Type of Grout	Grout Mix Per m^3			Gel Time	Injecting Pressure	Total No. of Grouthole	Depth of Injection	Total Injected Volume
	Cement kg	Sodium Silicate ℓ	Water ℓ	sec	MPa		m	m^3
Backfill Grouting	380	167	713	40-60	2-3	36	16-6	297
	250	250	671	35-60	0.3-0.5	14	16-5	298
Fracture Grouting	250	250	671	34-60	0.3-2.2	14	14.5-9	320

April 1995. The settlement was caused by piping failure at a nearby launching shaft for bored tunnelling. A sinkhole of about 6 m in diameter was created next to the building. Although the reinforced concrete frame structure of Building A was not damaged the elevator could not be operated. Fracture grouting technique was selected for correcting the settlement and for restoring excessive tilt.

Founded on a mat foundation at depth of 5 m, the underlying subsoil beneath Building A has been sedimentary silty sand layer of about 12 m in thickness overlying silty clay layer of about 5 m in thickness. The average piezometric elevation of the sand layer was 1.1 m.

IMMEDIATE REMEDIAL MEASURES

Prior to the execution of the building uplifting process several immediate remedial measures were conducted to stop the settlement caused by the piping failure. About 200 m^3 sand and gravel material were dumped into the sinkhole on the day of the incident. Grout material of labile wasserglas (LW) of about 600 m^3 was then injected along the edge of Building A on the following 10 days. Table 1 presents the details of the immediate grouting. During the implementation of this grouting maximum heave of 32 mm and backward tilt of 1/640 at Building A were recorded. It appeared that the ground loss caused by piping was reinstated by backfilling with the gravel and grout materials.

CORRECTION OF SETTLEMENT

The correction of settlement of Building A comprised the activities of installation of grout curtain, instrumentation and fracture grouting.

A grout curtain, formed by jet grout piles, was installed along the eastern and the southern edge of Building A as that shown in Figs. 1 and 2. This grout curtain has the advantage of confining the extent of fracture grouting to within the mat foundation and protecting Building A from settlement during the driving of the nearby bored tunnel.

Totally 6 settlement markers, 4 tilt-meters and 11 automatic settlement monitoring points were installed at the columns of Building A to monitor the amount of heave induced by fracture grouting. The monitoring is of utmost importance to preserve the structural

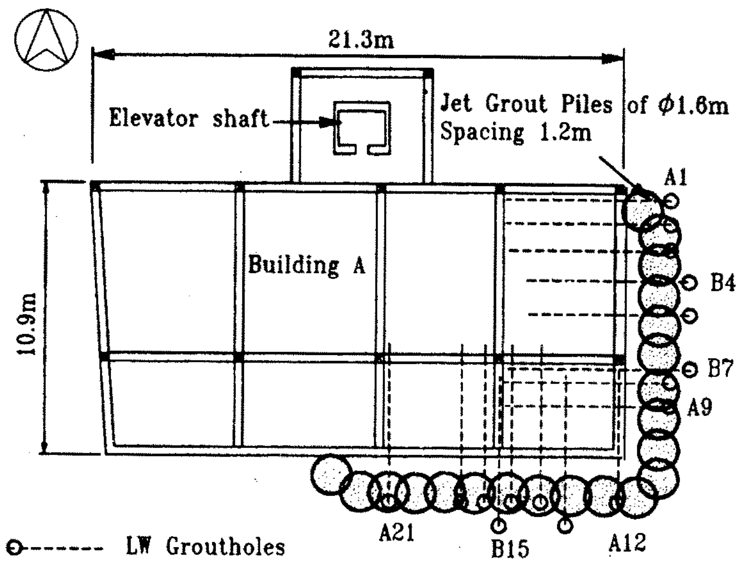

Fig. 1 Layout of Groutholes and grout Curtain

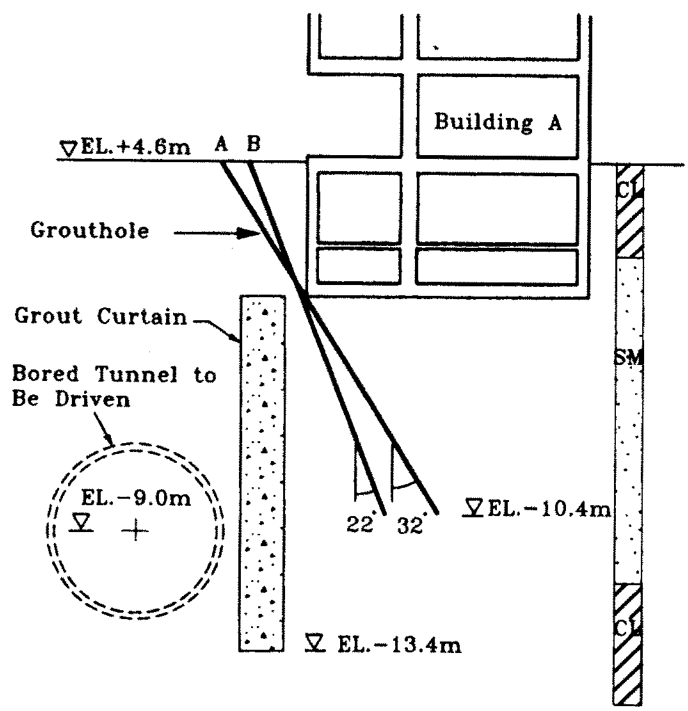

Fig. 2 Arrangment of the Groutholes

integrity of Building A. A criteria of differential heave between adjacent columns not exceeding 5.5 mm was stipulated during fracture grouting.

The LW grout material was applied for fracture grouting. As shown in Table 1 the grout mix and injection parameters were similiar to that for backfill grouting. However, for uplifting purpose 2 to 4 grouting units were used simultaneously. The grouting was basically the 1.5 shot procedure. The cement grout and the sodium silicate solution were

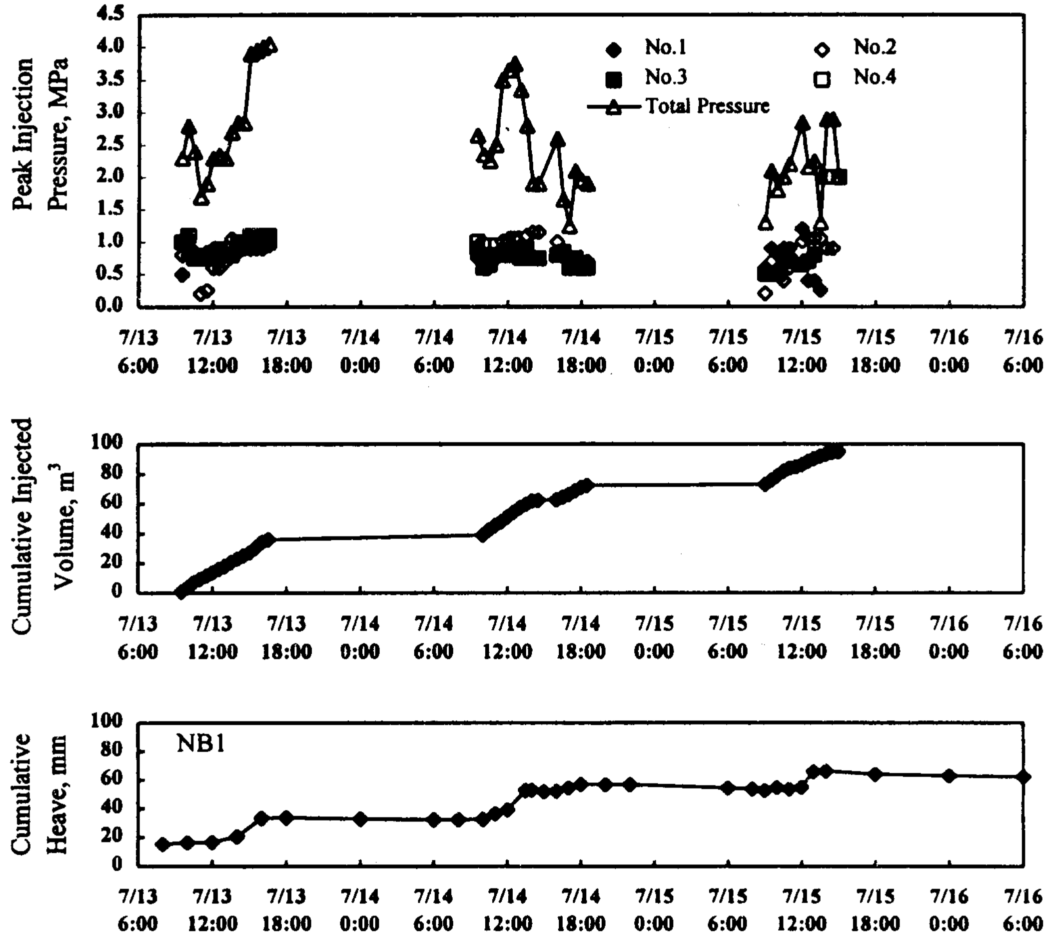

Fig. 3 Relationship Between Heave and Grouting

mixed at the piston chamber and then were injected through a single pipe into the ground. Grouting started at the depth of about 14 m and proceeded upward at 0.5 m vertical intervals up to the depth about of 9 m. The peak injecting pressure, occurred at the forward stroke of the piston, ranged from 0.3 to 2.2 MPa.

PERFORMANCE

Heave of Building

During the 11 days of simultaneously grouting with 2 to 4 grouting units the maximum daily heave, occurred at the southeast corner of Building A, ranged from 3.8 mm to 24.7 mm. The average settlement at 12 hr after grouting was 2.5 mm. On the 11th day cumulative heave of 127 mm was achieved. The tilt was restored from 1/110 to 1/285 along the E-W direction. The function of the elevator was reinstated.

Critical Pressure

It is observed that there has been a critical pressure which could induce heave. Figure 3 presents the details of fracture grouting during the period from 13 July to 16 July 1995. With the operation of 3 to 4 grouting units simultaneously the total rate of injection ranged

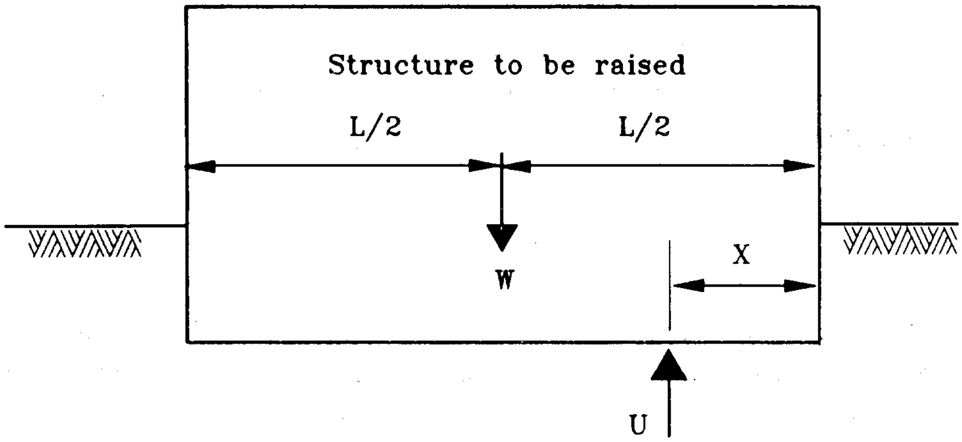

Fig. 4 Forces Exerting on the Building Uplifting

from 80 to 130 ℓ/min. The peak injecting pressure for each pump ranged from 0.3 MPa to 2.2 MPa and the summation of the peak pressure ranged from 1.5 MPa to 4.2 MPa.

It could be inferred from Fig. 3 that significant heave occurred whenever the summation peak injecting pressure reached the critical value of 3.3 MPa. This critical pressure was basically produced by grout pumps operated simultaneously. Meanwhile no correlation between heave and the injected volume could be made.

HEAVE MECHANISM

Based on the observation of this case history the mechanism of heave could be interpreted by the simple mechanics of moment equilibrium. As shown in Fig.4, at moment equilibrium condition,

$$\frac{WL}{2} - U(L - X) = 0 \quad \text{.......... (1)}$$

$$U = \sum_{i=1}^{n} P_i A_i \quad \text{.......... (2)}$$

in which:

- W weight of the building
- U resultant of the uplift force
- L length of the mat foundation
- X distance from the edge of building to the uplift force
- P_i peak injecting pressure of each grouthole
- A_i area of the fractured zone for each grouthole
- n number of simultaneously grouting units

The exact area of the fractured zone, A_i, for each grouthole is difficult to be measured. However, with same type of grout material having same gel time in same subsoil conditions, it would be a fair assumption that at the same injecting pressure, the travelling distance of the grout would be identical. Therefore, at the critical pressure, it could be assumed that A_i equals to a common value of A_g, the average area of fractured zone induced by a grouthole. Equation 2 can be simplified to:

$$U = A_g \sum_{i=1}^{n} P_i = A_g \sum P \qquad (3)$$

The term $\sum P$ represents the summation of the peak injecting pressure of each grouthole. Equation 3 substantiates the relationship between the critical summation injecting pressure and heave as described in the previous Section.

Based on the data of this case history, the W, L, X and the $\sum P$ values could be reliably estimated. From Eqs. 1 and 3, with $\sum P$ value of 3.3 MPa the back-calculated A_g value has been 5.9 m^2, for grout material having gel time of 34 to 60 sec.

CONCLUSIONS

Experience obtained from this case history provides concluding remarks on fracture grouting of the following:

(1)A critical injection pressure shall be reached before the structure could be uplifted.
(2)The critical injecting pressure which could induce uplift is proportional to the weight of the structure.
(3)In order to minimise differential displacement and due to the limited injecting pressure of the grout pumps, the operation of multiple grouting unit simultaneously would be essential for raising heavy structures.

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