

! " # \$ % & ' ( ) \* + , - . / 0

梁恒昌<sup>1,2</sup>, 周国庆<sup>1,2</sup>, 刘志强<sup>1,2</sup>

(1. +, -. / ' 01# \$2' 345%&, 6789: ; <=> ?@ 221008A2. +, -. / ' 2' 3BC%&' D<=> ?@ 221008)

1 2EOF G\$+HI J 3KLMNOPQH4RST<UVWXYZ[ \L2H] ^\_` a^bcde4Rfg I Jhi j <4R[ \LPQ<k` bcl mj <4Rn[ opqHMN<` 4RHPQR MNs&+[ tI JHud2\LpqHvwr xy\_zsI J{ | } Hud~yHy• ! 4RMN" #Hy• ST\$%t &<' () \* G +E4RMNr I JSTo, - HW. /<4RPQj <I J ud~yO1A4RMNj <I J ud~y2d\_34zs4GMN} 5' ( 6789I J: ; ud2H/1<tV<o=>| } ?@I J <A zs4GMN' ( B7~ I J ud2H/1<( 4BC} I J HDEFG\_ 345EHI I J Aud~yAI J ud2A4RbcAMNAPQA9} 67/89: TD265.32 ; <=>?: A ; @A9: 1000B4548(2010)06B0924B06 CDEFEKLM(1977N )<O<PQRST<UV<WXYZL<[ \- I B>] # \$2' 3%&^\_H` ' YZ %] \_E-mail: liangcumt@163.com\_

### In-situ tests on ground surface settlement and additional strain of shaft linings

LIANG Heng-chang<sup>1,2</sup> < ZHOU Guo-qing<sup>1,2</sup> < LIU Zhi-qiang<sup>1,2</sup>

(1. State Key Laboratory for Geomechanics & Deep Underground Engineering, China University of Mining & Technology, Xuzhou 221008, China; 2. School of Mechanics & Civil Engineering, China University of Mining & Technology, Xuzhou 221008, China)

**Abstract:** More than 100 shafts have ruptured in China during the past three decades. The vertical additional force is regarded as the mechanism of the rupture. Grouting of the surrounding soil to reduce the additional stress is found to be an effective method to cure the shafts. During the grouting period, the ground surface around the shafts upheaves, and the additional stress decreases. During the non-grouting period, the ground surface subsides, and the additional stress increases. The strain of shaft linings and the settlement are highly consistent. The additional force can be obtained from the settlement of the ground surface for the shafts without stress state monitoring system.

**Key words:** shaft lining; additional strain; vertical additional force; grouting; settlement; upheaval; in-situ test

0 G H 1987) B<` /ab?@bcdbe@bfgbhJbi j ] -kl o 100mn- I KLoFG\$R +I Jhi pq<sup>[1]</sup>\_I Jhr " st+` G\$3u# vw\_ux<hi j <yJz{ \$|F} ~<• ! y" ) <z{ \$#! i \$%&' Fv( <hi ) o\* &b+&, - . /<O7j <z{ \$123r >4r I 564\_47<8K! { " ) <89b: &; b< =; ] KL•! " ) <O7j [ >) y?<@AB8 \C\_t I Jhi DgHYZ<?AoI Jud2E FbaGvwEFbHI @JGEF] \_/KgL\$ %<' MNOr PQ9} YZHARSToI Jud 2EFEUV4RW&R3Xa] YGkZ &<@A &" 5N<\$Ro[ ~22/be\<] <^\_{ ` \$a5M\_ \$a` MNs&+ 3I JWX] ^<bd

VI J 7G\_pnud2?\_c22depqMj < z{ \$I J 3f 6g; khhr <sup>[2-5]</sup>\_ I Jhi i FG\$R3I J \I WX] ^H\ R<34I Jhi fg^j kl ol Jder 4Rdemn\_t) gl JH^j kl oEopl (qz{ \$dej <drI Jj <Xos<j \_t 4Rtu) gH^j kl oEJvbcR 4\_bcde\_[ xy 4R/Fr \I wx<t@AI Jud2HyZ — Z: &W&Rtubcde<xy{ 4RH\I r / 6<I Jr | } 4RSTHWXYZxy<A O~ tI JHud2<\_e• I 5H] ^<sup>[6-9]</sup>\_ bcHs&+<UVc Hb < { o4R I I I I I I I JKLM: , 6 ' u 78 50534040 A+, -. /' u 2006B003 A+, -. /' ) u 2007A007 NOPQ: 2009N03N11

epq& HPQ< mbc" T<4R[ 3 7H  
 e\kopq& H7HMN<PQOMNHKM3  
 I J Hud2 `pqH. ?< 9} H - I  
 J|} 4Rbcs&+4GMN' (rI Jud~y  
 ' (& u <YZ\$%4Rbcj " I J Hud  
 ~yr 4GMNU <YZ\RG+4GMNrI J  
 ud~yy• p <[kA zsmN\$%' (tI  
 5Hud; 2tupq& H < I J H  
 DEFG<tV<o=>|} ?@I J< p\L  
 7I \_

1 %&' ( ) \* R, ST

1.1 %&UVR, WT/O

- I I 5O459.0m<I 5 J 6.0m\_  
 I 5y64ptp - R 8 <p89<I  
 5y>o Tb: &; b<=; bG2 r  
 ] ; \*\_G\$ I J a^ I j <JF 400  
 mmAu# a^ z{ \$<I J F 400mm\_G\$  
 I 5UV <o[J 5.8 m< I I 5 s  
 H ?G\$RF 153.22m\_

c I . 92 - 15. 6 TD (c) Tj / 456 Tf 44. 88 O TD (153. 22 m)

?



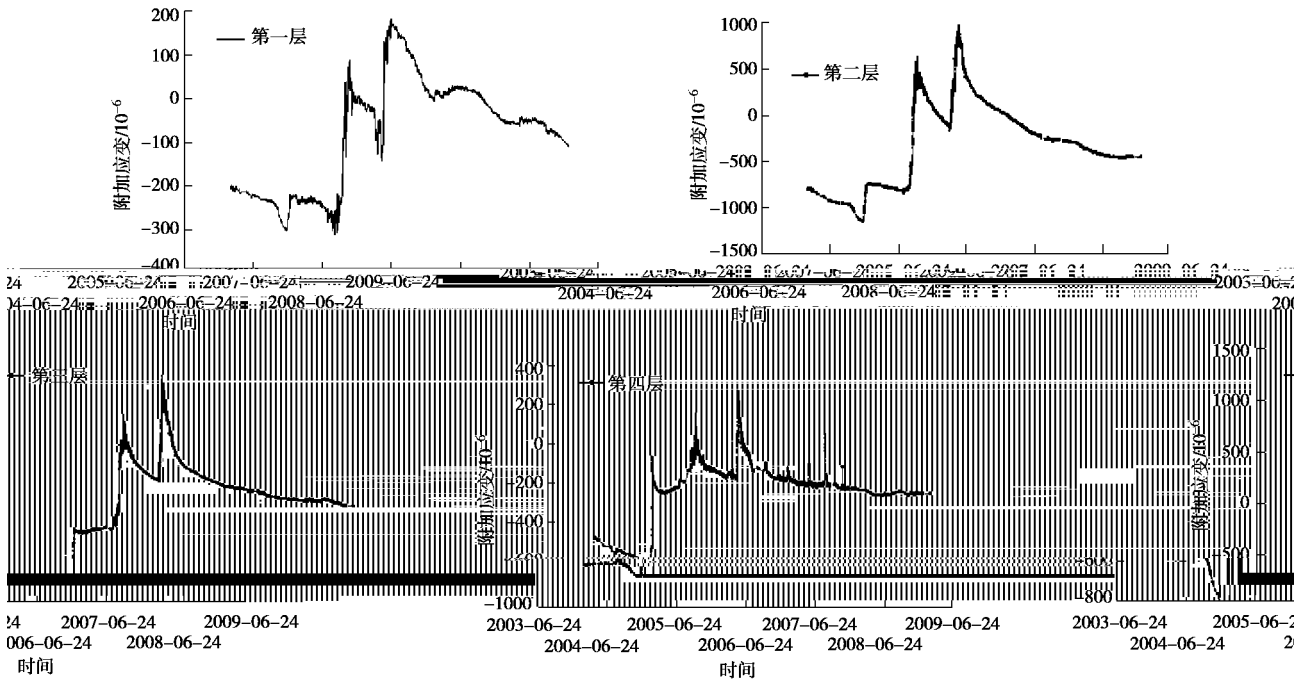


Fig. 3 Comparisons of additional strain at each layer of auxiliary shaft linings

Table 1 Characters of additional strain of shaft linings

R"	hr	$\sim y'$	$-hr ! \sim$	hr	p" bc	" bc	3l Jhi
	2	$10^{6 \cdot * -1}$	$y 2(10^{6 \cdot a^{-1}})$	$\sim y/10^6$	$\sim y/10^6$	$\sim y/10^6$	j $\sim y$ M/10 <sup>-6</sup>
p 100		35	100	85	350	250	200
125		65	115	260	1200	1000	350
145		70	225	370	1000	1250	700
165		55	195	340	250	400	500

R B\$%p5~yy• G\_ 80 100 -

[ 2004) 2\* - 10\* < l R" 9

} l! ~y% 2dOu qA [ 10\* \_<l

! ud~y' 70 10<sup>6</sup>/\* H 2dA- 12

\* 16 ` =>R" 5 13m) l JKL 1h

i <l J l! ~y 2K 130 300 10<sup>6</sup>/a<' 225

10<sup>6</sup>/a\_ l Jud l! ~yy• J ; 1hi H]

^<l! ~y <` vH10dyu A

p y< K 340 440 10<sup>6</sup><' 370 10<sup>6</sup>\_

` 4Sv<l J l! % q2d<3 2004) ) W&<

l! ~y -20 -340 10<sup>6</sup><' 130 10<sup>6</sup><4n

l! } M %P9 <l J l! ud~

yO e 2003) HF \_ R ! ud~y9

}) \* Hy• \$W < y• U 3 pb

Rn+ f < 158m) l JKL 1hi v<

l J ! ~2y• t~Vl! ~y` " yH y<

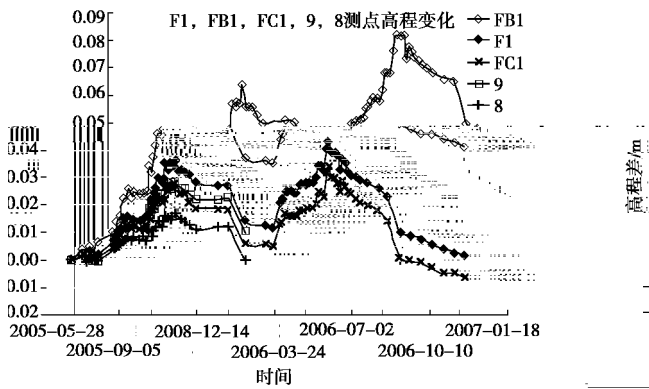
` p /H Gy• <` Hj Ty ! ~y

O 600 10<sup>6</sup>< n < vn 5N<

` 2005) H5n\* +< ! ud~y j TO1o

9b `I 5|} tuoMN } 8H s <  
 I 5+ \* H x ! 7I BC H y?  
 ] I t u s } 8 < \$ ` I 5HI { so  
 F1 F4 } 8 < ` I J 1 m 4 \_ ) so FB1  
 FB2 } 8 < ` bc ux so FC1 FC4 } 8 < `  
 ) so #9r #8 } 8 \_  
 ` p " bc " Tr " bc " Tt n } 8 tu  
 o t HMN } < y ( bc KHf < 2 3  
 dt up } K < bc \ v p tu } K \_  
 n } 8 } 5 HMN & y . ) \* 4 \_

5 + ) \* I 5I Jud~y ) \* r 4GMN  
 ) \* < 4GMN ) \* + ` 2005 ) 7 \* 20 2005 )  
 11 \* 16 r 2006 ) 3 \* 23 2006 ) 6 \* 24 j  
 " \$ GP9PQ < i 3 cj " I 5 | } 9  
 bo4Rbc < I Jud~y GP9PQ r 4R  
 GP9HPQ - 4 eo Z < F + 4RHP  
 Qr I J ; 2ST ` O W. / \_ 4RHy . xy  
 ol J H ; 2 \_ 4 \_ PQj < PQ ) \* ! " Vud  
 ~yy . < F + 4RPO @ AI J Hud 2O < ^  
 \_ud~y \_ k 4RMNj < 4RMN ) \* j T  
 { " Vud~yy . < F + < 4RMN @ Aud 2H  
 2d < ^ \_ud~y \_  
 W j T 8HMNr ud~y ' ( # VG 2 \_  
 ] 2 z { | } ` % & ' ( ) \* \$ st / O



7 4 j % [ \ " # , ` sthi

Fig. 4 Comparisons of elevation of measuring points for ground surface settlement

[ + H ) \* A e < n R " H } 8 &  
 4Rbc KHb k K Ly . < ` c b j < &  
 PQ < ` bcl m " T < 8 & opq ~ \_ 8  
 & HKM < w I 5 + \* H xkof  
 < ( I 5 x H 4 \_ < & y . KMWt / < k  
 I 5 + \* & H } 8 & y . KMWt

1 \_

2.4 ' ( ) \* \$ " # kl u . hi

5 9 } ebc " T ! bc \ v HI J O  
 125 myJ } 8 ud~yr I MN' ( ) \* &



7 5 % v " # \$ wx 125 m y ' ( ) \* kl hi

Fig. 5 Comparative curve of additional strain and ground surface settlement of shaft linings

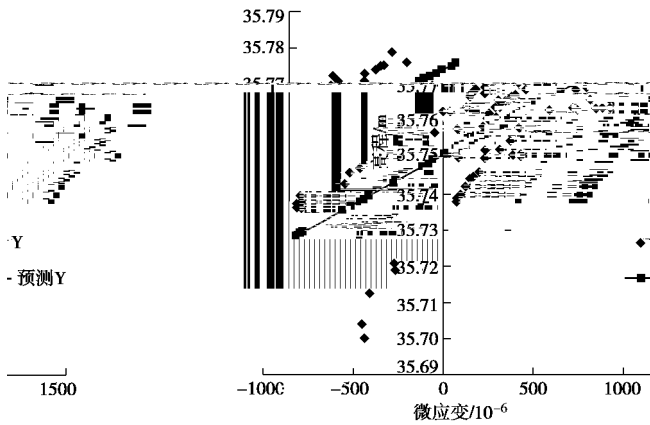
Table 2 Analysis of additional strain and settlement

j T ud~  
 y / 10<sup>6</sup>

$\% \$ \%^{[13]} < ud \sim y y k t u \% \$ \% \& <$   
 $e \% ) * 6 : \_$   
 $] 3 Y \sim / O ]$

Table 3 Statistical analysis

W. ?'	R <sup>2</sup>	&' √ R <sup>2</sup>	( ) *	} M
0.7136	0.509	0.503	296.15	83



7 6 ' ( ) \* \$ " # c d . 归 / O

Fig. 6 Statistical analysis of additional strain and settlement

$[ I J ud \sim yr 4GMN' ( H \% \$ \% \&$   
 $A e < I J ud \sim yy \cdot r MNy \cdot o / HW$   
 $. / < W. ?' eo 0.7136\_F + 4Ry \cdot r I J$   
 $ud \sim yST \ ` W. . ?\_ [ k + 9o I J H$   
 $ud \sim ykl i 3 4Ry \cdot t I J \ L ] ^ 2 H \$   
 $R\_ r I J hr H, ud \sim 2F - Wp E 4RW$   
 $t VI J ! 5o J GOJ G j < I J Hud 22$   
 $/ < I ! ud \sim y 2 / < \ ` epq \& KLI$   
 $Jhi A 4Rbcj < UVc Hb < p ^ \_ x$   
 $o 4R. / < p ^ \_ 4RWt VI J \ L ! { JG$   
 $H < I JHI ! ud 2O1 < [ k I J Hu$   
 $d \sim y O1A RO1 Hud 2s / < , - [ I J$   
 $z { \$ \ L ; OF - VI J \ LO1 hr < @A$   
 $I J HOi \$ H ` < ` bcs \ + 23o 9P <$   
 $UVc H { es \& [ 4R 7H e < ] re$   
 $\ < I J HOi \$ 4Z f 59 \& Oc \_$   
 2.5 z 3性的成因机理

$\ ` 4Rbcs \ + < UVc Hb < 4R e$   
 $oder PQ < 4j I J ud \sim y [ \% P F <$   
 $4G \} 5 \% PPQF Abc m" T < UVc$   
 $+ 1 \$ \& \$ H : 9 ! 4RH 7He \ < I J Hu$   
 $d \sim y [ 9Ppq \& H < 4G \} 5 \% Ppq H$   
 $5M \_ 4R` PQHs \ + < I J Hud \sim y$   
 $\} 5' M6V 4GPO \} 5' MHGP < k ` 4R$   
 $5Ms \& + < I J ud \sim y \} 5' M7v 34R$   
 $5M \} 5' MHGP < 34RHxy ^ \_ I J ud$   
 $2Hxy H 8W Z < [ k 2 [ 87p ^ \_ + 9o$   
 $I J , ud \sim 2F - \_ [10-12]$

$OF G \$ + HI Jr 4RSTHWXYZ < 9V$   
 $\# \$ \% \& WX ] ^ : ; < 4Rbc H 9bxy o 4R$   
 $\ I r / < < J GPi 4G epq \& HPQ <$   
 $PQ \& ! PQ \} 34R \ I bbc sbbc$   
 $\ ^ bbc Kbbc < 2b = > ] ' o. \_$   
 $I 5 + < pqJ \} mbc tum ? b$   
 $\$ \{ ubcj < 4R bcR " \_ Wt VI J ! {$   
 $J G < 4Rr I JSTHWt J G < p ^ \_ xy o I$   
 $J \{ Bg ; 2HKM < 8p ^ \_ @A o I 5ux$   
 $4GHy \cdot < 34 [ 9 \} \ RA e < 4GHMN$   
 $\} * r I J Hud \sim y ) * ' ( \{ GP 9 Hp$   
 $/ \_ j 2 e < I 5 + f \{ H 4\_ M$   
 $N \} 8 < y \cdot W < KM \{ opq H @ <$   
 $f i ` bc ( \{ 4GPQA / < ki I J ux$   
 $4\_ PQA / < V 4 ^ \_ i 5p BCI YZ Hy D \_$

### 3 结论与展望

$zsl J ypq 8H 9 \} ud \sim y ) * r I 5 |$   
 $\} pq 8PQMN) * H \& ! OZ \$ \% A$   
 $9E$   
 $1 I J ud \sim yy \cdot i | \} FG \$ r I J W$   
 $X ] ^ H \ R < 4GMNj < ud \sim y A 4GP$   
 $Qj < ud \sim y O1 \_$   
 $2 4GMN) * r I J ud \sim y ) * ` ,$   
 $- Hp W. / \_$   
 $3 tV < o > sl J | \} ? @ HFG \$ + H$   
 $I J < A z sMN \$ \% ' ( t I 5Hud ; 2tu$   
 $pq \& H < I J HDEFG \_$   
 $4 a ^ 4Rbc ^ j fgl J < bcdeo$   
 $Z \& 4R < \{ BI e \ MNH 4R eo PQ <$   
 $E o I Jr 4RSTH, ud 2 - F < I J$   
 $HI J ud 2 e + HO1 < t I J H ; 2F o$   
 $\_ F + o, W \& Rr | \} \$ Rbc 6 [ y \{ E$   
 $I J ; 2F - gL \_ 4Rbc \ v H 6n * y <$   
 $I J Hud \sim y nopq \& F < KM$   
 $KMH 1/3 1/2 < \{ 3 \$ \% bca H \{ e$   
 $\ ! | \} 4RH 7e \ @AH < 34BGbcc \sim$   
 $KHd HI J \_$   
 $[ P ! ' ( \{ \$ \% o I 5I J ; 2r I 5$   
 $| \} 4\_ y ? STH. ? < k. V Ktbctu$   
 $d ^ HY Zbbc Kr 4\_ PQH. ? HY$   
 $Zbbcde r " sHY Zbbcf gl Jhi$   
 $Hd" [ RLMYZNi 5p BI tuH \% ] yD \_$

参考; <:

[1] ZHOU Guo-qing, CUI Guang-xin, et al. Simulation study on

reinforcing overburden to prevent and cure the rupture of shaft lining[J]. Journal of China University of Mining & Technology, 1999, **9**(1): 1N7.

- [2] | , O, PQR, ] . } \$ b c r S l J u d 2 [ ~ ! ~ ^ [J]. # \$ % & ' ( , 2005, **27**(7): 742N745. (ZHOU Guo-qing, LIU Yu-zhong, et al. Application and effect of grouting in surrounding soil on releasing and restraining additional stress of shaft lining[J]. Chinese Journal of Geotechnical Engineering, 2005, **27**(7): 742N745. (in Chinese))

- [3] | , O, K L M, T U V. W X \$ b c Y W g 2 5 : Y Z [J]. + , - . / ' ' ( , 2005, **34**(3): 265N269. (ZHOU Guo-qing, LIANG Heng-chang, ZHAO Guang-si. Test of grouting surrounding pile for improving bearing capacity[J]. Journal of China University of Mining & Technology, 2005, **34**(3): 265N269. (in Chinese))

- [4] | , O, Z [ - . + / \ M " # 3 W ] 2 . ? H 5 : Y Z [J]. + , - . / ' ' ( , 1999, **28**(6): 535N538. (ZHOU Guo-qing, YANG Wei-hao. Test study on relation between thaw-collapse displacement of medium sand and negative friction of single pile[J]. Journal of China University of Mining & Technology, 1999, **28**(6): 535 N 538. (in Chinese))

- [5] Z [ - , ^ \_ , | , O. U V 4 R. / 5 l J h i D g 3 ` f a H Y Z ( S p ) [J]. + , - . / ' ' ( , 1996, **25**(4): 1 N 5. (YANG Wei-hao, CUI Guang-xin, ZHOU

Guo-qing, et al. Fr/F3 9.12 Tf10.8 0 TD 0 (q) Tj0.10464 Tc c (,) Tj2.04 Tc ( ) Tj0.03072 Tc (e) Tc (x) 0.10464 Tc (HO) Tj-00 TD (a) Tj/F1+