TOWER CONSTRUCTION
ON LAYERED GROUND
Data of beam centrifuge tests

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1 Introduction

This research was undertaken to develop a technique of simulating tower construction on layered ground in a centrifuge model test. This pilot study was conducted using the beam centrifuge at the Geotechnical Centrifuge Centre of Cambridge University Engineering Department.

The model conditions were chosen to be similar to those at the leaning tower of Pisa site. Exact modelling of the Pisa site conditions was not attempted, as centrifuge modellers at other centres were undertaking this work.

Two centrifuge model tests were undertaken on 13 September 1991 and 10 March 1992 designated Pisa 1 and Pisa 2 respectively. These simple models provided data of tilting of an initially vertical tower constructed in-flight on a uniform layered soil foundation.

2 Technical Development

2.1 Model Test Design

The selection of scaling factors for the model tower design are described below. Two separate sets of scaling factors were used for geometry and load. These scaling factors were also varied within the model to account for the increase of the centrifuge acceleration field with radius.

The geometric scaling factor for the tower foundation was 110. This scaling factor was used to fix the required centrifuge acceleration of 110g at a distance of 1/3 the base diameter below the base of the tower. The 20m diameter tower base was modelled by a 182mm diameter 25mm thick perspex disc. This disc located centrally in a 850mm diameter tub was more than 2 base diameters from the tub wall thus minimising boundary effects.

The 400mm tub depth allowed about 37.4m of soil depth to be modelled. At Pisa, the soil profile to 37.4m includes horizon A and part of horizon B. Horizon A is about 10m thick and is essentially a low plasticity clayey silt. Horizon B extends from 10 to 40m and consists of 4 layers: the Upper Clay, the Intermediate Clay, the Intermediate Sand and the Lower Clay. The Lower Clay layer was not modelled in these model tests.

The Upper Clay layer is considered to be particularly influential in the settlement of the tower, for example Mitchell et al (1977). This layer is a slightly overconsolidated, medium to high plasticity aged clay. The undrained shear strength of this clay has been evaluated as:

$$\frac{c_u}{\sigma'_{vo}} = 0.23\ OCR^{1.24} \qquad (1$$

from constant volume direct simple shear tests, Beradi et al (1991). The overconsolidation ratio within this layer is about 1.5 to 2.0 (ibid).

Speswhite kaolin was used to model this layer. An equivalent undrained strength of Speswhite kaolin has been determined as:

$$\frac{c_u}{\sigma'_{vo}} = 0.19\ OCR^{0.67} \qquad (2$$

from shearvane tests, Hamilton et al (1991). Assuming identical vertical stresses, overconsolidation ratios of **2.8** to 4.7 would be required ta model the undrained strength of the Upper Clay.

A critical state finite element analysis of the tower construction was performed by Guell (1991): under the tower the stress paths in horizon B during stage 1 of tower construction from 1173 to 1178 were similar to those of drained triaxial compression, with yielding on the wet side of critical state, figure 1. If the initial overconsolication ratio was increased, these stress paths would have been onto the dry side of critical state, changing the class of behaviour.

The overconsolidation profile of the Upper Clay was therefore modelled. Assuming submerged unit weights of 0.84 and 0.7 for the overlying material at Pisa and in the model test respectively, the ratio of undrained strengths from equations 1 and 2 is 1.8 to 2.2. The triaxial compression drained strength can be estimated from:

$$q_f = K_o \; \sigma'_{vo} \; \frac{3M}{3 - M} \qquad (3$$

Soil properties were taken from Beradi et al (1991) and Jamiolkowski (1988) for the Upper Pisa Clay and Phillips (1986) for Speswhite Kaolin. K_o values were calculated using

$$K_o = K_o(NC) \; [OCR - OCR, + 1]^{0.5} \qquad (4$$

after Mesri and Choi (1985). For overconsolidation ratios of 1.5 to 2, the K_o values used are 0.65 to 0.77 and 0.78 to 0.91 for the Upper Clay and Speswhite kaolin respectively. Similarly, M values used are 0.984 and 0.8. The ratio of drained strengths from equation 3 is then 1.93 to 1.90.

The model weight of the tower was reduced by a load factor of 1.9 below the geometrically scaled value to account for the lower strength of the model foundation. The geometric scale for the tower was 100.2 allowing for the radial increase of acceleration. The model towerconsisted of a 182mm diameter 25mm thick perspex base glued to a 133mm diameter 580mm long perspex tube with a 5mm thick wall, figure 2. A 240mm diameter 1 mm thick aluminium annular disc was supported on 4 brass pillars 60mm up from the base of the tower as a reference plate for settlement measurements.

The Pisa tower was constructed in three stages, after Mitchell et al (1977):

Tower Construction

	Year		Tower Weight
	Start	End	Tons
Stage 1	1173	1178	9,500
Stage 2	1272	1278	4,200
Stage 3	1360	1370	750
Total			14,450

The overall height of the tower from the base of the foundation is 58m. The model tower was designed to simulate the correct weight and centre-of-gravity of the tower after each stage of construction. The centre-of-gravity after each stage was assumed to be at one half of the current tower height, which was taken as the overall height of the tower factored by the current to final tower weight ratio. The model tower construction sequence is shown in figure 3. The tower moment is defined as the tower weight times the centre-of-gravity. The mass of the empty tower was 1.8kg. The staged construction of the tower was modelled by filling the empty model tower with up to 6.5kg of water. The empty model tower had an initial scaled weight of about 33,000kN. The effect of this initial load was partly compensated by increasing the final scaled weight of the model tower to about 155,000kN.

The rate of tower construction was modelled by considering the rate of primary consolidation within the Upper Clay. Representative coefficients of primary consolidation were taken as 5 and 100 cm^2/sec for the Upper Clay and Speswhite Kaolin respectively. This 20:1 ratio and the foundation scale factor of 110 implied that 1 year of prototype behaviour would be modelled in 2.2 minutes in the centrifuge test.

The average rates of tower construction was assumed to be 1,900 and 700 tons/year during stages 1 and 2. A nominal rate of 1,200 tons/year was modelled by a water flow into the tower of 0.26 litre/min.

In the absence of a suitable low plasticity clayey silt to model Horizon A, fine loose 100/170 Leighton Buzzard sand with a particle size of about 0.1 mm was used.

2.2 Equipment

The layered foundation was retained within an 850mm inside diameter tub with an inside height of 400mm, figure 2. The model tower was embedded 27mm into the foundation and contained within a 600mm high extension. Top aid middle circular support rings were bolted on top of the extension and between the extension and tub respectively as shown in figure 4. The top 3/8 HS15TB duraluminium ring was used lo locate the water flow control system into the tower, the instrumentation amplifier box and the tower supports.

The flow control system in test Pisa 1 comprised of a water feed at a pressure of about 1.5MPa, which was throttled through a filter and an 0.6mm diameter orifice to deliver the required water flow rate to the tower, figure 6. The water feed was controlled using an Asco D262D200 red-cap solenoid valve rated to 10MPa with a 1.2mm diameter orifice. As the valves operating pressure was significantly lower than the rated capacity, the solenoid coil was strong enough to lift the increased weight of the solenoid spindle. The flow rate from this system was not variable during the centrifuge test.

For test Pisa 2 the flow control system was changed to that shown on the top ring in figures 2, 4 and 7. The water feed was fed into a continually overflowing standpipe. The standpipe overflow was set to provide a positive pressure head of about 40kPa into a peristaltic pump. The pump was driven from a DC gearmotor, the flow rate was proportional to the DC motor supply voltage. The output of the pump was directed into the tower through a suction break. The feed pipe extended into the base of the tower and was supported from the gantry shown in figure 4. The water flow was controlled using the Asco solenoid valve. A second Asco solenoid valve was incorporated to bypass the peristaltic pump in the evert of pump failure, operation of this second valve was not required.

In test Pisa 1, figure 6, the tower supports consisted of three linearly variable differential transformers (designated LVDTs 8 to 9). These LVDTs may have provided significant support to the model tower in this test and were replaced in test Pisa 2 by 3 support fingers, figure 7. These support fingers were located such that following settlement of the empty tower during the initial consolidation phase of the centrifuge test the fingers came cut of contact with the tower.

The middle 3/8" HS15TB duraluminium ring, figure 5, was used to locate seven LVDTs. Three of these LVDTs, designated 1 to 3 in Pisa 1 and 5 to 7 in Pisa 2, were used to monitor lateral movement of the tower base. The other 4 LVDTs, designated 4 to 7 in Pisa 1 and 1 to 4 in Pisa 2, were used to monitor vertical settlement of the tower and the adjacent soil surface. The seven LVDT locations in test Pisa 2 are shown in figure 2: LVDT 4 monitored the vertical settlement of the soil surface, the other 6 LVDTs monitored the movement of the tower.

A tower drainage system was also incorporated on the middle ring. This system comprised of symmetric drainage ports into the base of the tower connected through an Asco solenoid valve to waste, figure 5. Care was taken to ensure that the tower was symmetrically loaded by this and other systems in contact with the tower: The LVDTs were orientated at 120 degree intervals around the tower. The horizontal LVDT spindles were fitted with identical springs to keep the spindles in contact with the tower, with a minimal amount of force. The ends of the spindles were fitted with tufnol tips.

A 1:110 aluminium wedge was placed under the test package to orientate the resultant acceleration of the centrifugal test acceleration level and earths gravity along the axis of the model tower. Pore pressure transducers were embedded with the foundation. One pore pressure transducer was placed within the model tower. A variely of visual techniques were used to complement the data from the electronic instrumentation as described below.

3 Centrifuge Model Tests

3.1 Model Construction

Each model test was constructed as follows. The soil foundation was formed inside the 850mm diameter, 400mm high circular tub. A steel plate was placed in the bottom of the tub, followed a 'Vyon' porous sintered plastic sheet. The steel plate contained drainage channels and was also used to support the soil foundation during extrusion from the tub. A medium dense fine 100/170 Leighton Buzzard sand layer was pluviated at 46% relative density into the tub between the levels of 227 and 340mm, figure 2. This sand layer simulated the intermediate Sand of Horizon B, and maintained the tower position at the correct elevation relative to the top and middle rings. This lower sand layer was slowly saturated with water from below through the drainage plate. A pore pressure transducer with a sintered bronze filter element was sealed through the tub wall and buried beneath the surface of the lower sand layer.

The Speswhite kaolin clay was reconstituted from a slurry. Each batch of slurry normally comprised 50kg of Speswhite kaolin powder and 60 litres of deionised water. Each batch was mixed for about 2hours under a vacuum of approximately an atmosphere. The resulting slurry had a nominal water content of 120%; this is about twice the liquid limit of the clay. The walls of the tub were coated with a film of water pump grease to minimise sidewall friction. Each batch of slurry was placed by hand scoop with care to expel air from within the slurry mass and not to disturb the lower sand layer.

About 278mm of slurry was required to achieve the 136mm thick clay layer. The 600mm stainless steel extension was added to the tub to retain the slurry. The clay layer was consolidated in two stages, first under a uniform consolidation pressure and then underadownward hydraulicgradient. Sheets of fitter paper and another sheet of porous plastic were placed on the surface of the day slurry. The tub and extension were placed on the base of the consolidometer reaction frame. The reaction frame was then assembled around the tub consolidometer and a circular piston was brought to bear evenly on the porous plastic sheet.

During consolidation under a uniform effective stress, drainage was allowed through the piston and the underlying base drain. The base drains were open to atmosphere via a water header tank set at the level of the piston. The slurry was left to consolidate under the ram and piston self weight

(5.2kPa) for about 24 hours. The stress on the clay was then doubled every day until a uniform consolidation stress of about 145kPa was reached. Each stage of consolidation was monitored by recording the settlement of the piston with time.

To monitor further consolidation of the clay specimen in the consolidometer and during the centrifuge test, three Druck PDCR 81 pore water pressure transducers (PPTs) were inserted at different horizons, via ports in the tub wall, into the clay specimen. At a particular horizon, the port in the tub wall was opened and cleaned out. An extension piece was screwed to the port to guide the insertion of the PPT. A 7mm diameler greased thin walled tube was then pushed about halfway towards the final position of the PPT and a clay core sample taken for water content determination. The tube was reinserted to a position about 5mm short of the required position of the PPT face. The inside of the tube was augered oul and the tube and guide withdrawn. The deaired PPT, fitted with a ceramic filter, was placed on a guide tube and slid along the hole. It was then pushed gently through the previously undisturbed material to its required position. The guide was removed and the hole backfilled with a thick kaolin slurry of about 80% water content using an old grease pump and hypodermic tube. The port was plugged with the PPT cable passing out through a polyethylene gland seal. The process was repeated until all the PPTs were inserted, each insertion took about 20 minutes.

The piston was replaced by a piston fitted with an annular irathane pressure bag, in preparation for downward hydraulic gradient consolidation. The consolidation stress was then returned to about 145kPa (with the irathane bag deflated) until equilibrium was attained, as monitored by the PPTs and settlement of the piston.

The irathane bag was inflated and a water pressure of about 30kPa applied to the top of the sample. The piston pressure and water pressure were increased until effective stresses of about 152 and 215kPa were achieved at the top and bottom of the clay sample respectively. Consolidation of the clay cake was monitored by the PPTs and further settlement of the piston for about 10 hours until effective stress equilibrium was achieved. The effective vertical stress was then reduced to a uniform stress of 110kPa.

After swelling of the clay was complete, pore pressures were recorded, free surface water removed, base drains sealed and the clay cake unloaded and removed in its tub from the consolidometer. The final height of the clay surface was measured. A lightly greased perspex template was placed on the clay and an array of 2mm lead shot indented into the clay surface. Pasta noodles coated in dry blue ink were pushed into the clay along two orthogonal lines, orientated at 45 degrees to the centre line of the sample to avoid damaging the PPT leads. These noodles absorbed water anddeformed with the clay providing information about gross sheardeformation of theclaysample.

After removing the template, the initial positions of the surface lead shot and noodles were photographed using a 70mm Hasselblad camera. A PPT with a sintered bronze filter was sealed into the tub wall for location in the upper sand layer. Two water feed outlets were placed on the surface of the clay close to the edge of the tub, and covered by damp filter paper. The lead shot, noodles and feed outlets are shown in figure 8. The upper sand layer was pluviated dry at 5% relative density onto the clay surface. 'This upper sand was constructed in 21 mm thick lifts. A thin coloured sand band was placed between each lift for visualisation of the sand movement after the test. Each lift was levelled using a vacuum system as shown in figure 9.

The model tower was founded at 27mm, figure 2. Before placing the final upper sand lift, the tower was gently placed centrally on the levelled coloured sand layer. The final sand lift was placed and levelled. The mass and volume of the upper sand layer was calculated for density determination. The drain line from the tower and the water feed to the upper sand layer were passed through pressure seals in the tub wall.

The LVDT mounts, LVDTs and the tower drain solenoid valve were attached to the middle aluminium ring. The LVDT spindles were taped back to the LVDTs to prevent premature interference with the tower. The middle ring was carefully lowered over the tower onto the tub. During this process the feed pipes to the water outlets and the tower drain line were passed through the middle ring. The middle ring was bolted to the tub and the feed pipes and drain line secured.

The LVDT spindles were untaped and the spindles brought to bear on the tower. The spindle of the LVDT measuring surface settlement was brought to bear on a 20mm bearing plate. The positions and outputs from the LVDTs were verified. The tower drain lines were connected through a manifold to the Asco solenoid valve and to waste through the tub wall.

The bolts connecting the middle ring to the tub were carefully removed and replaced by three guide pegs. The 600mm stainless steel extension was carefully lowered onto the guide pegs and bolted through the middle ring to the tub. The 3 tower supports, instrumentation amplifier box and tower water feed system were connected to the top ring. The electrical leads from the LVDTs and the solenoid valve on the middle ring and the water feed pipes to the clay surface were passed through holes and fittings in the top ring. The top ring was bolted to the top of the extension.

The 3 tower support fingers were brought gently into contact with the top edge of the tower. The pipe from the tower water feed system was placed inside the tower with a PPT to monitor the height of water within the tower. All instrumentation were connected to the amplifier box and their performance verified.

A standpipe was bolted to the outside! of the tub with water feeds to the lower and upper sand layers. The water feed to the lower sand layer was controlled through a manually operated valve to minimise swelling of the clay layer. The standpipe overflow controlled the water level to be 18mm (equivalent to 2m) below soil surface at test speed. The drain from the standpipe was connected through a pneumatically operated valve to waste.

The 1 :1 10 wedge was placed onto the centrifuge swinging platform on a rubber mat. The completed test package was weighed and sat on a second rubber mat on top of the wedge. All services were connected to the test package and verified. All instrumentation were energised and logged using Labtech Notebook on a PC-based data acquisition system.

The upper sand layer was not saturated until a few hours prior to centrifuge flight to minimise swelling of the clay layer.

3.2 Centrifuge Testing

After opening the valve to the base drain and verifying the instrumentation readings, the centrifuge was started and the test package accelerated to 10g. The centrifuge speed was then increased in 20g stages, after each stage the attitude of the tower was noted.

After reaching the test acceleration of 1 10g at 160.3 rpm, the water feed to the standpipe was turned on. The consolidation of the clay layer was monitored by measurement of the settlement of the tower and the pore pressures within the clay layer. Primary consolidation was complete after about 5 hours. During primary consolidation, two magnetic tape recording systems and a video recorder were set up to complement the PC-based data acquisition system during construction of the tower.

When primary consolidation was complete, the magnetic tape recording systems and the video recorder were turned on, and the rate of data acquisition to the PC increased. The water supply to the tower was turned on, and Stage 1 of tower construction undertaken. The tower water supply was turned off and the performance of the tower and its foundation monitored. Similarly at the appropriate times, stages 2 and 3 of the tower construction were undertaken and monitored.

After the centrifuge test was complete, the water feed to the upper and lower sand layers was turned off and the centrifuge stopped. Photographs were taken of the complete test package and as the package was dismantled.

After removing the extension and the top ring, the attitude of the tower was recorded. The middle ring was then removed and the tower removed carefully from the upper sand layer. The surface of the upper sand was profiled. This profile was not reliable due to the movement of water across the sand surface during stopping of the centrifuge.

An industrial vacuum cleaner was used to cut a series of vertical sections at 20mm intervals through the damp upper sand to expose the coloured sand bands. Each cross-section was photographed after exposure. The exposed clay surface was then carefully cleaned and the final position of the lead shot photographed. The negatives of the initial and final lead shot positions were measured using the film measuring machine described by Phillips (1992). The surface of the clay layer was profiled to obtain the distribution of vertical settlement.

The PPTs within the clay layer were excavated and their final positions measured. The noodles within the clay layer were exposed and photographed.

3.3 Test Pisa 1

Some of the data from this test are shown in figures 10 to 12. The positions of the pore pressure transducers are the same as those shown in figure 2. Each of these 3 data sets are divided as follows: From the start of each record to shortly after 02:24 are the data caused by the swelling of the clay due to the introduction of water into the upper sand layer. From then until after 07:12 are the data during starting of the centrifuge and primary consolidation. The data of stage 1 Of tower construction are then presented until 12:O0. at which time stage 2 Of tower construction was commenced.

During the period of acceleration from about 1 Og to test speed, the platform of the Cambridge beam centrifuge is restrained to be vertical. A wedge placed under the test package orientates the soil surface to be normal to the resultant acceleration of earths gravity and the centrifugal acceleration at test speed. During acceleration to test speed, the orientation of the resultant acceleration is changing and is not normal to the soil surface. This misalignment was sufficient in test Pisa 1 to cause a small premature rotation of the tower in the direction of earths gravitational pull.

The clay sample was about 98% consolidated at the end of the primary consolidation period. This degree of consolidation was determined from the settlement of the tower and the surface LVDT. During primary consolidation, there was no significant further rotation of the tower, as seen from the records of LVDTs 4 to 6, figure 11.

The commencement of stages 1 and 2 of tower construction can be seen from the step changes in the tower PPT readings in figure 10. The water depths in the tower at the end of stages 1 and 2 were 300 and 480mm respectively. The centreline settlement and inclination of the tower during construction are shown in figure 13. During and immediately after stage 2 of construction, the rate of inclination of the tower was very much greater than that observed during stage 1.

This movement of the tower was arrested when pipe fittings in the top of the tower came into contact with the top ring of the test package as seen in figure 6.

3.4 Pisa 2

Before undertaking test Pisa 2, the pipe fittings in the top of the model tower were removed. The LVDTs on the top ring were removed and replaced by three support fingers, figure 7. These fingers restrained the tower from rotating when accelerating the centrifuge to test speed.

The data from the instrumentation used in test Pisa 2 are shown in figures 14 to 16. The positions of the pore pressure transducers are as shown in figure 2. Each of these 3 data sets are divided as follows: From the start of each record to shortly after 0224 are the data caused by the swelling of the clay due to the introduction of water into the upper sand layer. From then until about 09:36 are the data during starting of the centrifuge and primary consolidation. The data of stages 1 to 3 of tower construction are then presented until 19:12. From then till midnight, the effects of a number of remedial measures were monitored At midnight the centrifuge was stopped.

During the first 3mm of settlement of the tower the tower was restrained from rotating by the three support fingers on the top ring. The clay sample was about 98% consolidated at the end of the primary consolidation period. This degree of consolidation was determined from the settlement of the tower and the surface LVDT. During primary consolidation, there was no significant rotation of the tower, as seen from the records of LVDTs 1 to 4, figure 15.

The commencement of the staged tower construction can be seen from the step changes in the tower PPT readings in figure 14. The water depths in the tower at the end of stages 1, 2 and 3 were 260, 440 and 550mm respectively. The centreline settlement and inclination of the tower during construction are shown in figure 17. The inclination and rate of inclination of the tower during stage 2 of construction is less than that measured in Pisa 1. Rotation of the tower was continuing when remedial measures were investigated.

At 19:54 the water level in the upper and lower sand layer was lowered by about 0.4m. This groundwater lowering and consequential consolidation caused a further increase in the inclination of the tower. At 22:30 the weight of the tower was decreased by draining water from the tower. This reduction in weight caused the inclination of the tower to decrease.

The bearing of the towers lean axis was calculated anti-clockwise from the x-axis shown in figure 23 from the tower settlement data. The bearing rotated from 45' at the start of tower construction to 15' at the end of the centrifuge test. The direction of inclination did not seem to be influenced by either earths gravity or coriolis forces.

The attitude of the tower after the centrifuge test is shown in figures 19 and 20. The distortion of the upper sand layer under the tower is shown in figure 21, the lean axis was towards the right hand side of the photograph, where a band of intense shear deformation has formed. The deformation of the surface of the clay layer is shown in figure 22. The different viewing angles for figures 21 and 22 are compared by observing the blue stain on the clay surface adjacent to the noodle line.

Vectors of horizontal movement of the clay surface are shown in figure 23. The clay under the right hand edge of the tower has moved vertically. The clay to the right of the tower has flowed outward to accommodate the clay displaced during tower settlement. Profiles of vertical movement are shown in figure 25. The angles of these profiles are measured clockwise from the x-axis in figure

23. The average measured settlement of the clay layer under the tower is 8mm. Allowing for the heave of the clay overnight before these measurements were taken, figure 15, the majority of the measured tower settlement appears to be due to distortion of the clay layer. The -20' to 20° profiles clearly indicates that the clay to the right of the tower has heaved.

The same observation of clay heave has been made at the Pisa site, Leonards (1979). The limited evidence of figures 23 and 25 suggests that shear distortion within the day layer caused the inclination of the tower as suggested by Leonards (1979) and others. Although no gross shear deformation of the clay layer was observed from the noodles, figures 26 and 27. The stress paths calculated by Guell (1991), figure 1, support this hypothesis showing the day under the tower to be at yield on the wet side of critical state. During stage 2 of construction of test Pisa 1 the rate of inclination of the tower indicated that the tower was close to failing in shear, as anticipated by Mitchell et al (1977).

Plastic deformations resulting from any perturbation of the clay in this condition can only result in further inclination of the tower. Further inclination can only be prevented by a load reversal, such as observed when reducing the weight of the tower in test Pisa 2.

The rate of inclination observed in these two centrifuge model tests will be greater than that observed at Pisa because the consolidation characteristics of Horizon A were not correctly modelled.

4 Conclusions

This data report presents a technique to simulate tower construction during centrifuge flight. This technique was used to successfully construct a tower on layered ground with site conditions similar to those found at the tower of Pisa.

Combining this technique with more representative models of the Pisa site conditions, a further series of centrifuge model tests can be conducted to examine the effects of different remedial measures on the tower.

5 Acknowledgements

The author gratefully acknowledges the contributions of Mr Neil Baker, Dr Malcolm Bolton, Mr Chris Collison, Mr Paul Gilbert and Prof Andrew Schofield in undertaking this research.

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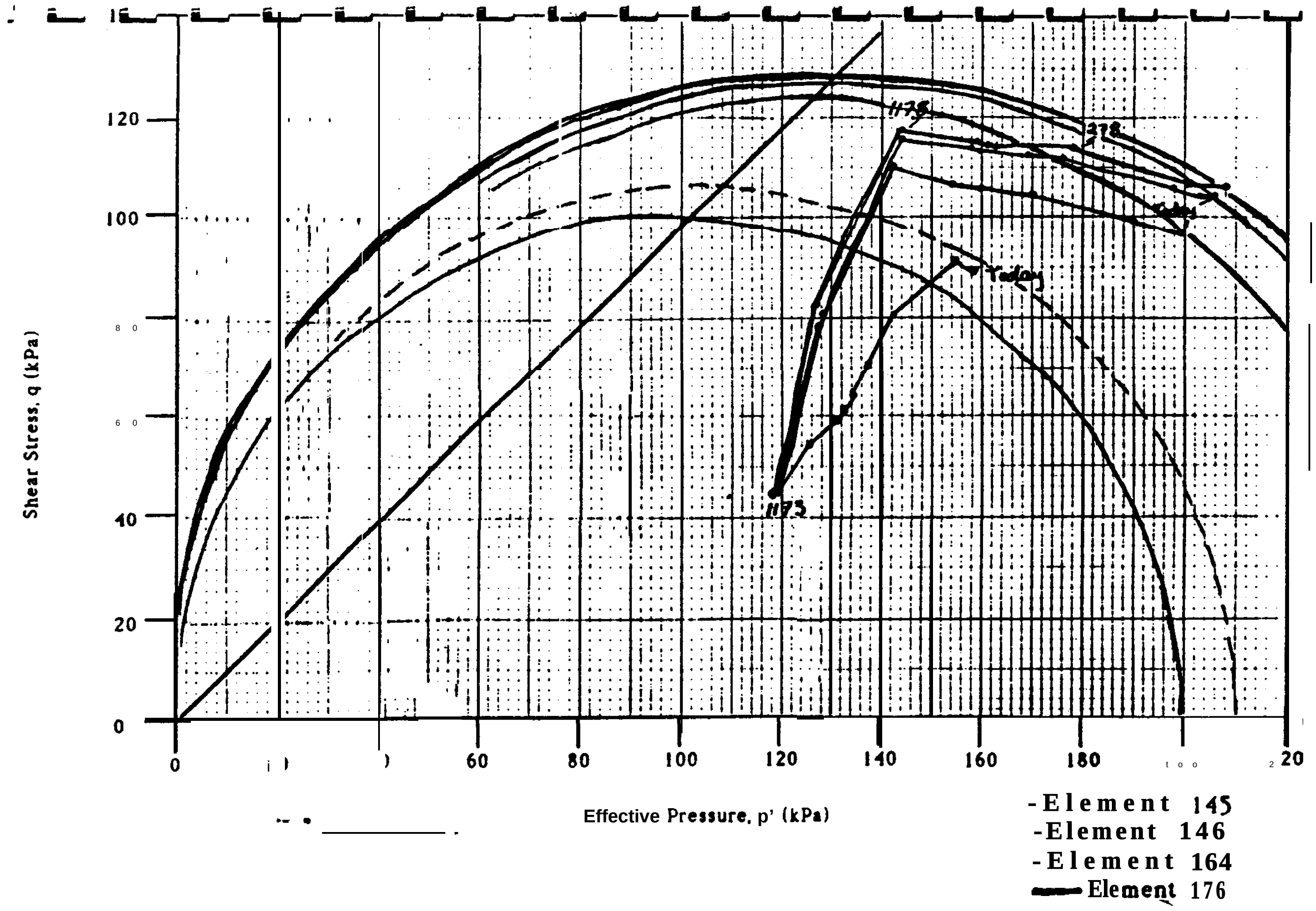


E ff ective Stress Paths
in Horizon B
After Guell, 1991

FIG.NO.
1

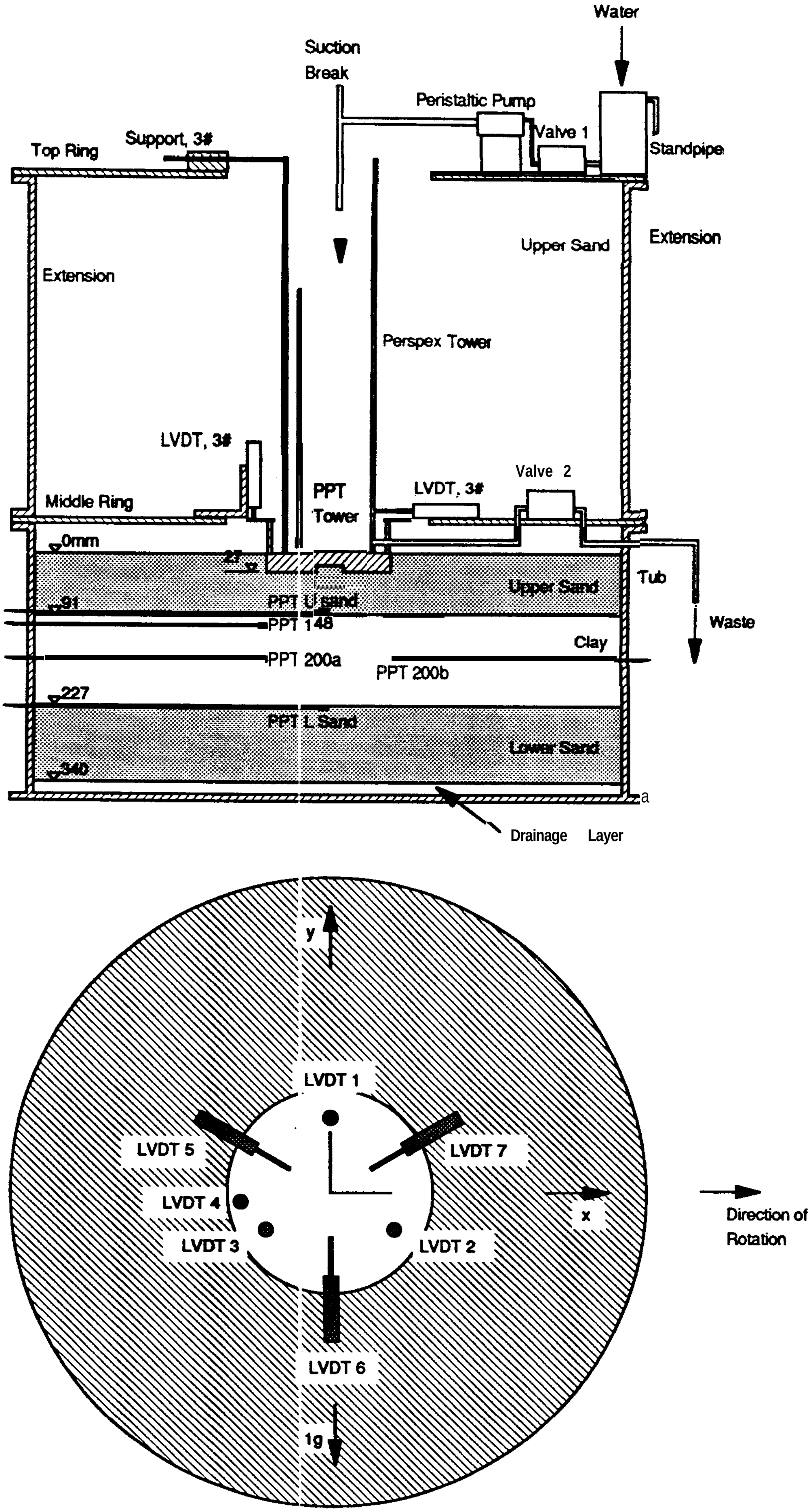
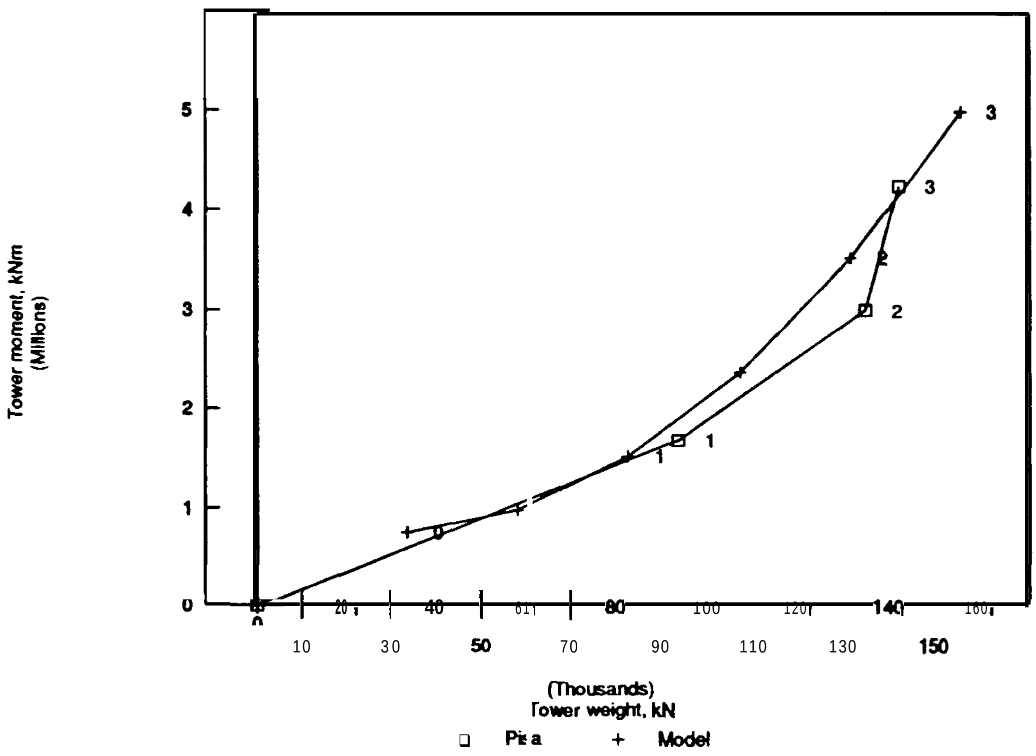


Figure 2 - General Arrangement of Package, Test Pisa 2

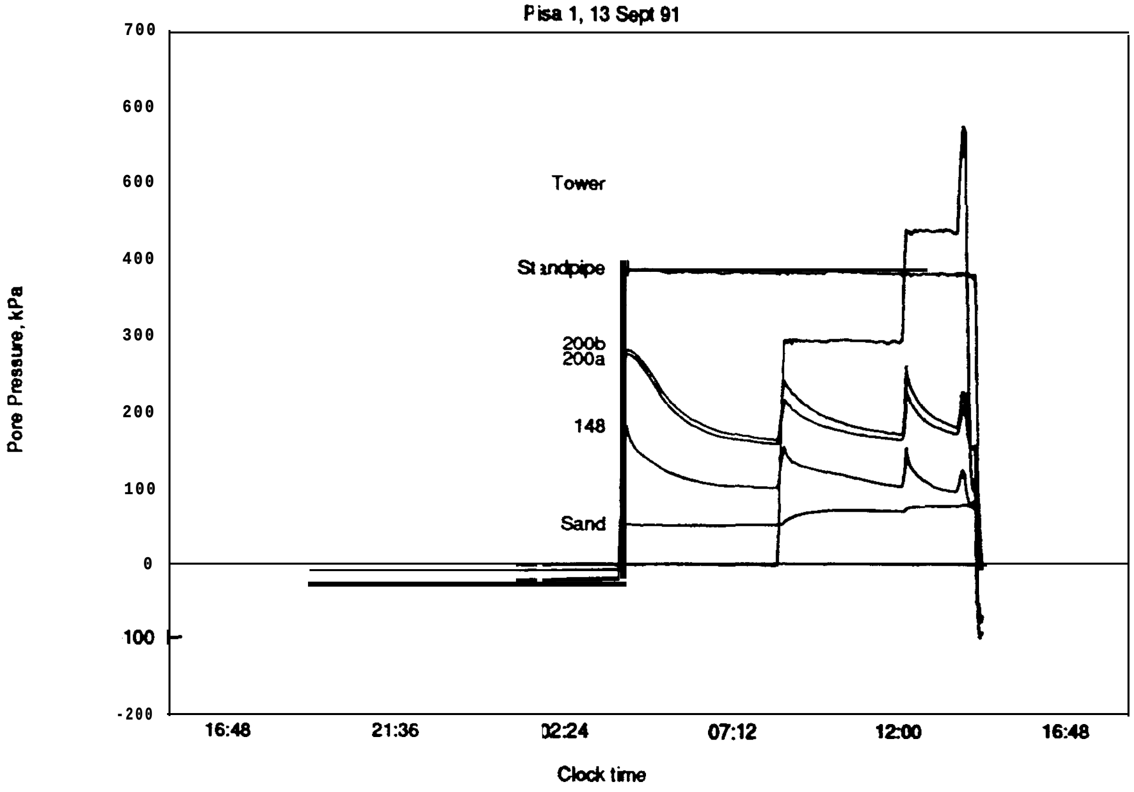
Model of Pisa Tower Construction

Scale 1:100.2, Load **factor 1.9**



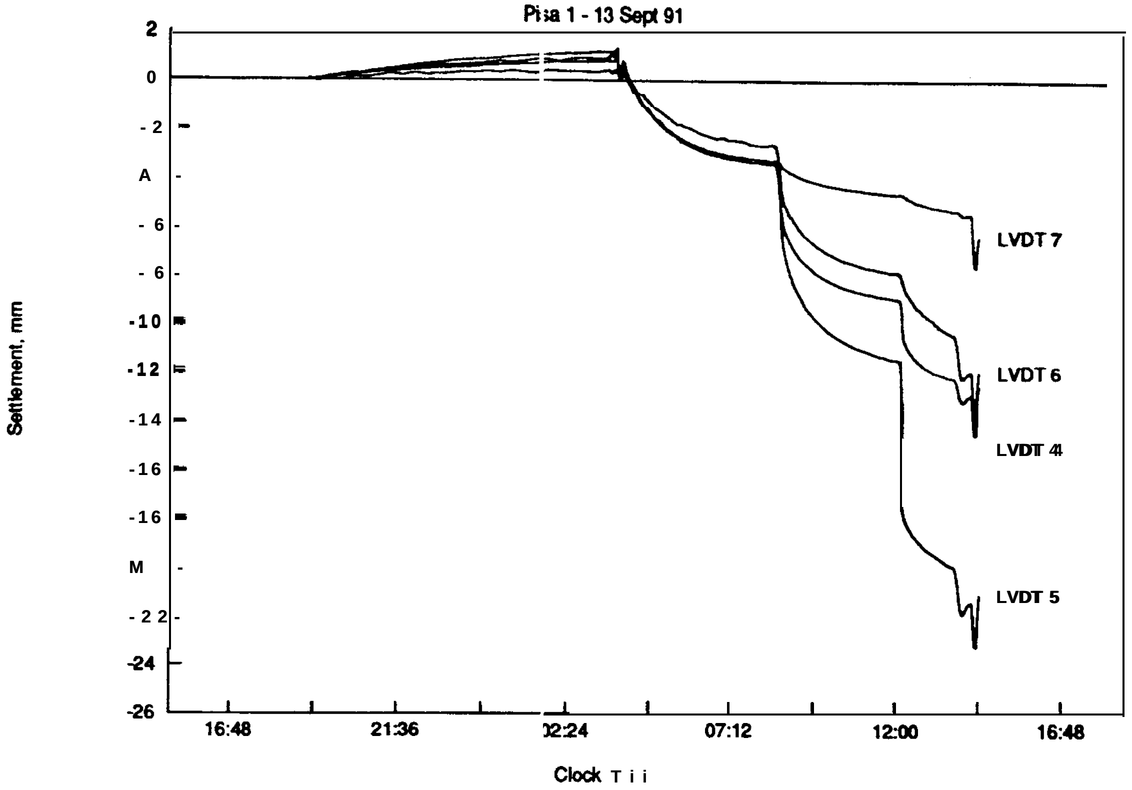
TEST **PISA** 1 & 2 MODEL Tower FLIGHT 1			Tower Construction Design		**FIG.NO.** 3

Overview of Pore Pressures

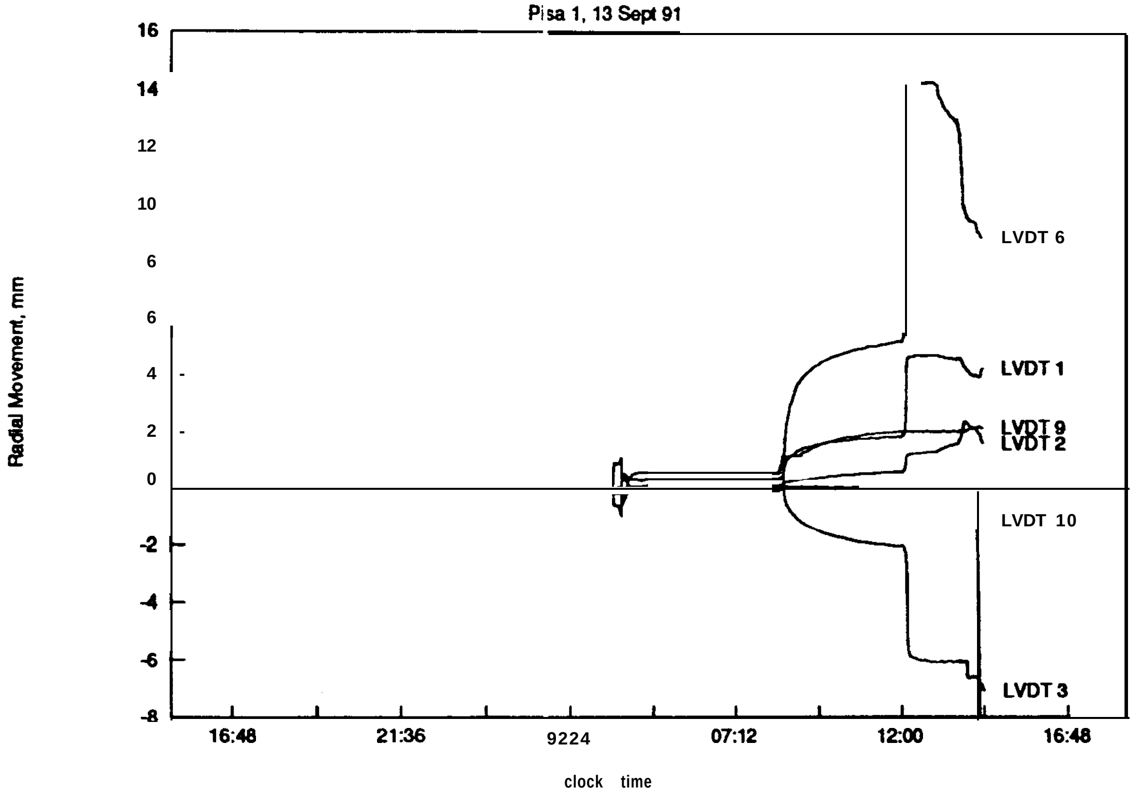


1 TEST PISA 1 MODEL Tower FLIGHT 1			Pore Pressure Response		FIG.NO. 0

Overview of Tower Settlement



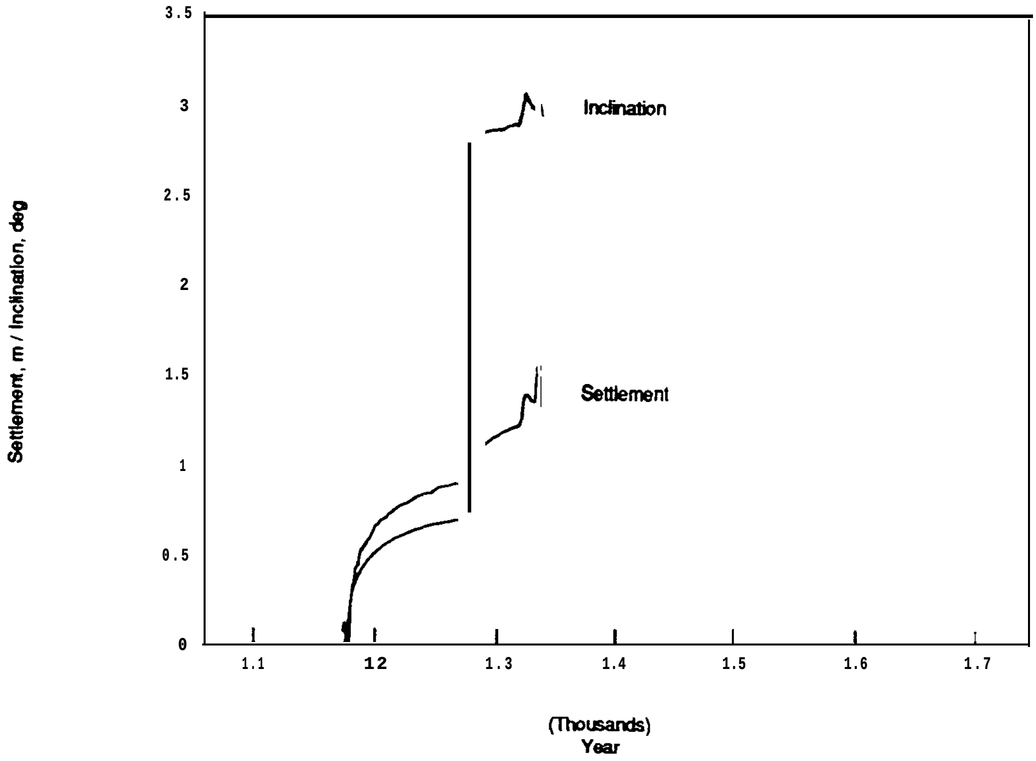
Overview of Tower Lateral Movement



TEST PISA 1 MODEL Tower FLIGHT 1		Vertical LVDT Response Horizontal LVDT Response		FIG.NO. 11 12

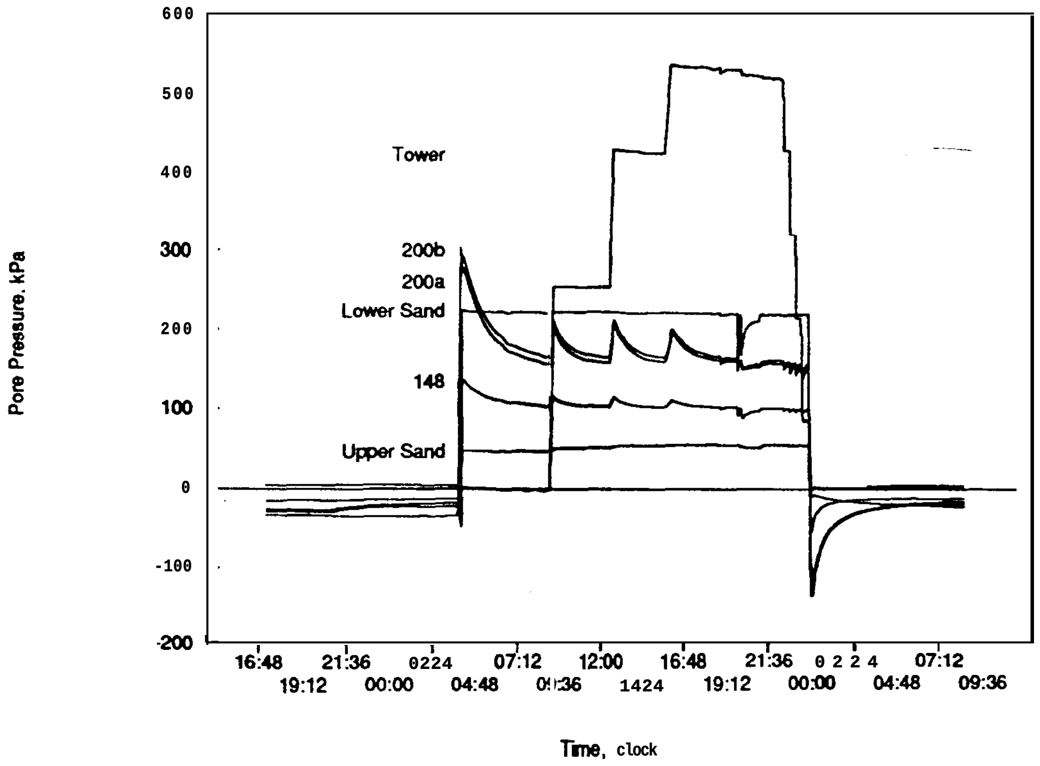
Prototype Tower Movement

Pisa 1, 13 Sept 91



Overview of Pore Pressures

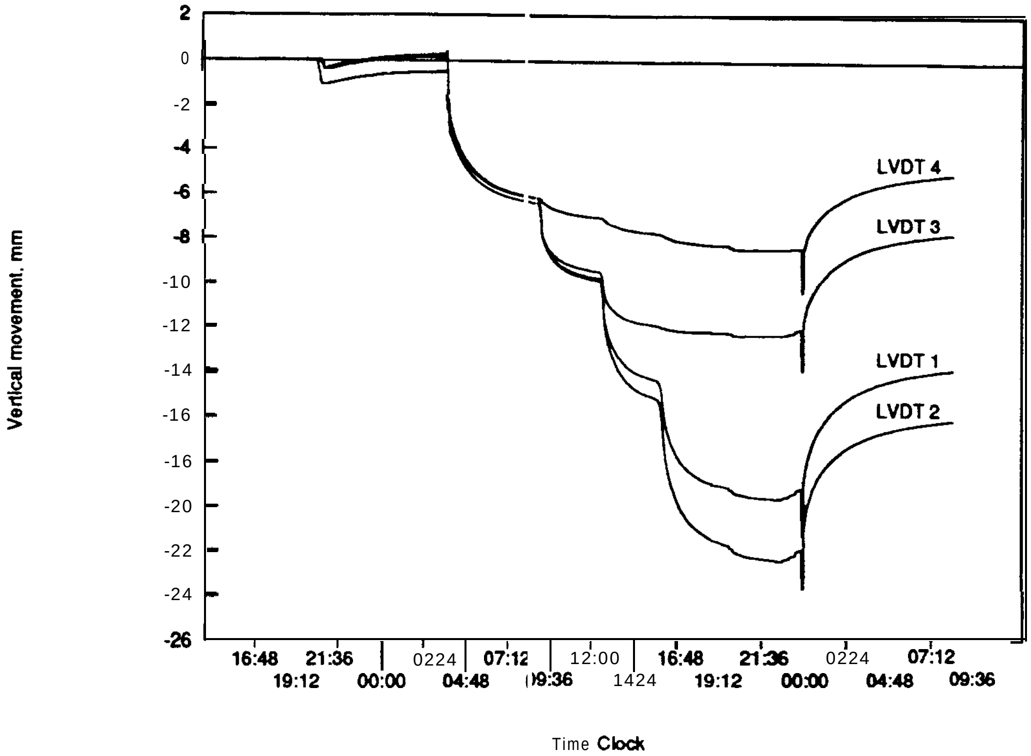
Pisa 2, 10 Mar 92



TEST PISA 1 & 2 MODEL Tower FLIGHT 1		Movement of Tower, PISA 1 Pore Pressure Response, PISA 2		FIG.NO. 13 14

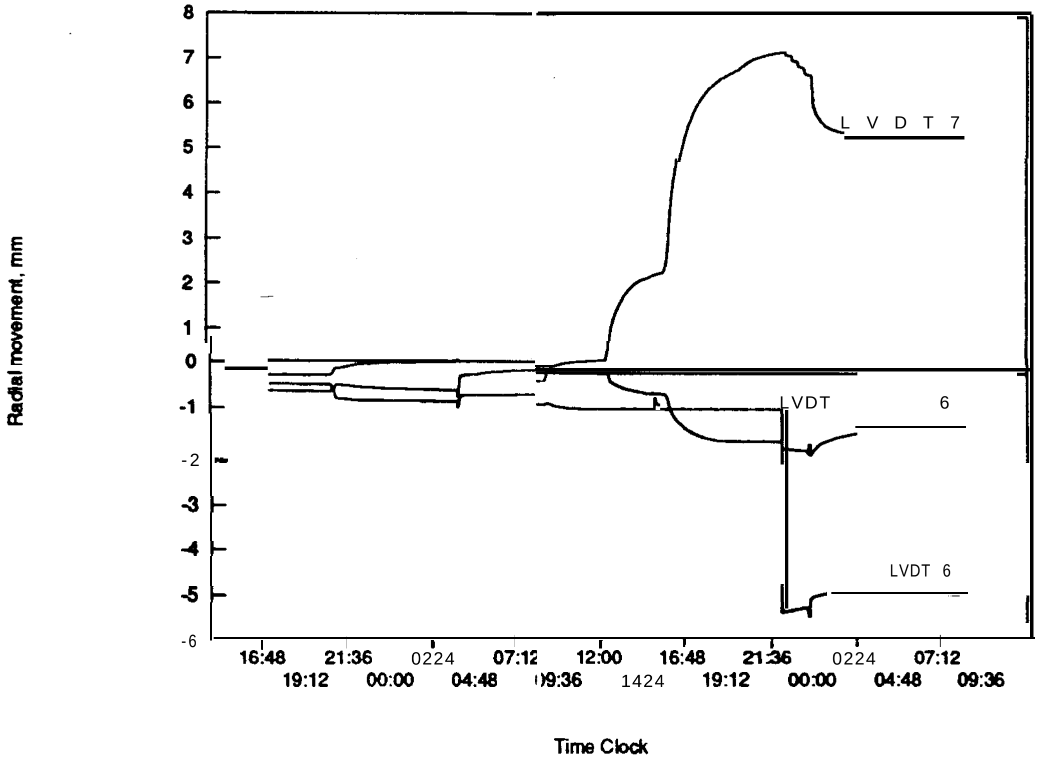
Overview of Tower Settlement

Pisa 2, 10 Mar 92



Overview of Tower Lateral Movement

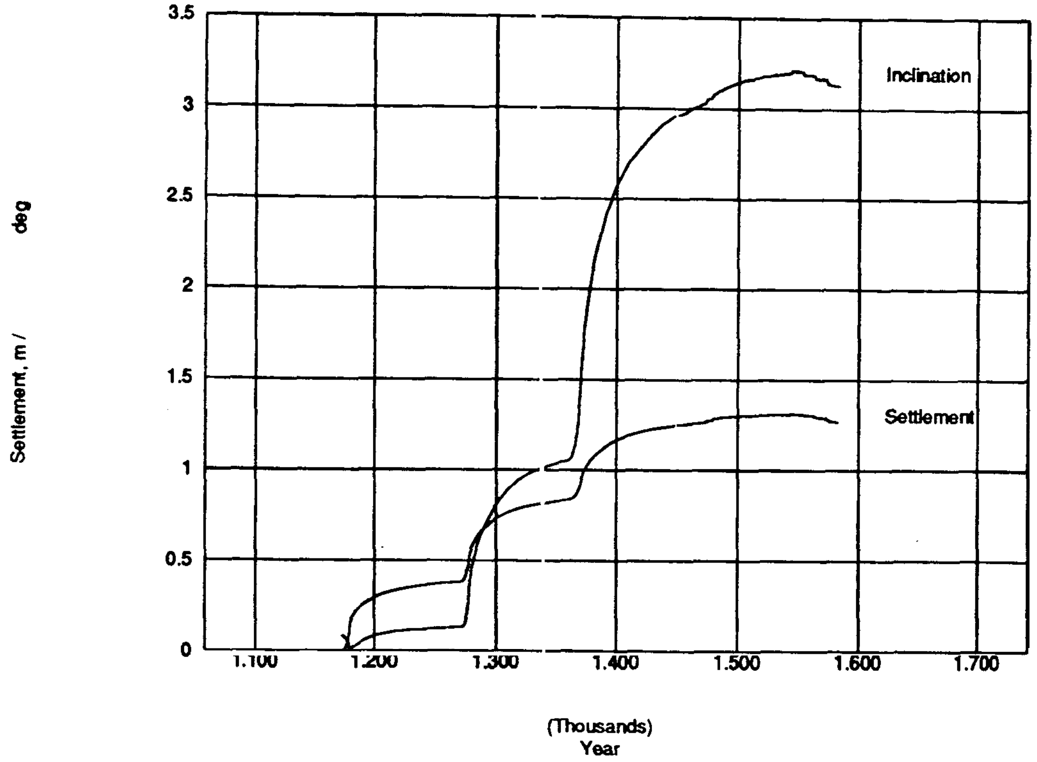
Pisa 2, 10 Mar 92



TEST PISA 2 MODEL Tower FLIGHT 1			Vertical LVDT Response Horizontal LVDT Response		FIG.NO. 15 16

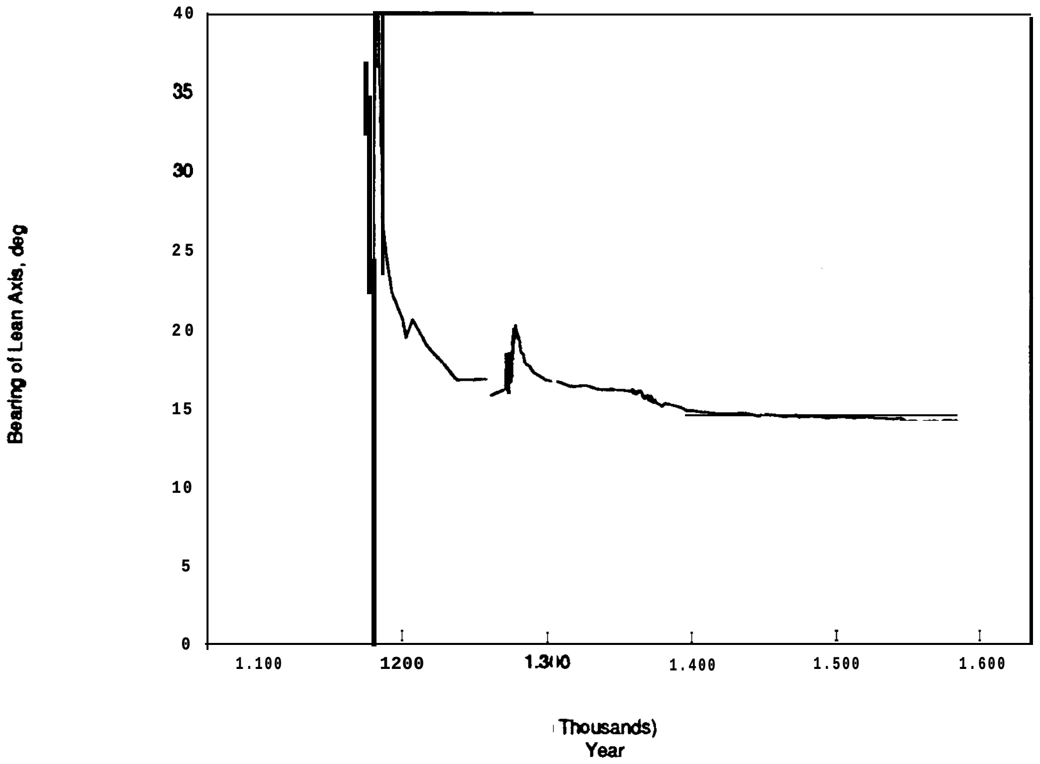
Prototype Tower Movement

Pisa 2, 10 Mar 92



Prototype ‘Tower Movement

Pisa 2, 10 Mar 92



TEST PISA 2 MODEL Tower FLIGHT 1		Movement of Tower Bearing of Lean Axis		FIG.NO. 17 18