

**Use of cemented zones as a  
liquefaction remediation method for  
existing buildings – Data report on  
centrifuge tests CZ1P, CZ1F and CZ3**

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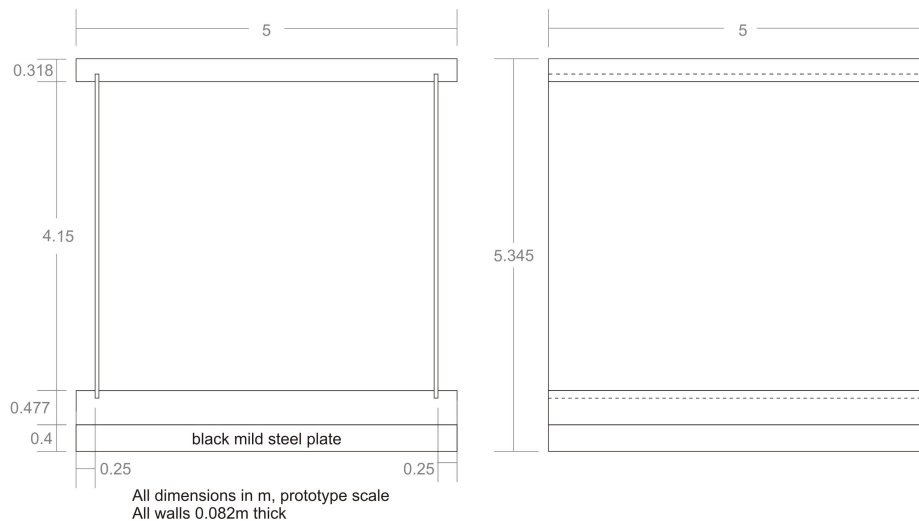
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## 1. Introduction

This report describes three centrifuge tests carried out as part of the NEMISREF project, at 50g, to investigate the performance of cemented zones as a liquefaction remediation measure beneath the base of existing buildings. Both cemented zones extending through the full depth and part of the depth of the liquefiable foundation soil layer were tested and the complete set of results is presented. It should be noted that in all three centrifuge tests, the focus was on the overall behaviour of the structure-cemented zone-soil system, not of the cemented zone itself. In addition, the grouting process was not considered, as it was deemed to complex to create grouted zones in-situ in the centrifuge models. Instead, sand-cement blocks were constructed separately and placed in the models. This is described in more detail in section 3. In order to assess the effectiveness of the cemented zones tested, the results can be compared with those from centrifuge tests on similar unimproved soil profiles. These results can be found in technical report CUED/D-SOILS/TR.342 and full analysis, comparison and discussion of the results is given in Mitrani 2006, PhD thesis, University of Cambridge.

## 2. Description of centrifuge models

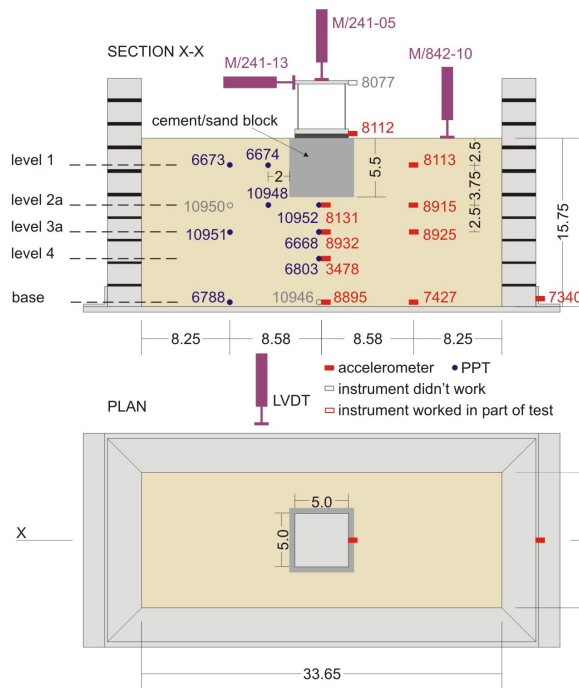
The model structure used in this series of centrifuge tests was a single degree of freedom (SDOF) frame structure with a natural frequency of 1.52Hz (prototype, *76Hz model scale*) and a bearing pressure of 58kPa. This structure is shown in figure 1, at prototype scale.



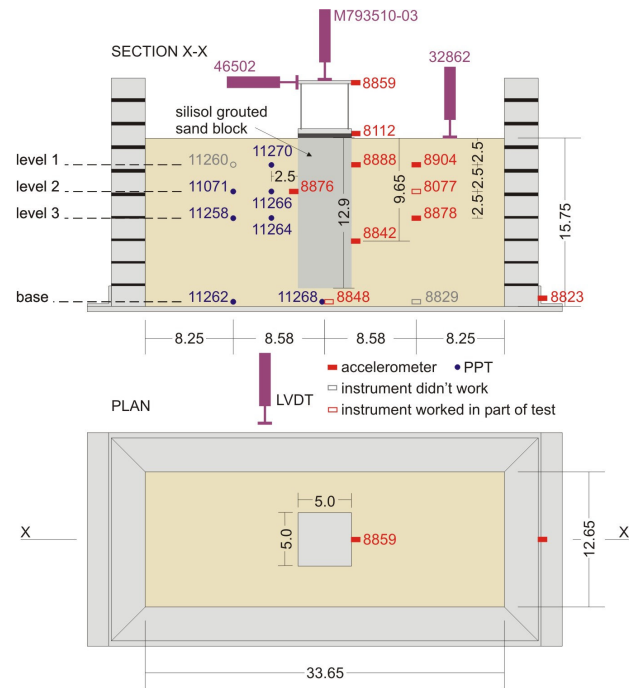
**Figure 1:** Diagram of SDOF structure

Centrifuge test CZ1P was carried out on a model consisting of the SDOF structure founded on a deep (15.75m, 315mm) homogeneous bed of liquefiable sand. A partial-depth cemented zone placed under the structure. This zone extended to a depth of 5.5m (110mm) and was slightly (0.25m, 5mm) wider than the structure base on either side. The cemented zone in this test was constructed from a sand and Portland cement block, with a mix ratio of cement:sand:water of approximately 1:10:2.8. The instrument layout for this model is shown in figure 2, at prototype scale.

Figure 3 shows the instrument layout for centrifuge test CZ1F, at prototype scale. This centrifuge test was similar to CZ1P, except a virtually full-depth cemented zone ( $\approx 12.9$ m, 258mm deep) was adopted, which had the same plan area as the base of the structure. In addition, the cemented zone in this centrifuge test was constructed from sand and Silisol grout and was prepared by an employee of Soletanche-Bachy (coordinators of the NEMISREF project).



**Figure 2:** Instrument layout for centrifuge test CZ1P

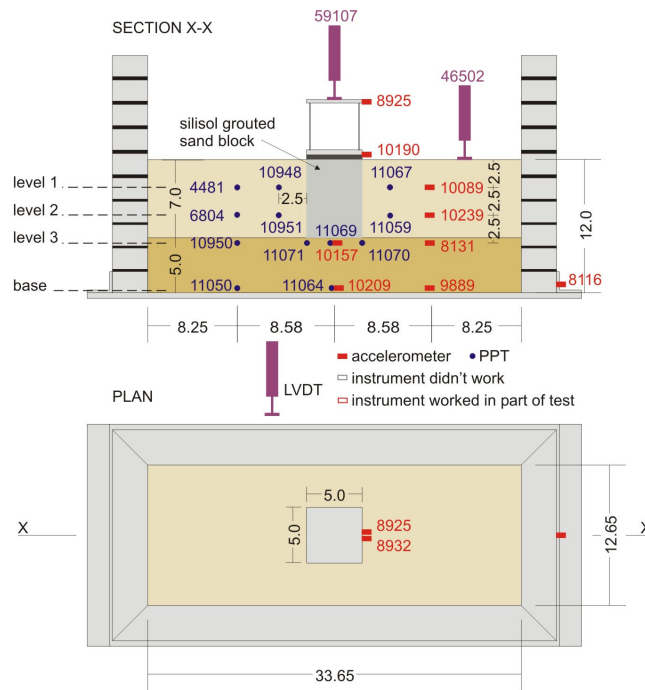


**Figure 3:** Instrument layout for centrifuge test CZ1F

Centrifuge test CZ3 was carried out on a model with a layered sand profile. This profile consisted of a loose layer of liquefiable sand 7m (140mm) deep, overlying a dense layer of the same sand, 5m (100m) deep. A sand-Silisol block was placed under the structure, which extended through



the full depth of the liquefiable layer. The instrument layout for centrifuge test CZ3 is shown in figure 4, at prototype scale.



**Figure 4:** Instrument layout for centrifuge test CZ3

Three types of instruments were used in all the centrifuge tests: accelerometers to measure soil and structural accelerations, pore pressure transducers (PPTs) to measure pore pressures in the soil bed and linear variable differential transformers (LVDTs) to measure displacements of the structure and the sand surface.

### 3. Model Preparation

Each model was prepared in essentially the same way. Hostun S28 sand was air pluviated from an over-head hopper into the deep ESB box. A large orifice was used to produce the loose layers, and a small orifice, low flow rate and sieves were used to pour the dense layer in centrifuge test CZ3. For centrifuge tests CZ1F and CZ3, the models were saturated from the base using 50cS methylcellulose, under vacuum, after the completion of sand pouring and placement of the cemented blocks. For centrifuge test CZ1P, saturation was carried out in stages: first the sand below the cemented zone was saturated, then the cemented block was placed and the remaining sand poured around it, then finally this sand was saturated. This method was adopted to try and

avoid sinking of the cemented zone during saturation. In all three models, the structure was placed on the surface of the cemented zones, after the models had been loaded onto the centrifuge. Full details of preparation of the models and the materials and equipment used can be found in Mitrani 2006.

It should be noted that the dimensions and instrument positions shown in figures 2 to 4 represent the geometry that was aimed for during construction of the models. However, due to the difficulties of making precise models by hand, the actual prototype dimensions were often different. In addition, due to deterioration of the Silisol blocks, they had a very irregular shape and it was difficult to determine their volume and hence the relative density of the sand around them (see Mitrani 2006). The actual properties of the sand layers in centrifuge test CZ1P and the dense layer in centrifuge test CZ3 are shown in table 1 at prototype scale. Properties for the loose layer in centrifuge test CZ3 are also estimated but these are not likely to be very accurate.

**Table 1:** Properties of sand layers in models for centrifuge tests WA1P, WA1F and WA3

	<b>CZ1P</b>	<b>CZ1F</b>	<b>CZ3</b>	
			loose	dense
layer thickness (m)	15.6	14.6	6.7	4.9
$\gamma_{\text{dry}}$ (kN/m <sup>3</sup> )	14.4	not known	13.8 (estimate)	15.9
$\gamma_{\text{sat}}$ (kN/m <sup>3</sup> )	18.8	not known	18.4 (estimate)	19.7
$D_r$ (%)	46	not known	27 (estimate)	83

#### 4. Centrifuge Test Procedure

All three centrifuge tests were carried out at 50g and five earthquakes were fired in each. The earthquakes were of difference size and frequency to investigate the behaviour of the structure thoroughly. The main details of the earthquakes fired in each test are shown in table 2, at prototype scale. It should be noted that in centrifuge tests CZ1F and CZ3, the order of the frequency sweep earthquake and earthquake 4 was reversed. The earthquakes were fired in order of increasing magnitude and frequency to try and minimise the effects of firing multiple earthquakes on a single model. Further details of the earthquakes fired can be found in Mitrani 2006.

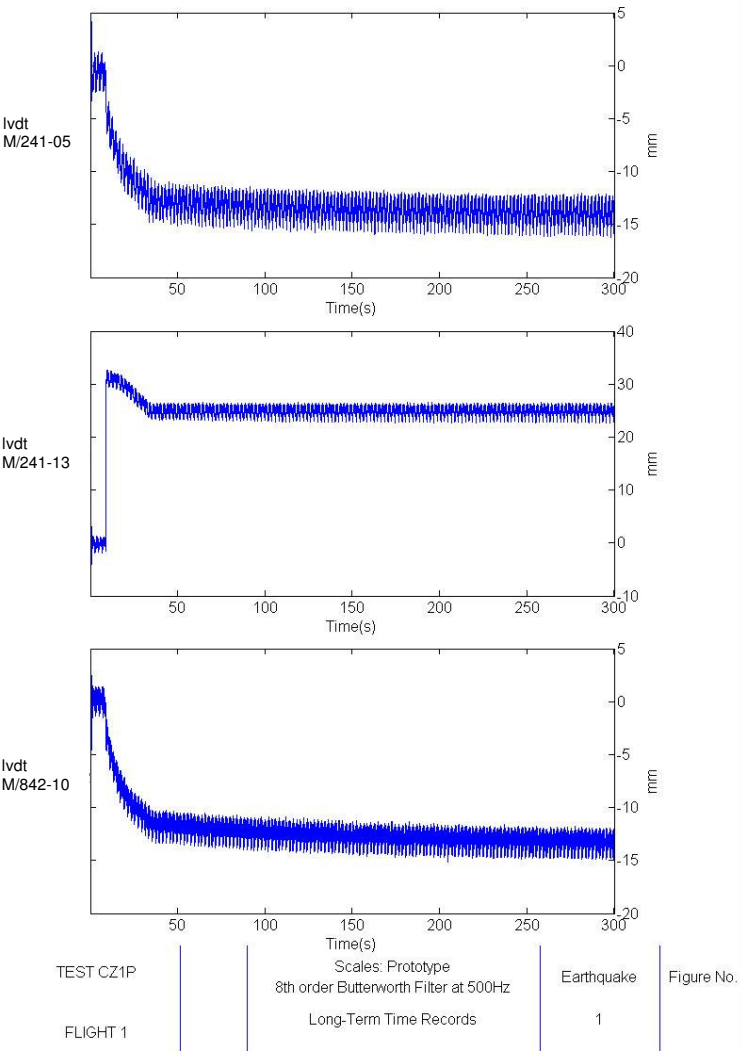
**Table 2:** Details of earthquakes fired in centrifuge tests WA1P, WA1F and WA3

	frequency (Hz)	duration (s)			max. base acc. (g)			no. of cycles		
		CZ1P	CZ1F	CZ3	CZ1P	CZ1F	CZ3	CZ1P	CZ1F	CZ3
EQ1	0.6	28	27	27	0.1	0.06	0.1	17	17	17
EQ2	0.8	28	27	30	0.13	0.16	0.19	22	22	25
EQ3	1	27	27	29	0.19	0.25	0.32	26	27	20
sweep	1→0	≈149	≈171	≈187	0.23	0.24	0.34	≈101	≈106	≈116
EQ4	1	27	27	30	0.28	0.35	0.48	28	28	30

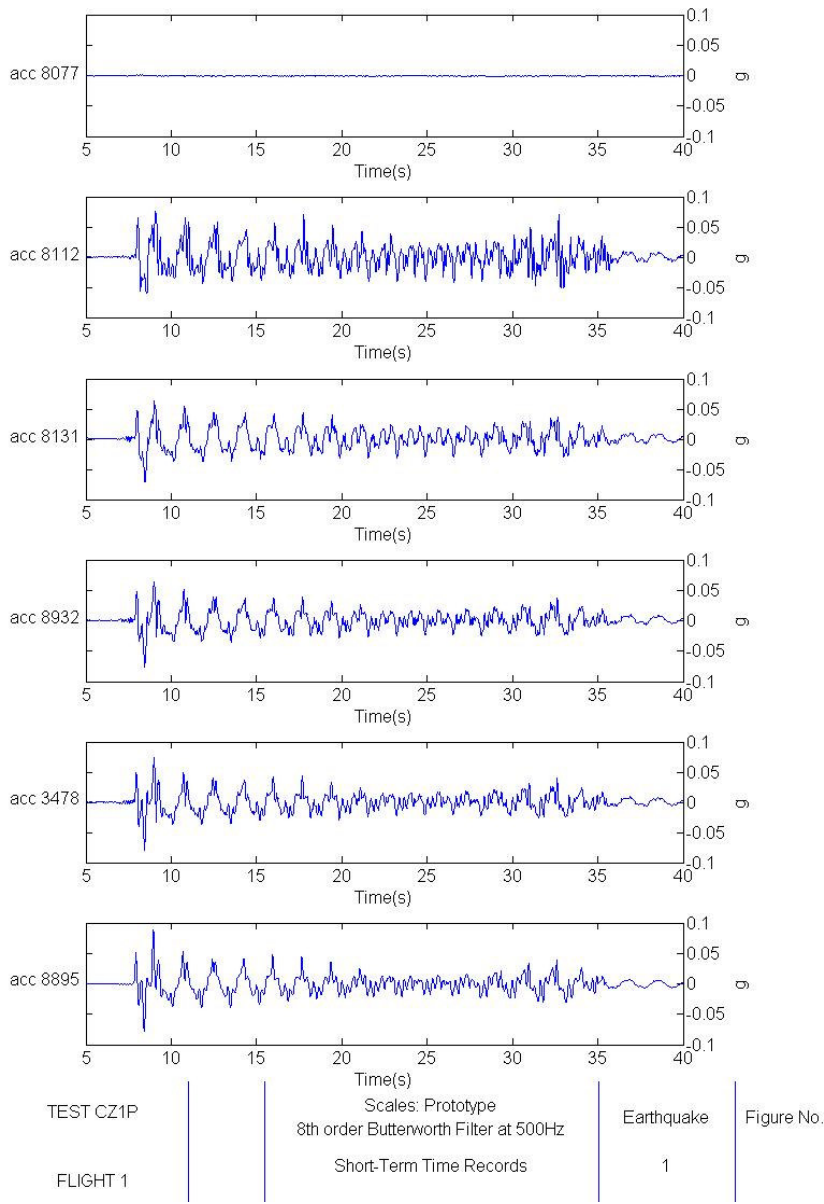
5. Results

5.1 Centrifuge test CZ1P, earthquake 1

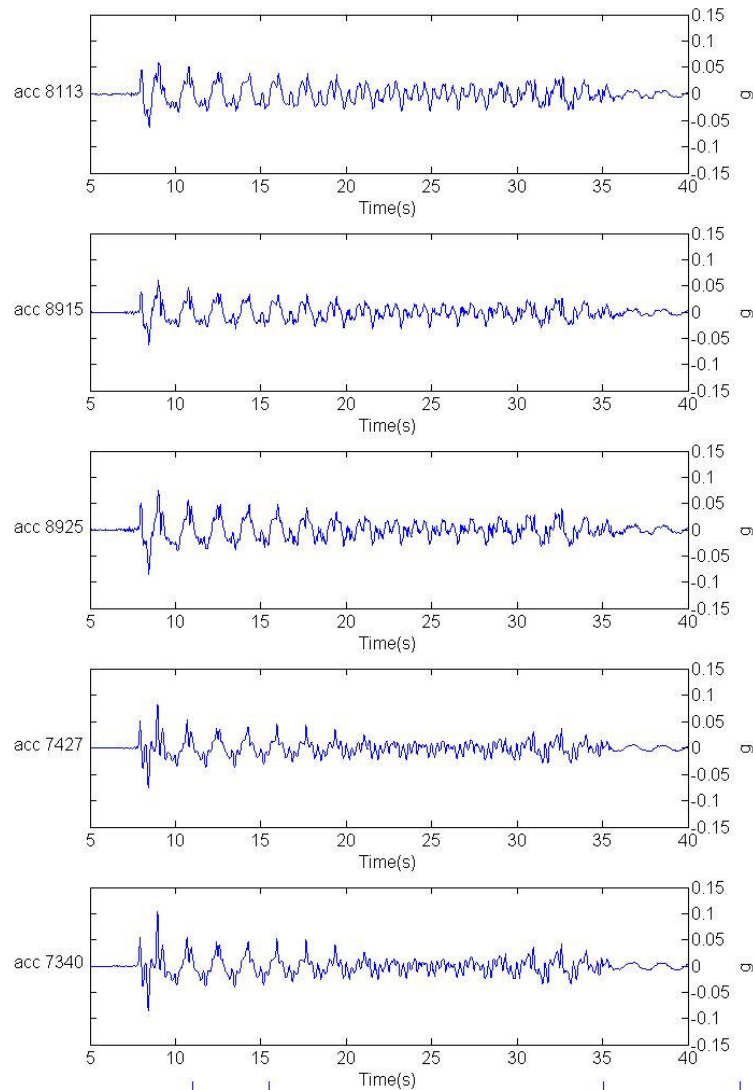
Soil and structural displacements



Accelerations of structure and soil under base of cemented zone



## Free field soil accelerations and box (input) acceleration



TEST CZ1P

Scales: Prototype  
8th order Butterworth Filter at 500Hz

Earthquake

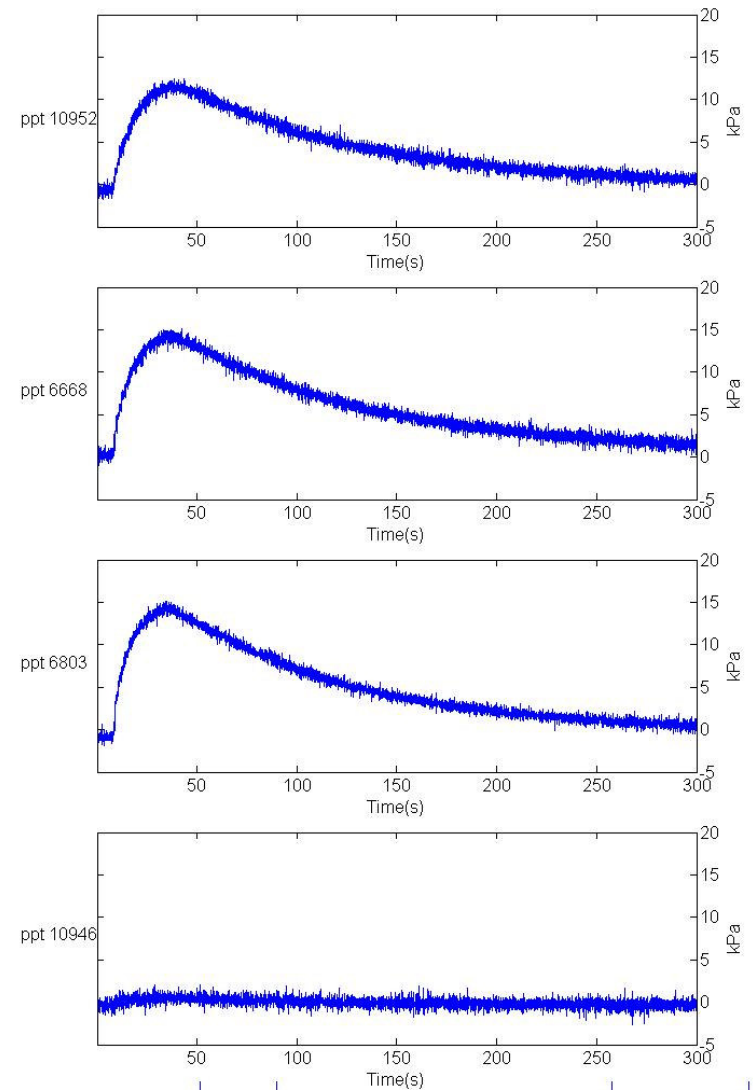
Figure No.

FLIGHT 1

Short-Term Time Records

1

## Excess pore pressures under base of cemented zone



TEST CZ1P

Scales: Prototype  
8th order Butterworth Filter at 500Hz

Earthquake

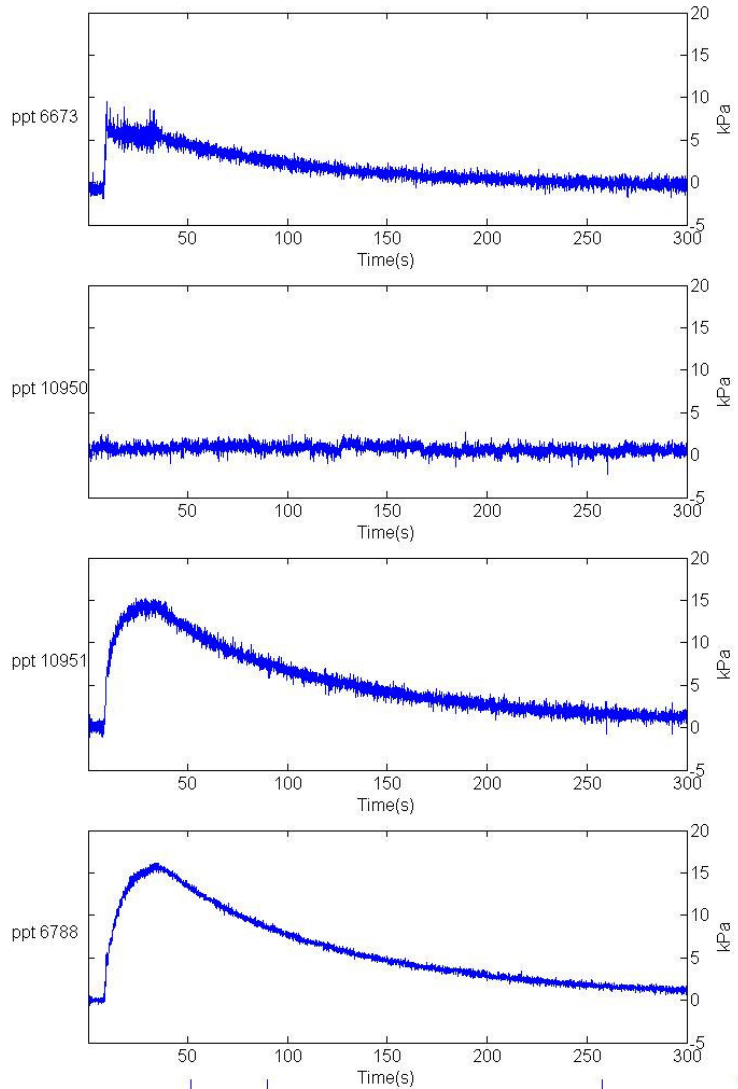
Figure No.

FLIGHT 1

Long-Term Time Records

1

Free field excess pore pressures



TEST CZ1P

FLIGHT 1

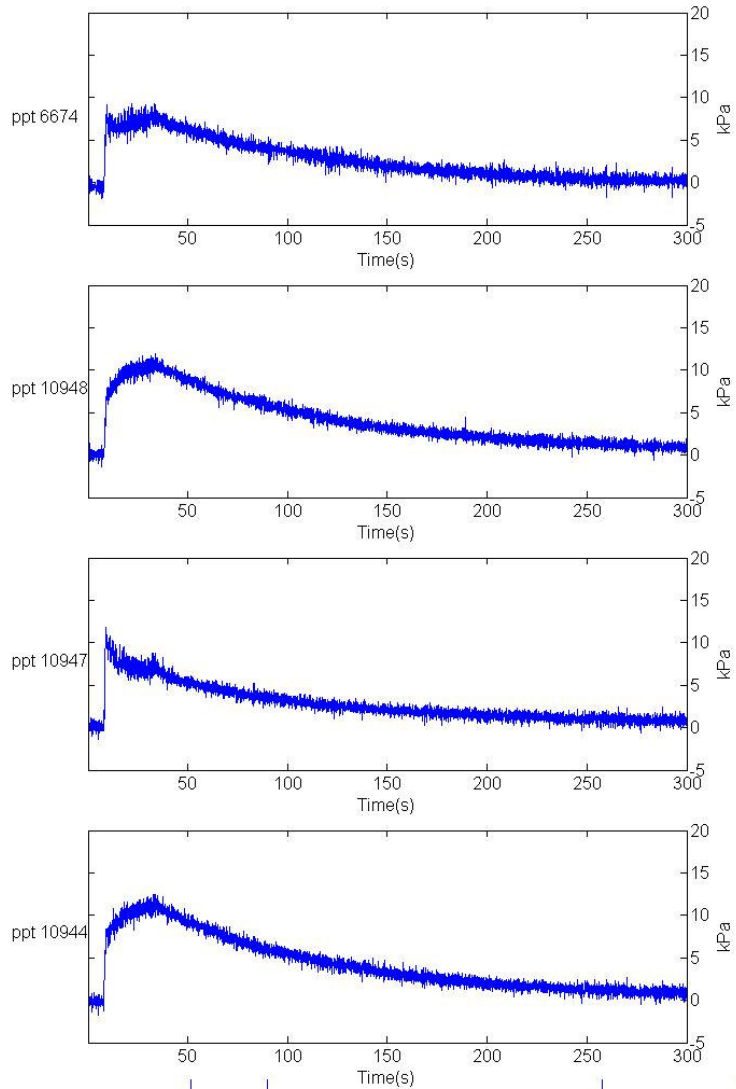
Scales: Prototype  
8th order Butterworth Filter at 500Hz  
Long-Term Time Records

Earthquake

1

Figure No.

Excess pore pressures at sides of cemented zone



TEST CZ1P

FLIGHT 1

Scales: Prototype  
8th order Butterworth Filter at 500Hz  
Long-Term Time Records

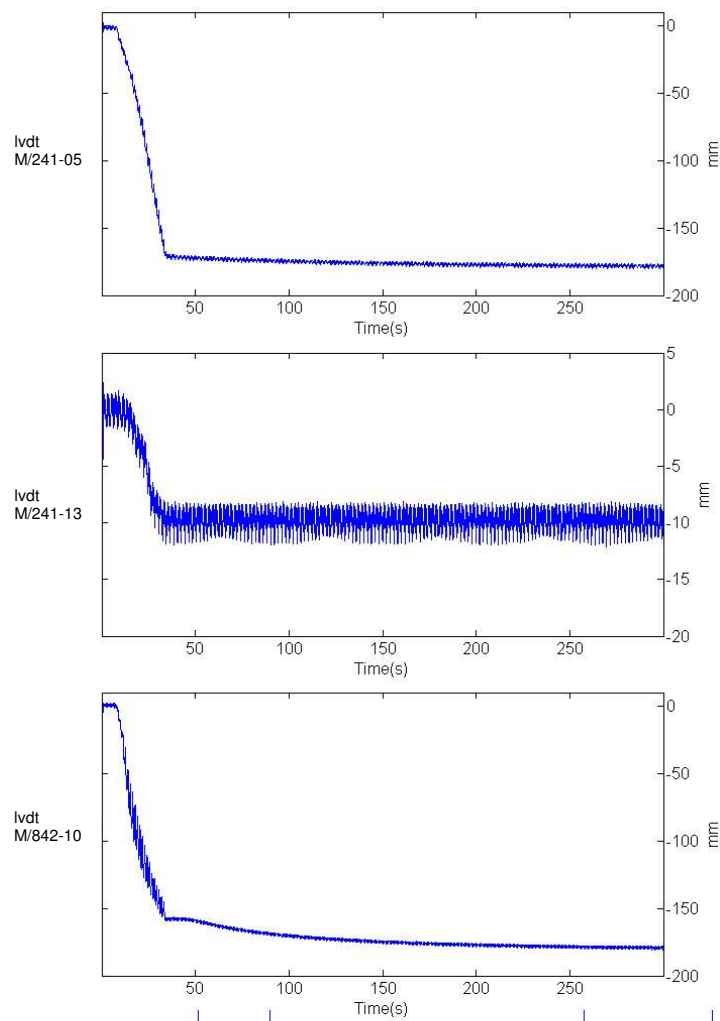
Earthquake

1

Figure No.

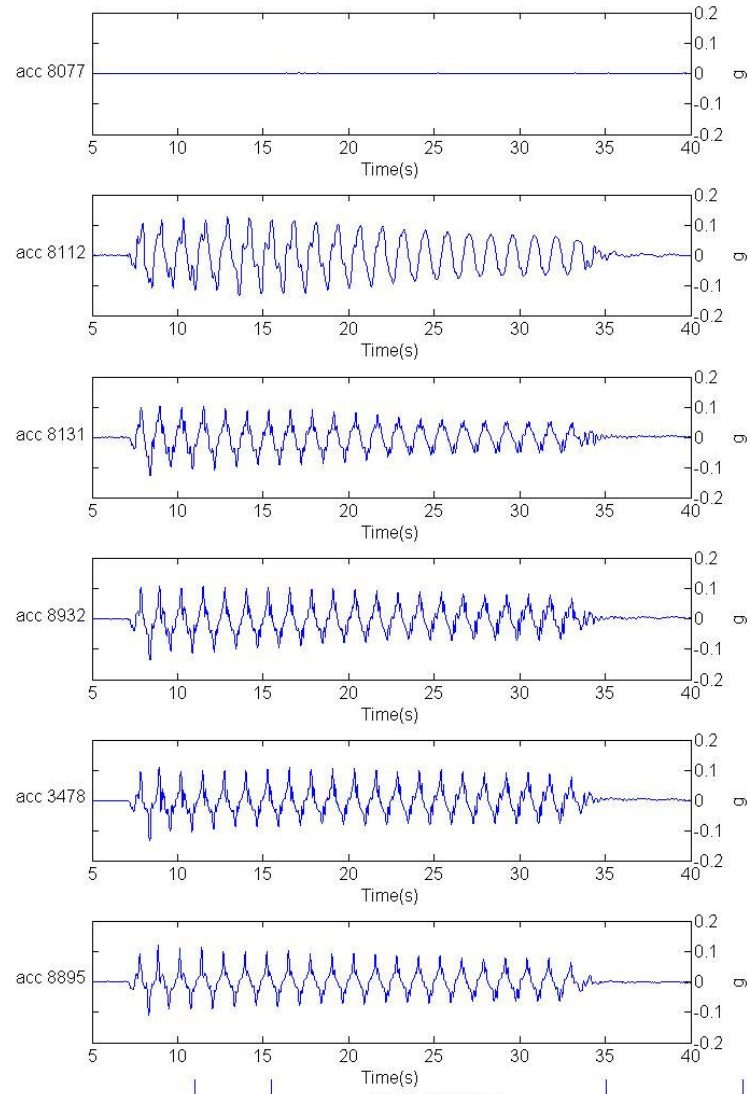
5.2 Centrifuge test CZ1P, earthquake 2

Soil and structural displacements



TEST CZ1P	Scales: Prototype 8th order Butterworth Filter at 500Hz	Earthquake	Figure No.
FLIGHT 1	Long-Term Time Records	2	

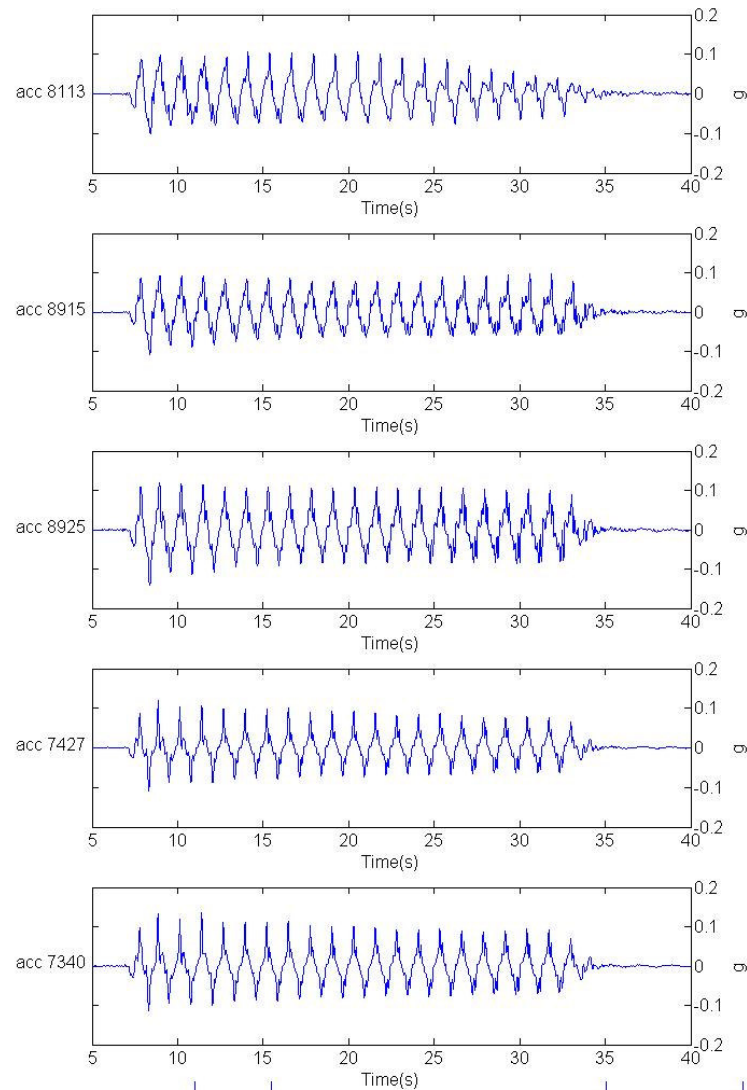
Accelerations of structure and soil under base of cemented zone



TEST CZ1P	Scales: Prototype 8th order Butterworth Filter at 500Hz	Earthquake	Figure No.
FLIGHT 1	Short-Term Time Records	2	



## Free field soil accelerations and box (input) acceleration



TEST CZ1P

FLIGHT 1

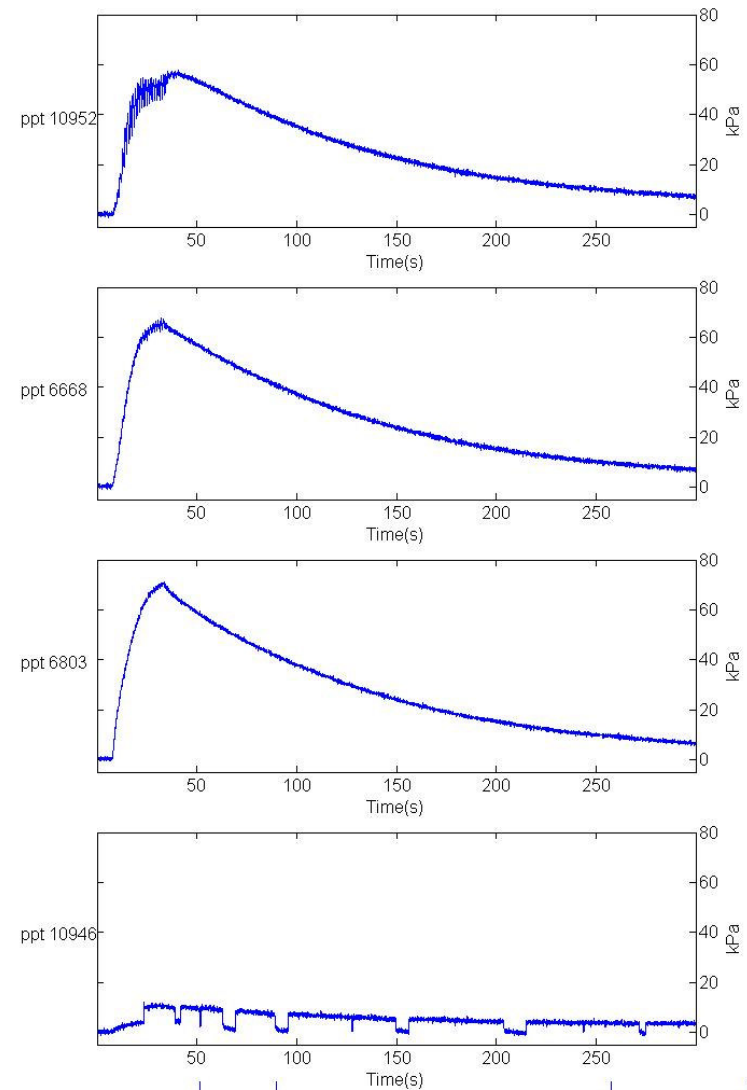
Scales: Prototype  
8th order Butterworth Filter at 500Hz  
Short-Term Time Records

Earthquake

2

Figure No.

## Excess pore pressures under base of cemented zone



TEST CZ1P

FLIGHT 1

Scales: Prototype  
8th order Butterworth Filter at 500Hz  
Long-Term Time Records

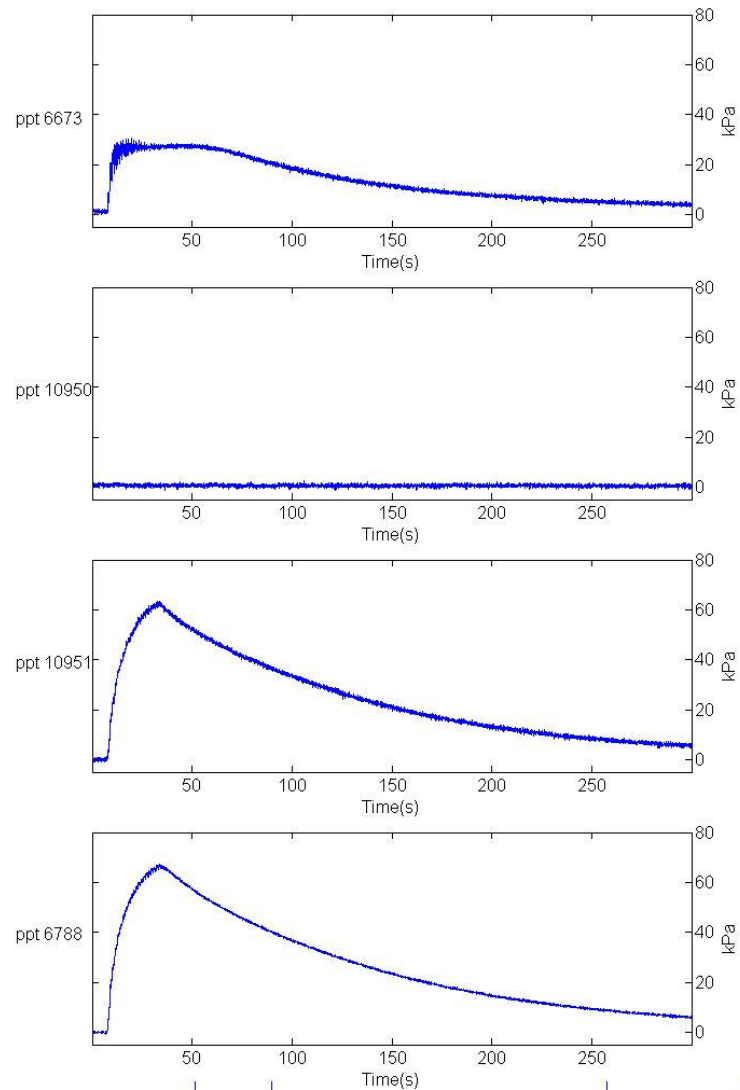
Earthquake

2

Figure No.



## Free field excess pore pressures



TEST CZ1P

FLIGHT 1

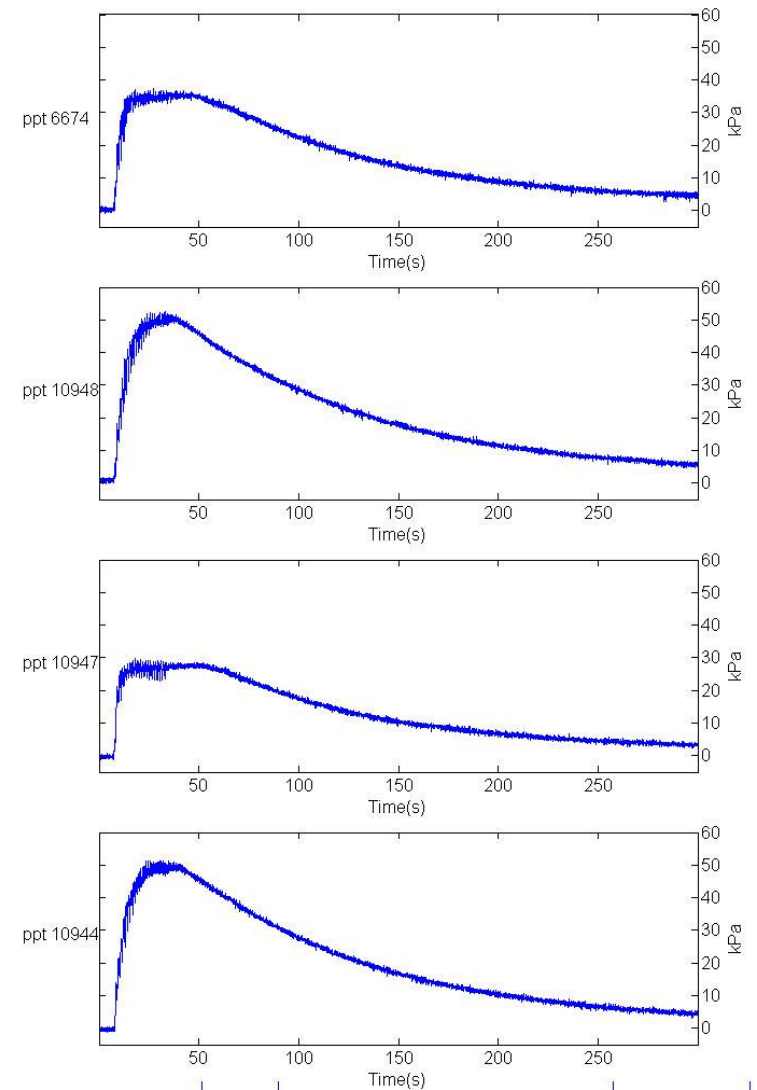
Scales: Prototype  
8th order Butterworth Filter at 500Hz  
Long-Term Time Records

Earthquake

2

Figure No.

## Excess pore pressures at sides of cemented zone



TEST CZ1P

FLIGHT 1

Scales: Prototype  
8th order Butterworth Filter at 500Hz  
Long-Term Time Records

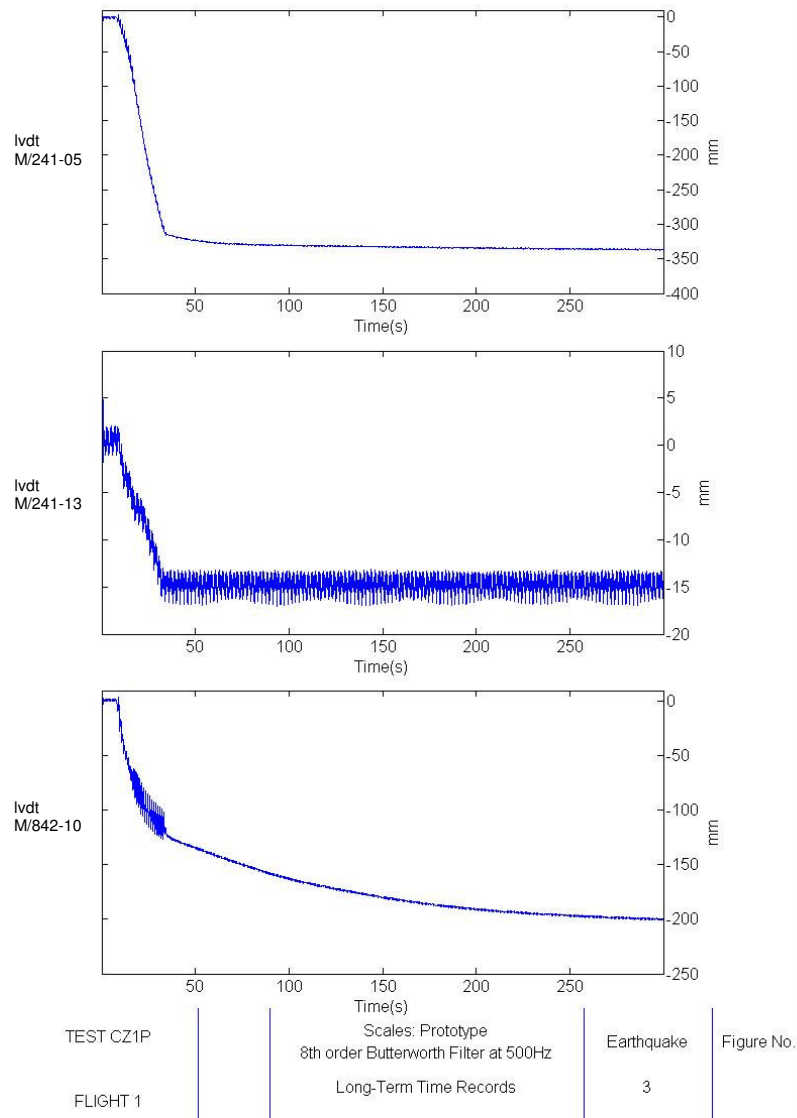
Earthquake

2

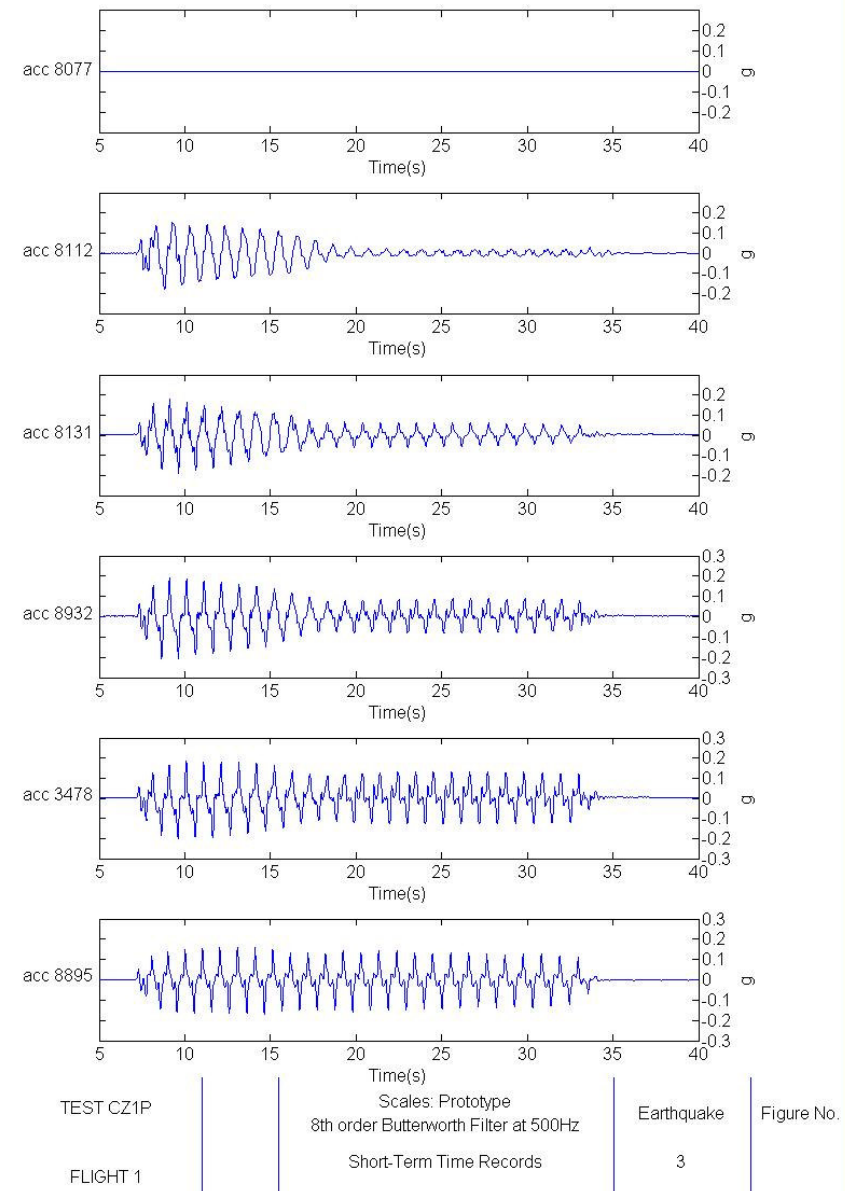
Figure No.

### 5.3 Centrifuge test CZ1P, earthquake 3

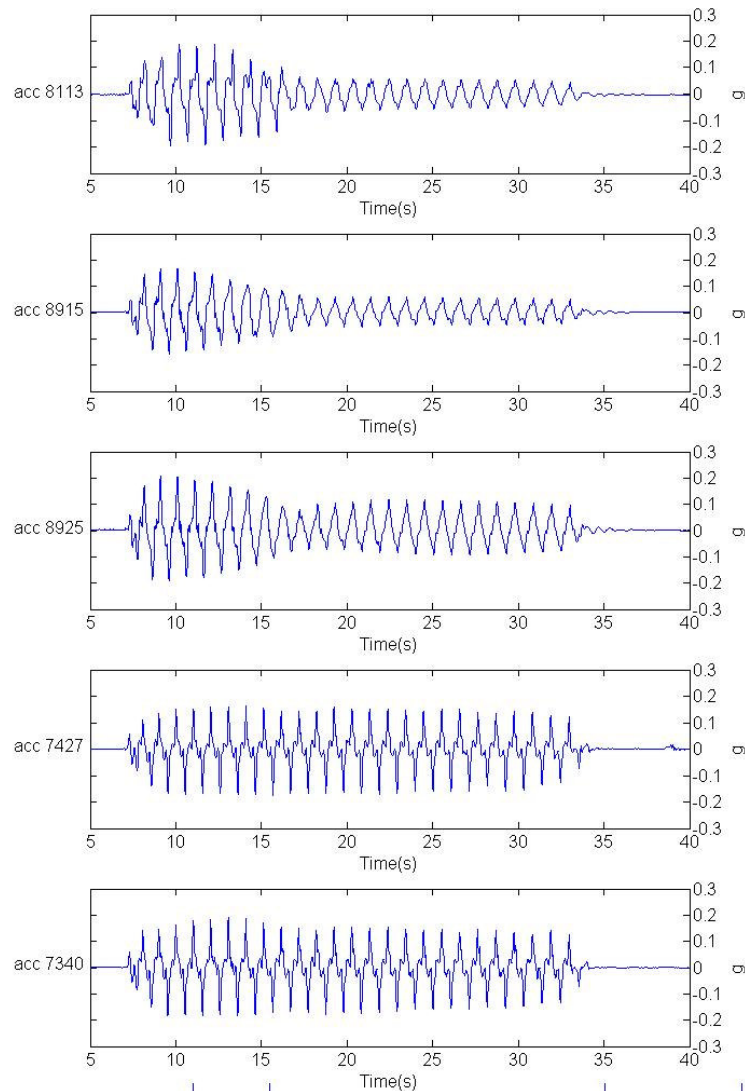
#### Soil and structural displacements



#### Accelerations of structure and soil under base of cemented zone



## Free field soil accelerations and box (input) acceleration



TEST CZ1P

Scales: Prototype  
8th order Butterworth Filter at 500Hz

Earthquake

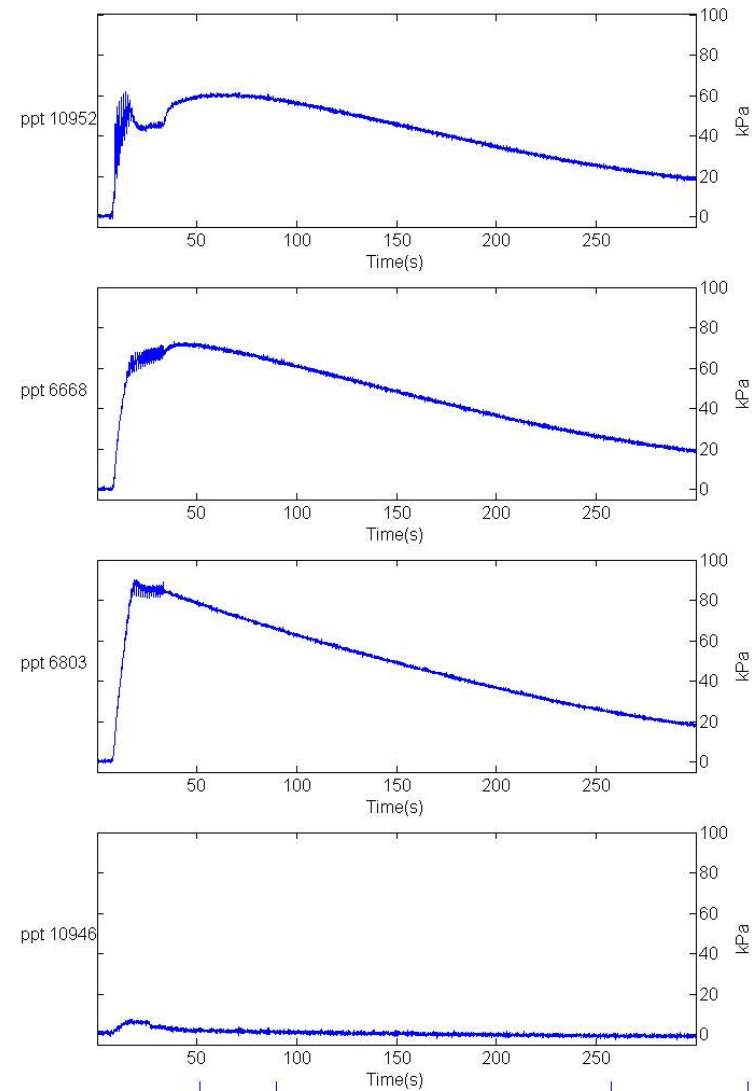
Figure No.

FLIGHT 1

Short-Term Time Records

3

## Excess pore pressures under base of cemented zone



TEST CZ1P

Scales: Prototype  
8th order Butterworth Filter at 500Hz

Earthquake

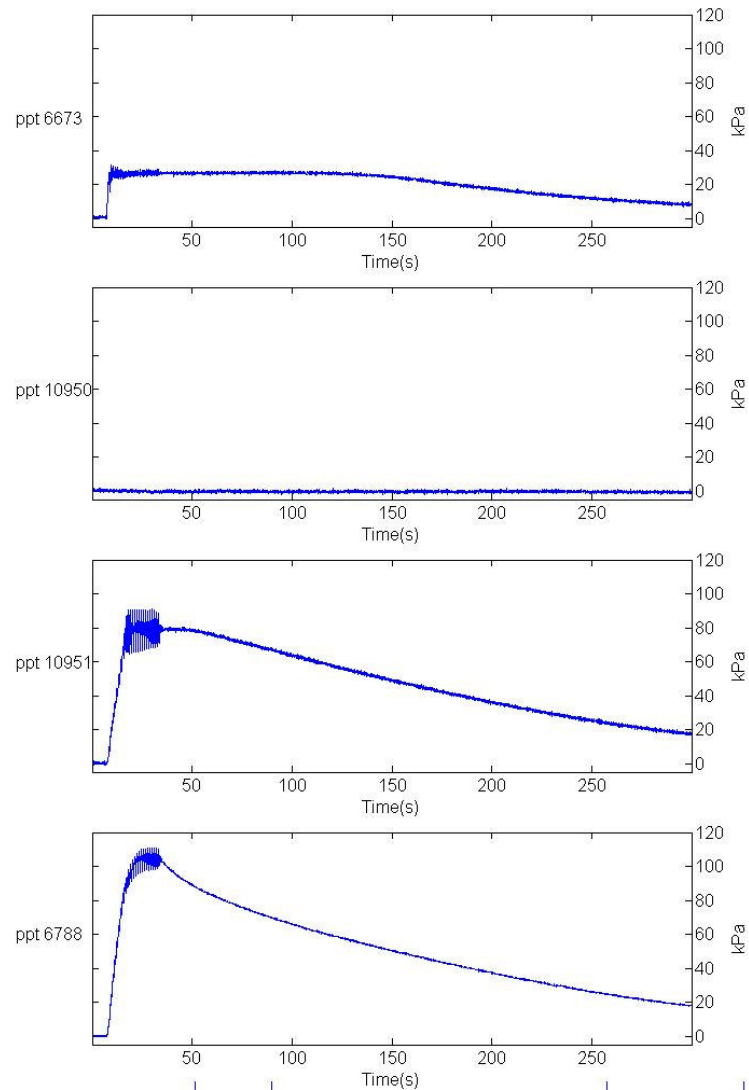
Figure No.

FLIGHT 1

Long-Term Time Records

3

## Free field excess pore pressures



TEST CZ1P

Scales: Prototype  
8th order Butterworth Filter at 500Hz

Earthquake

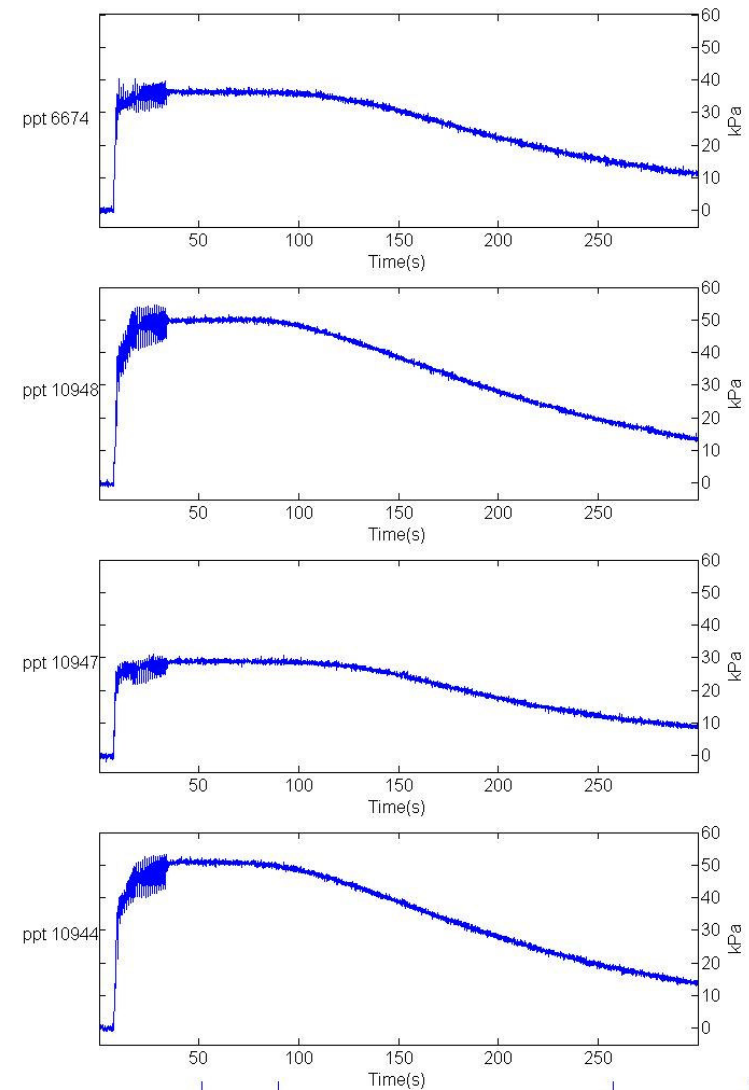
Figure No.

FLIGHT 1

Long-Term Time Records

3

## Excess pore pressures at sides of cemented zone



TEST CZ1P

Scales: Prototype  
8th order Butterworth Filter at 500Hz

Earthquake

Figure No.

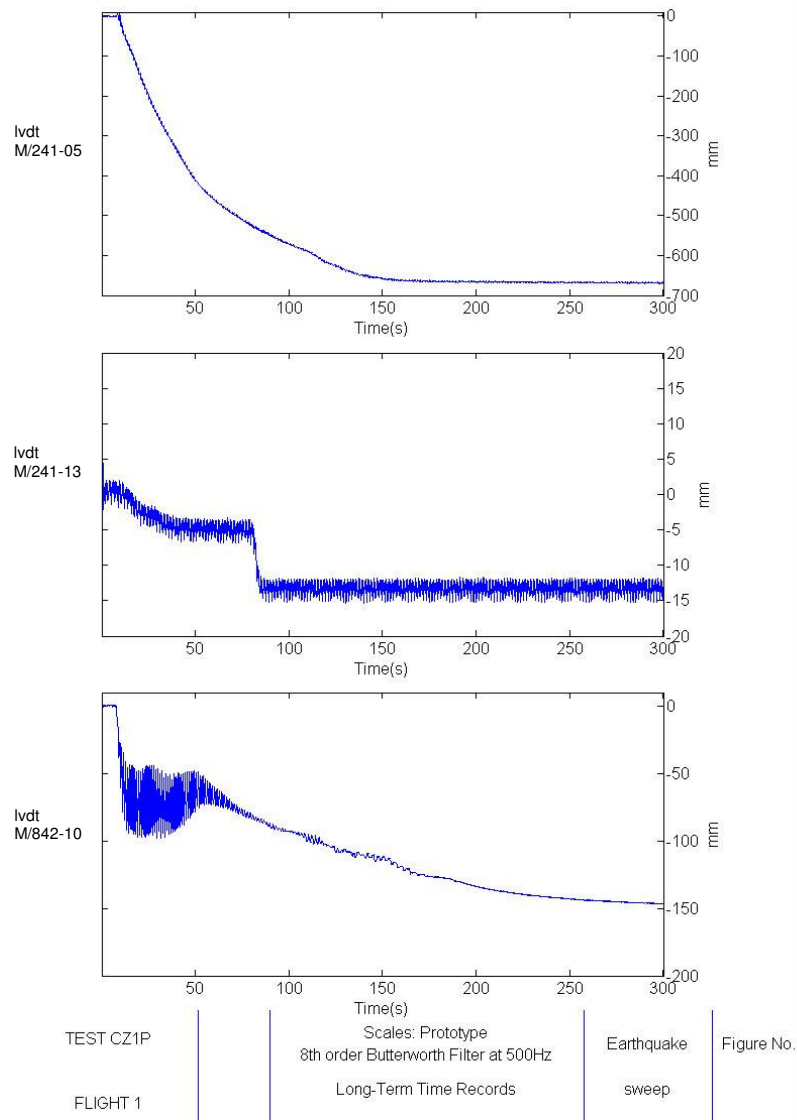
FLIGHT 1

Long-Term Time Records

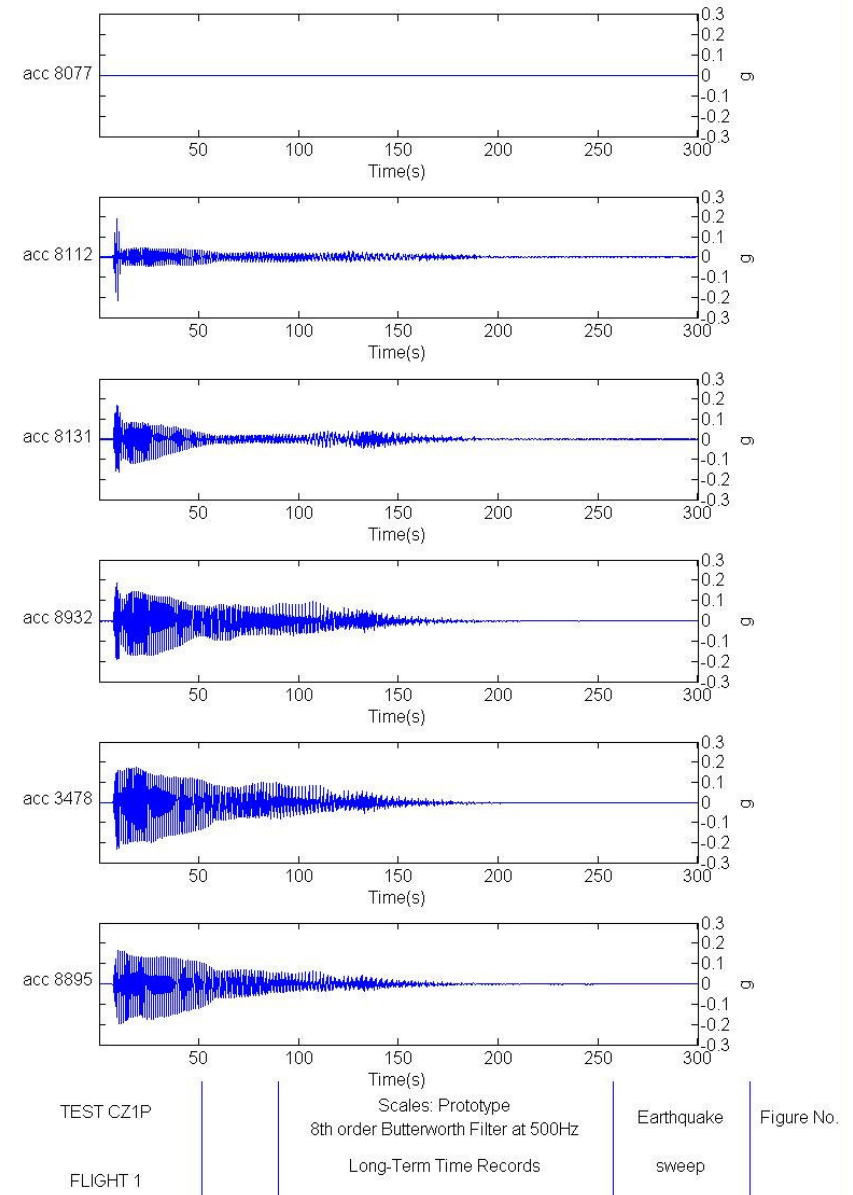
3

## 5.4 Centrifuge test CZ1P, frequency sweep earthquake

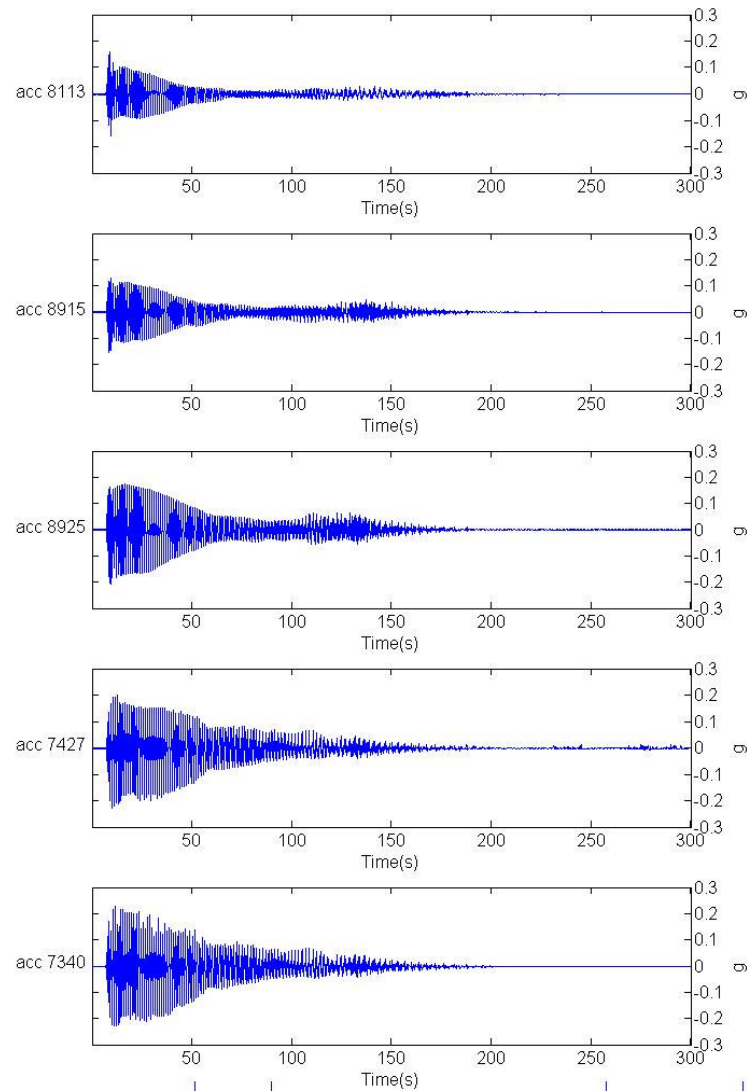
### Soil and structural displacements



### Accelerations of structure and soil under base of cemented zone



## Free field soil accelerations and box (input) acceleration



TEST CZ1P

Scales: Prototype  
8th order Butterworth Filter at 500Hz

Earthquake

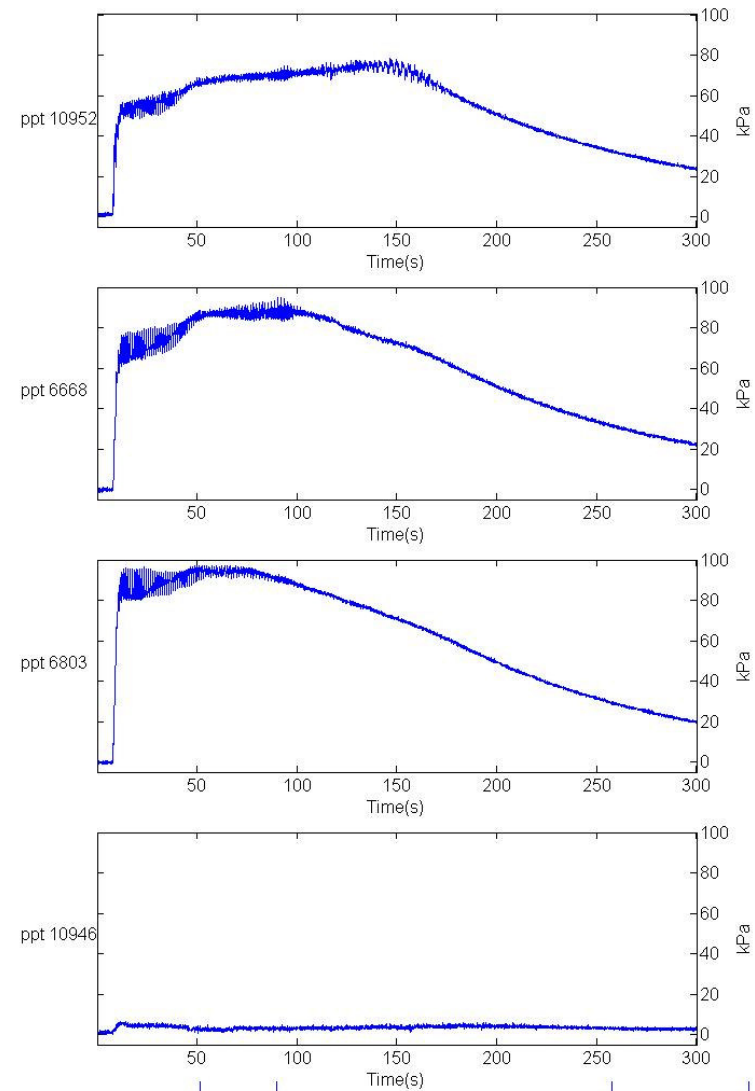
Figure No.

FLIGHT 1

Long-Term Time Records

sweep

## Excess pore pressures under base of cemented zone



TEST CZ1P

Scales: Prototype  
8th order Butterworth Filter at 500Hz

Earthquake

Figure No.

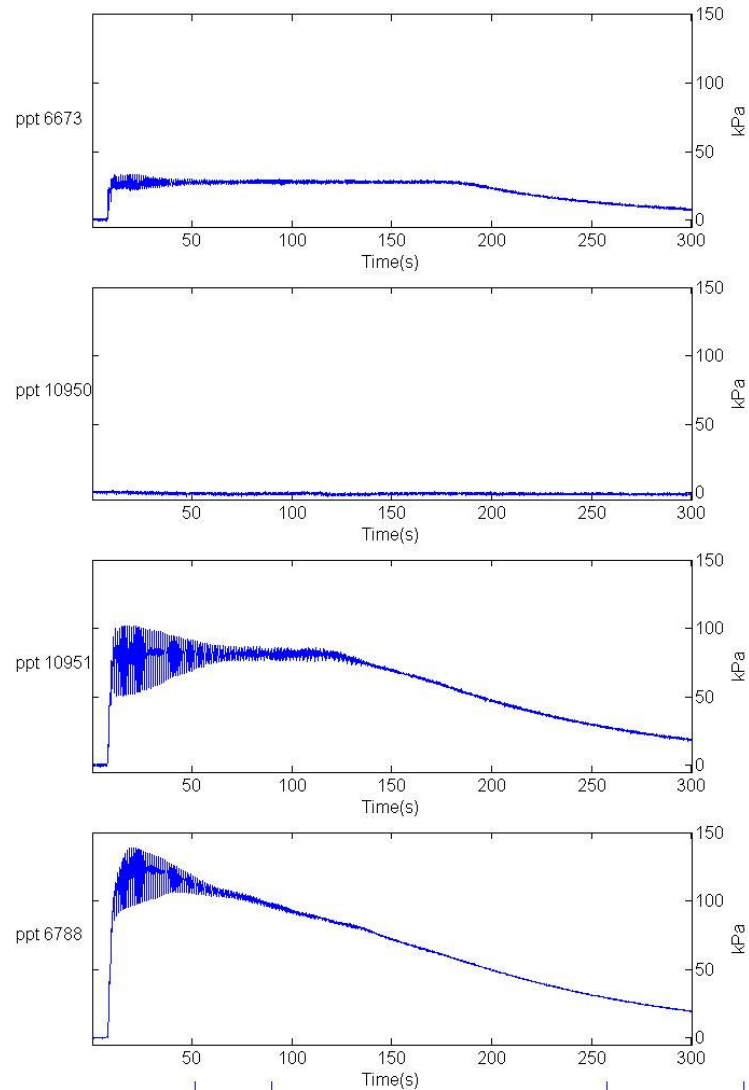
FLIGHT 1

Long-Term Time Records

sweep



## Free field excess pore pressures



TEST CZ1P

Scales: Prototype  
8th order Butterworth Filter at 500Hz

Earthquake

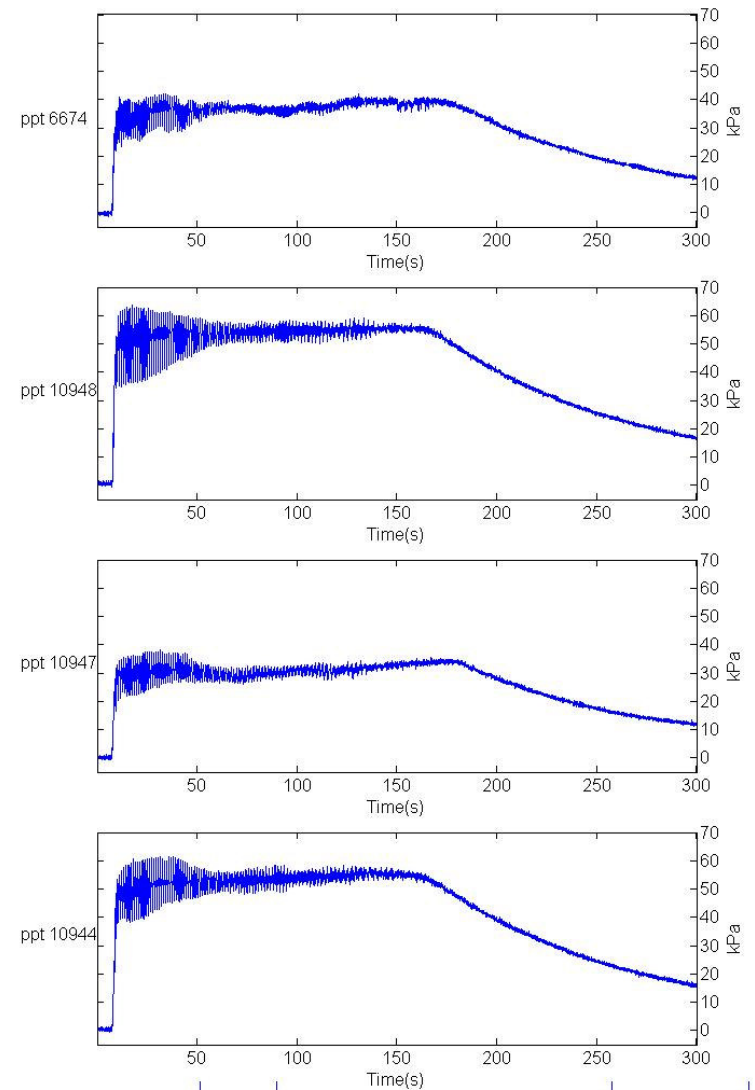
Figure No.

FLIGHT 1

Long-Term Time Records

sweep

## Excess pore pressures at sides of cemented zone



TEST CZ1P

Scales: Prototype  
8th order Butterworth Filter at 500Hz

Earthquake

Figure No.

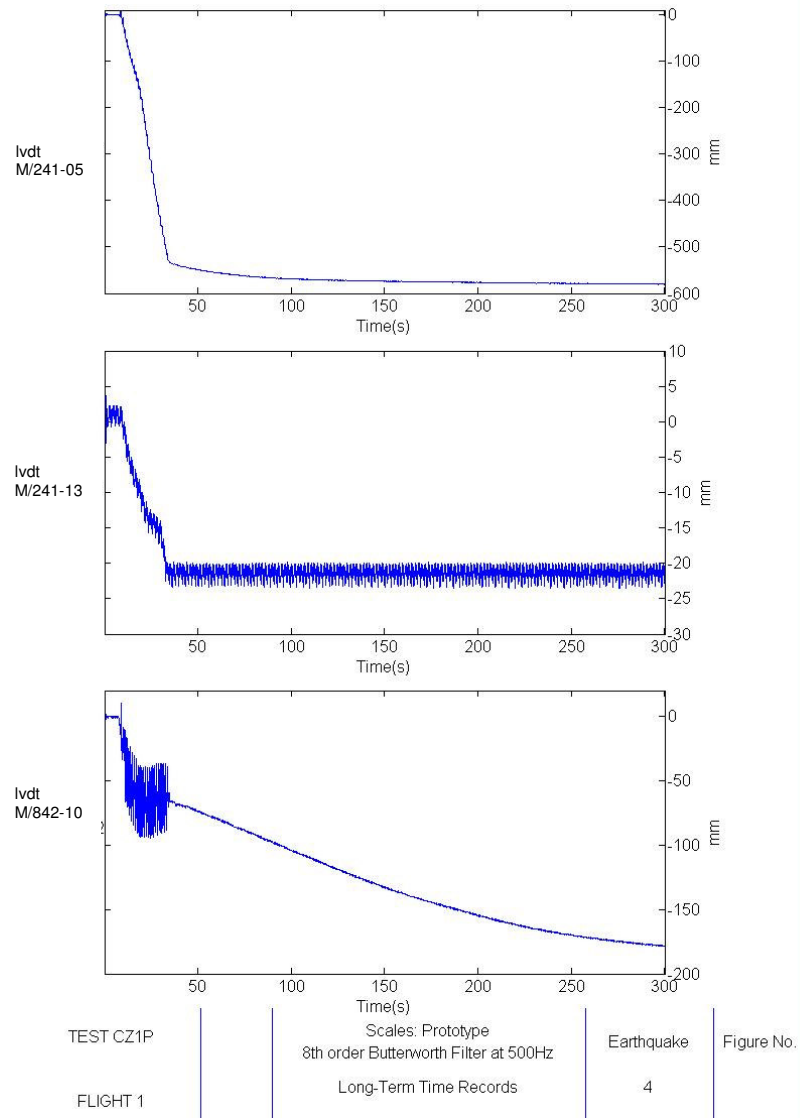
FLIGHT 1

Long-Term Time Records

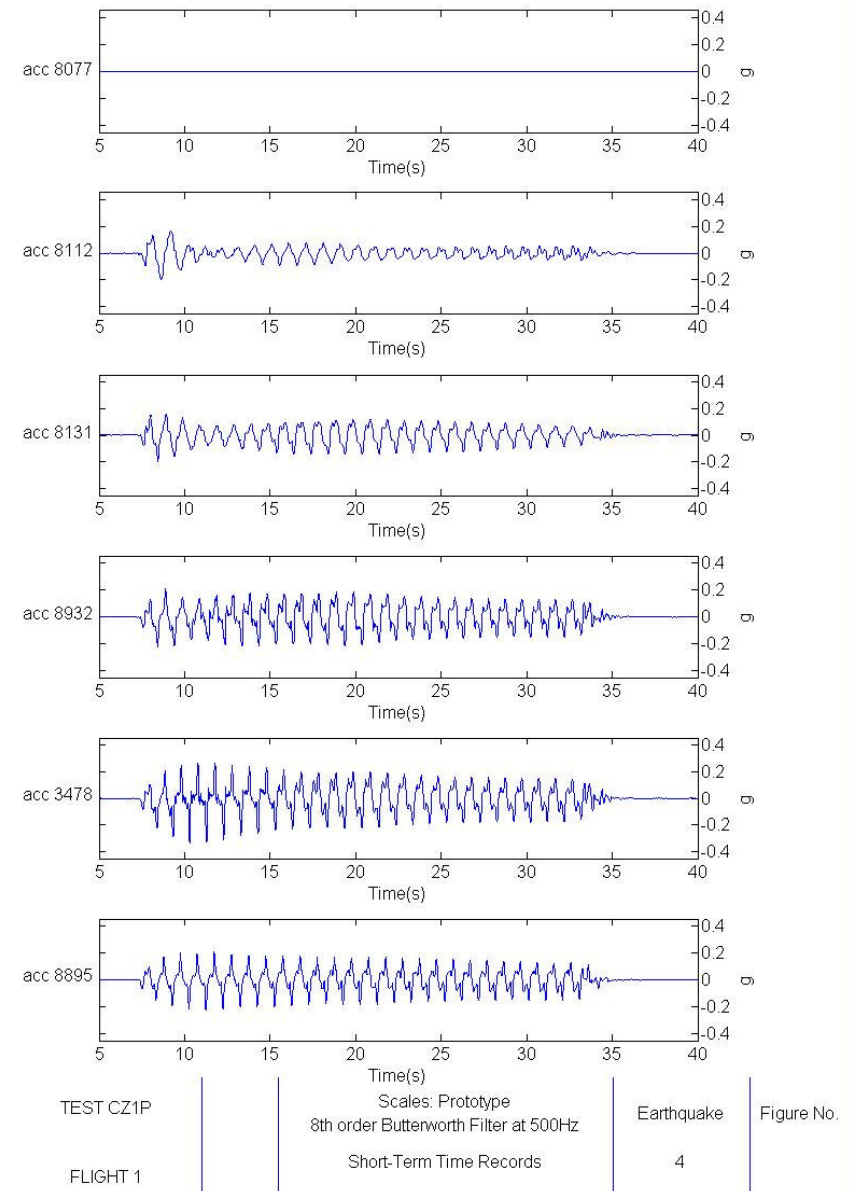
sweep

## 5.5 Centrifuge test CZ1P, earthquake 4

### Soil and structural displacements

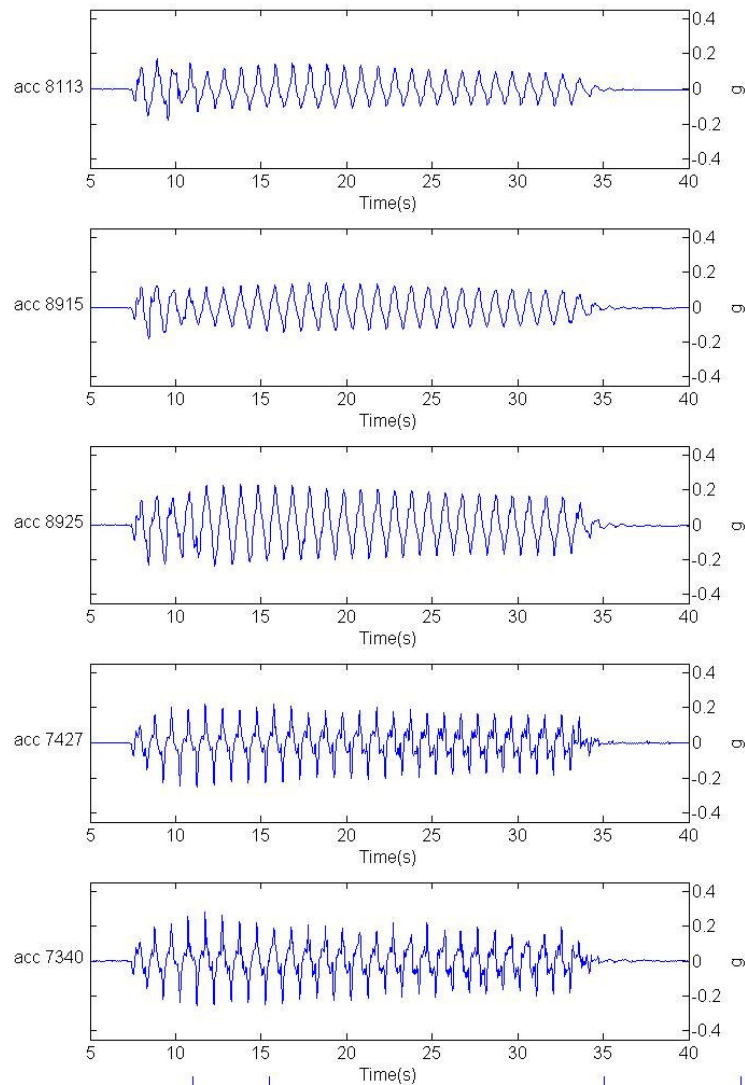


### Accelerations of structure and soil under base of cemented zone





## Free field soil accelerations and box (input) acceleration



TEST CZ1P

Scales: Prototype  
8th order Butterworth Filter at 500Hz

Earthquake

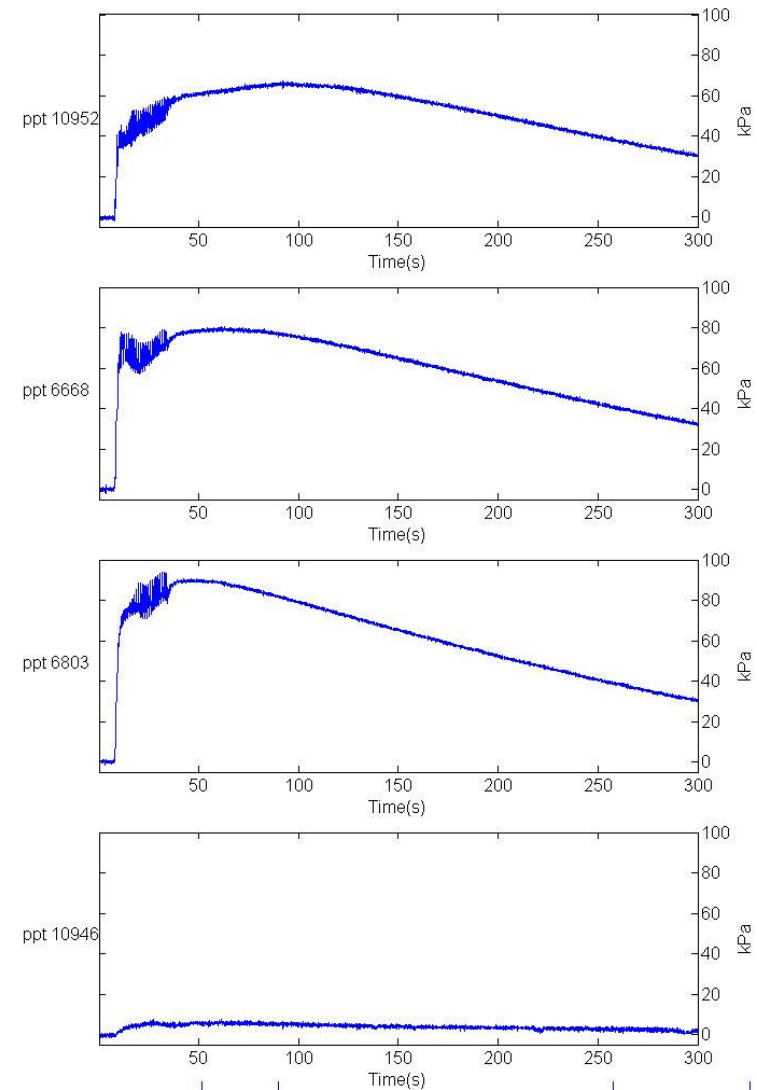
Figure No.

FLIGHT 1

Short-Term Time Records

4

## Excess pore pressures under base of cemented zone



TEST CZ1P

Scales: Prototype  
8th order Butterworth Filter at 500Hz

Earthquake

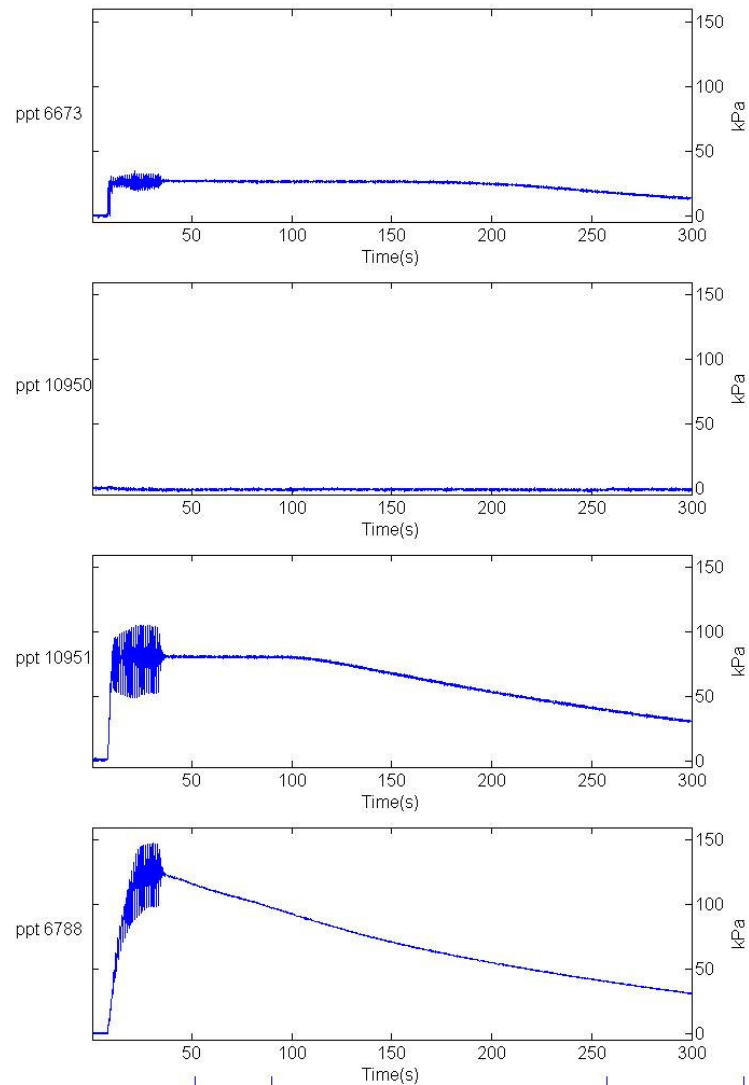
Figure No.

FLIGHT 1

Long-Term Time Records

4

## Free field excess pore pressures



TEST CZ1P

Scales: Prototype  
8th order Butterworth Filter at 500Hz

Earthquake

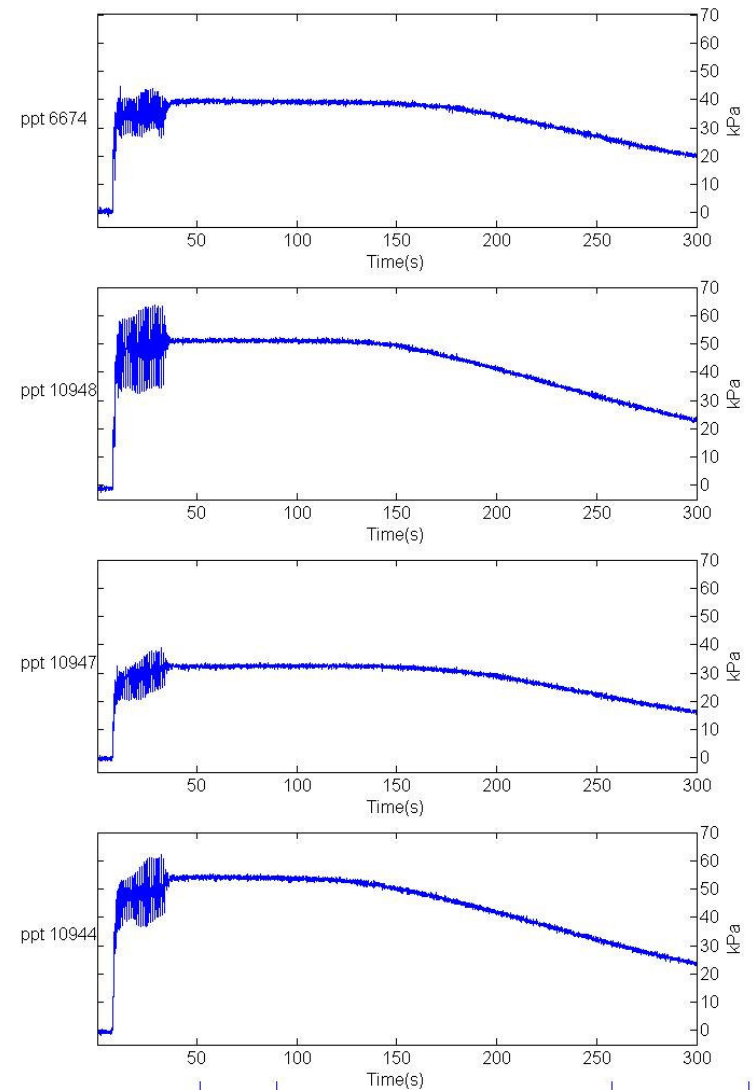
Figure No.

FLIGHT 1

Long-Term Time Records

4

## Excess pore pressures at sides of cemented zone



TEST CZ1P

Scales: Prototype  
8th order Butterworth Filter at 500Hz

Earthquake

Figure No.

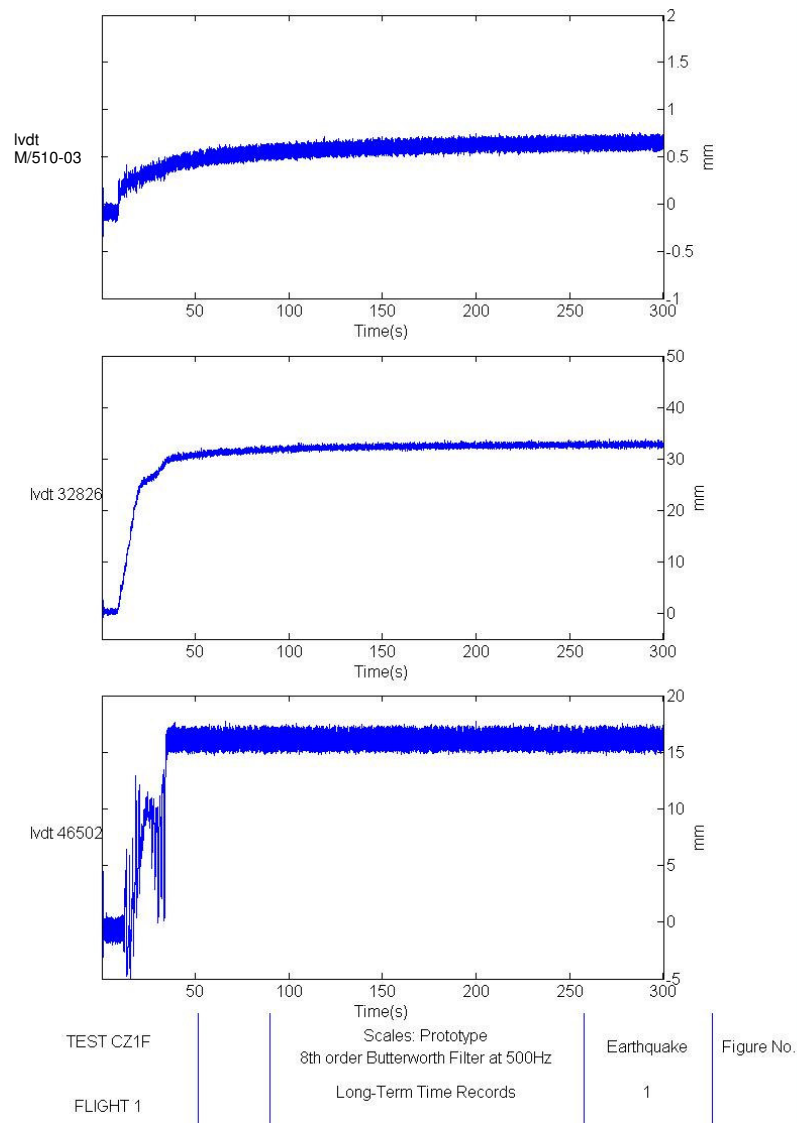
FLIGHT 1

Long-Term Time Records

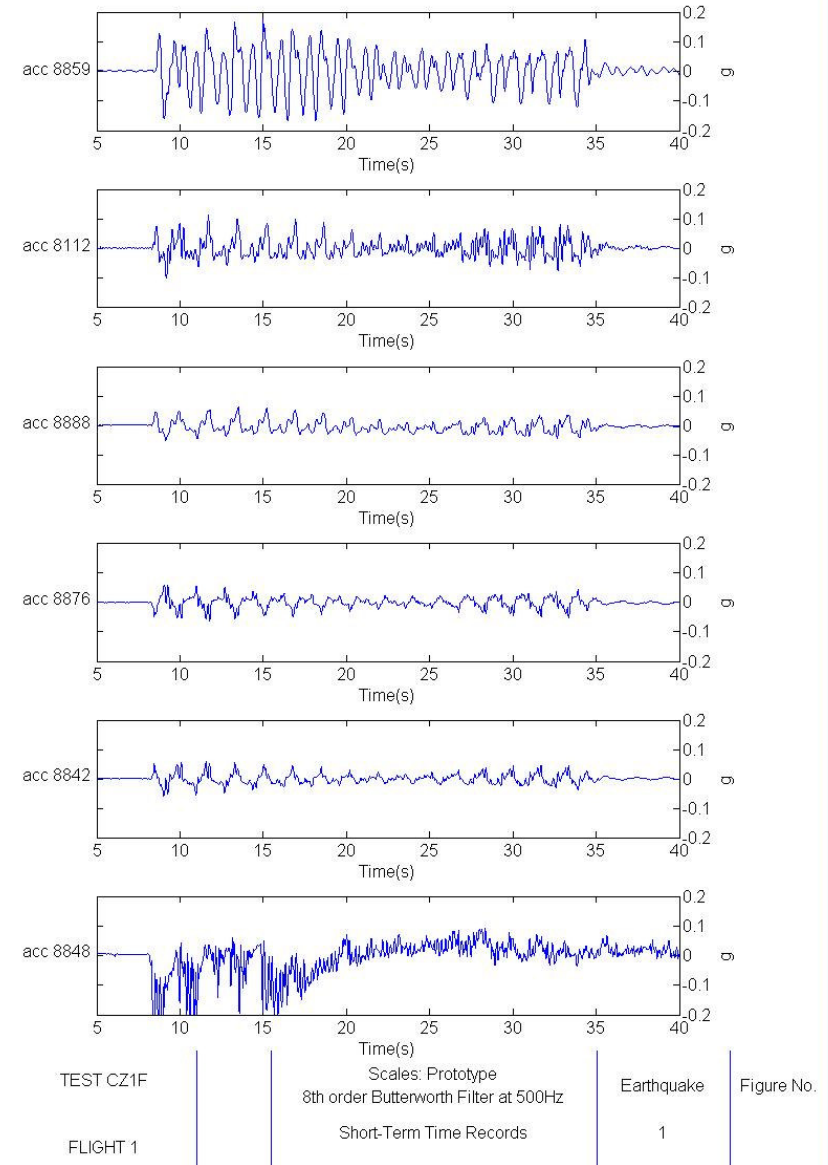
4

## 5.6 Centrifuge test CZ1F, earthquake 1

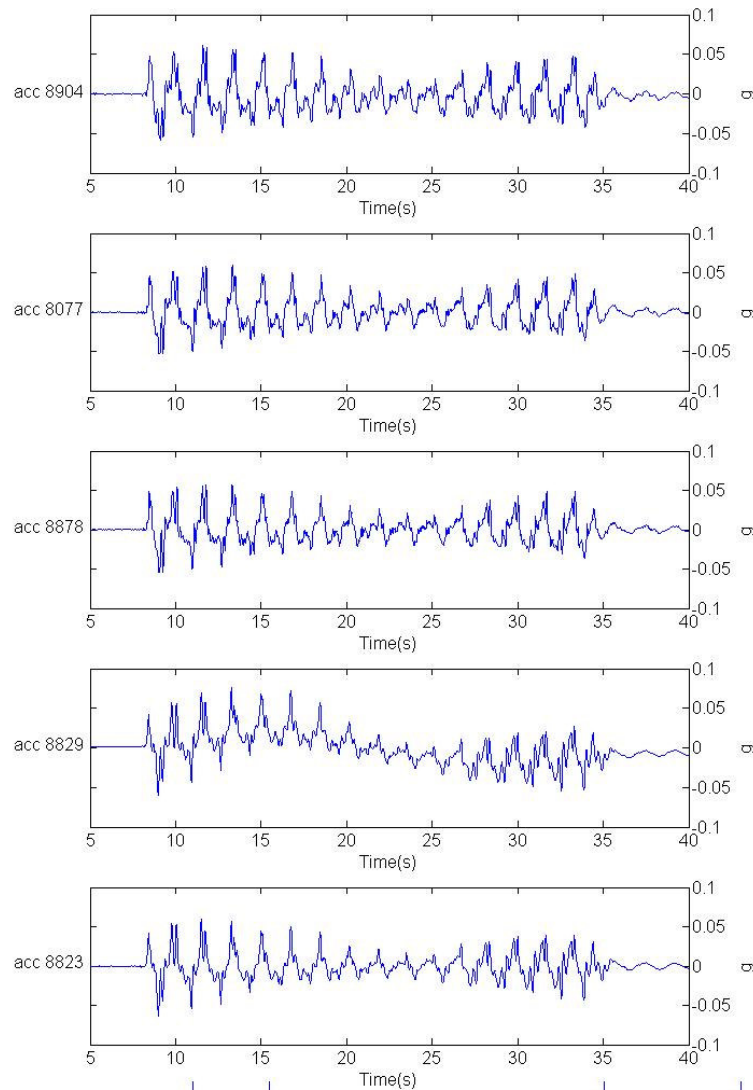
### Soil and structural displacements



### Accelerations of structure, cemented zone and soil under base of cemented zone



## Free field soil accelerations and box (input) acceleration



TEST CZ1F

Scales: Prototype  
8th order Butterworth Filter at 500Hz

Earthquake

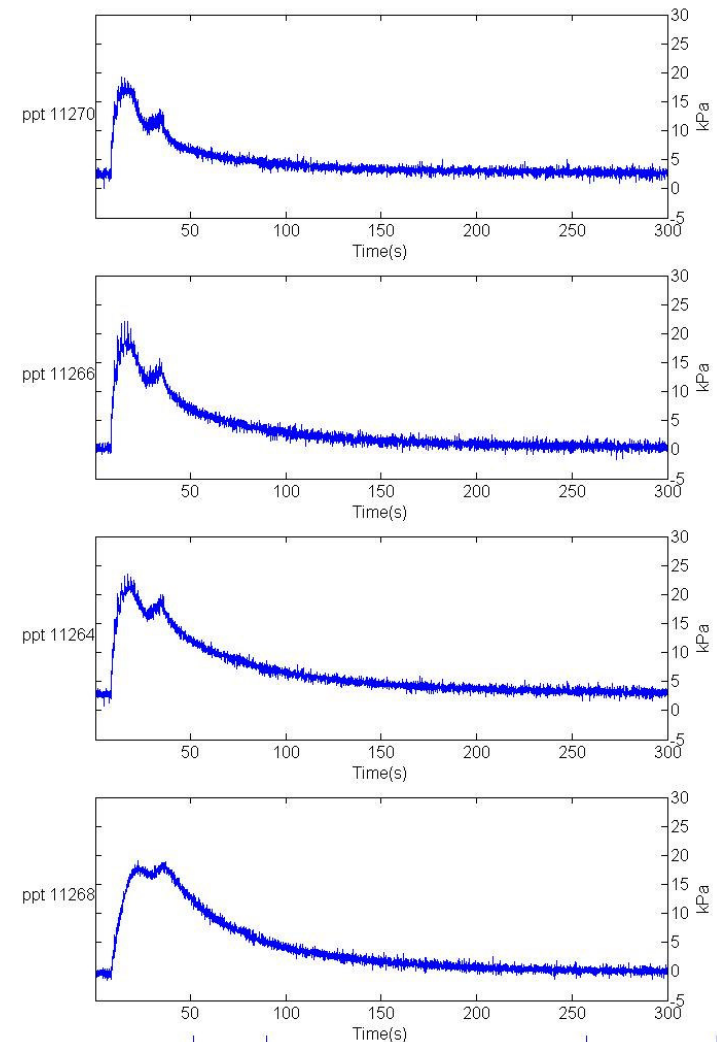
Figure No.

FLIGHT 1

Short-Term Time Records

1

## Excess pore pressures at the side and under the base of cemented zone



TEST CZ1F

Scales: Prototype  
8th order Butterworth Filter at 500Hz

Earthquake

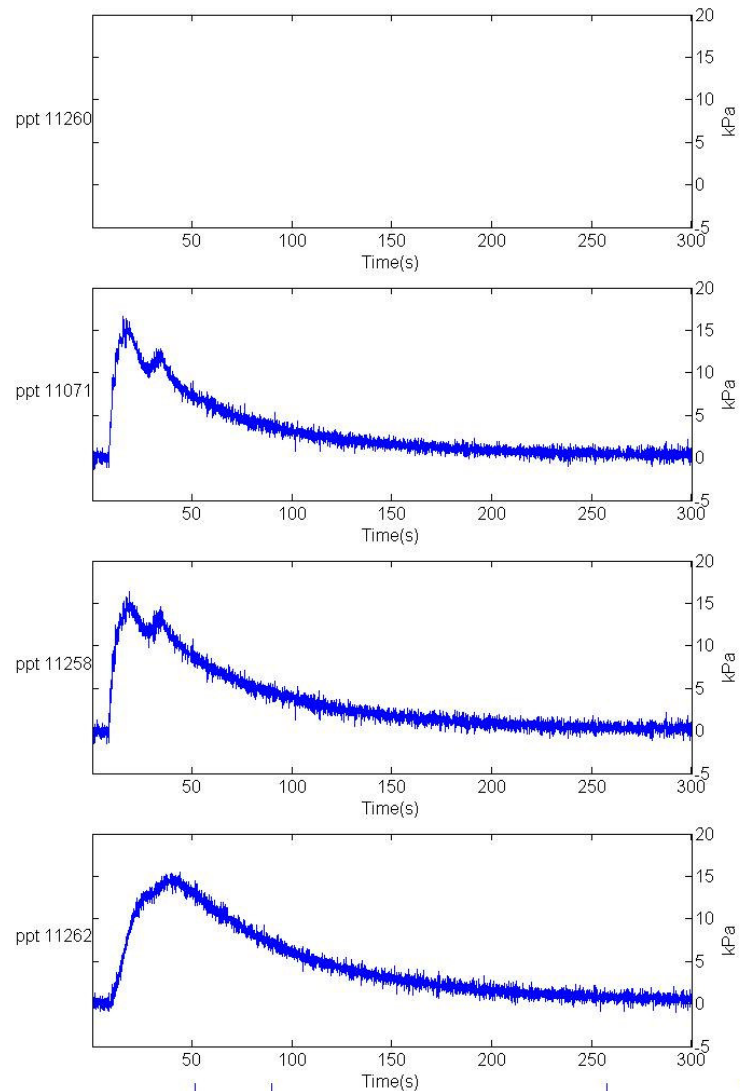
Figure No.

FLIGHT 1

Long-Term Time Records

1

## Free field excess pore pressures



TEST CZ1F

Scales: Prototype  
8th order Butterworth Filter at 500Hz

Earthquake

Figure No.

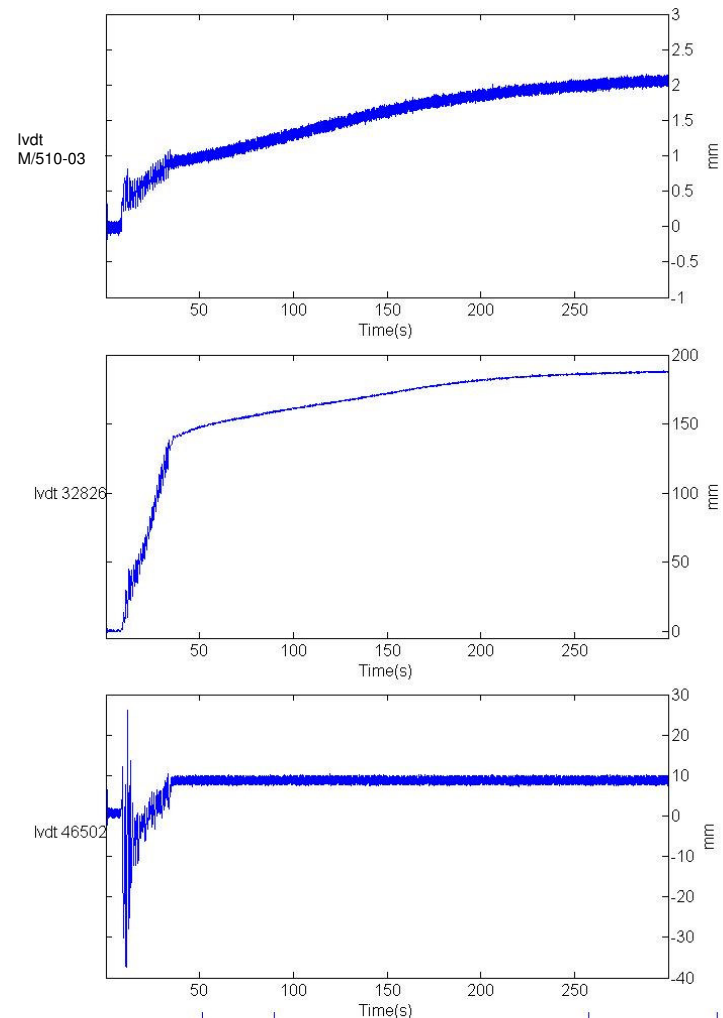
FLIGHT 1

Long-Term Time Records

1

## 5.7 Centrifuge test CZ1F, earthquake 2

## Soil and structural displacements



TEST CZ1F

Scales: Prototype  
8th order Butterworth Filter at 500Hz

Earthquake

Figure No.

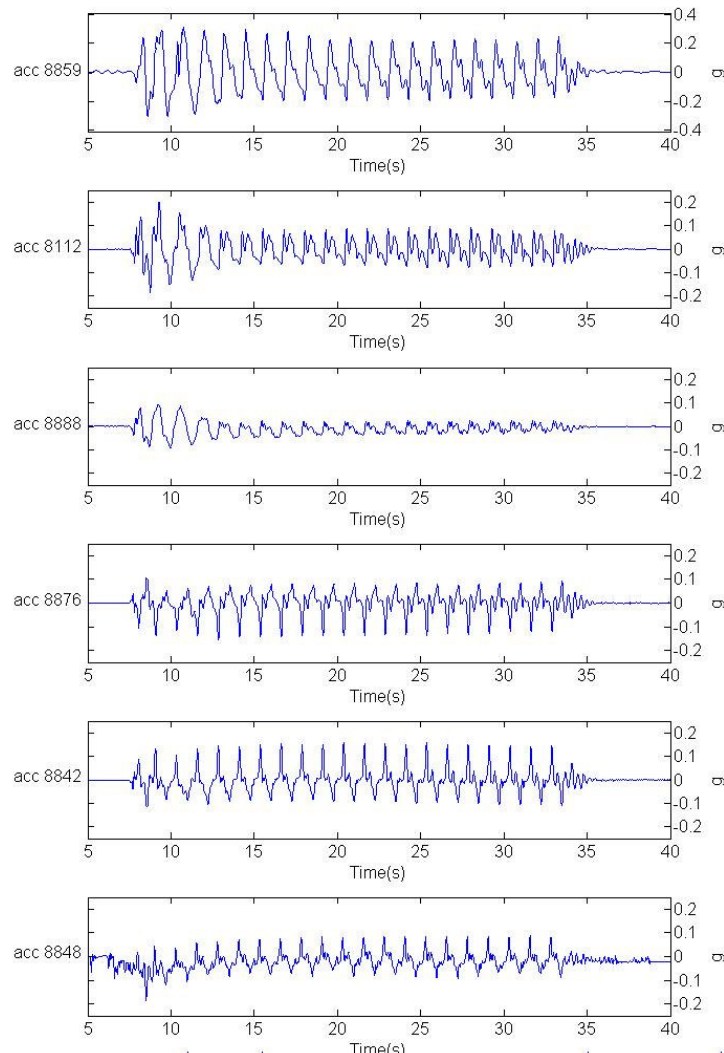
FLIGHT 1

Long-Term Time Records

2



### Accelerations of structure, cemented zone and soil under base of cemented zone



TEST CZ1F

FLIGHT 1

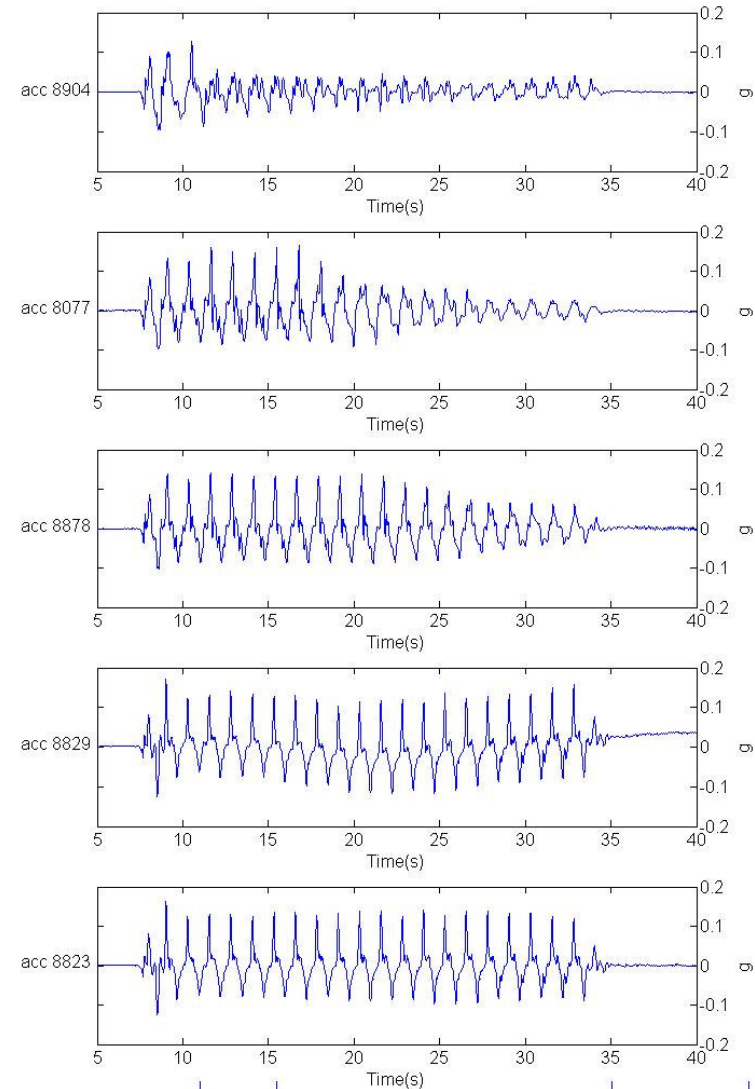
Scales: Prototype  
8th order Butterworth Filter at 500Hz  
Short-Term Time Records

Earthquake

2

Figure No.

### Free field soil accelerations and box (input) acceleration



TEST CZ1F

FLIGHT 1

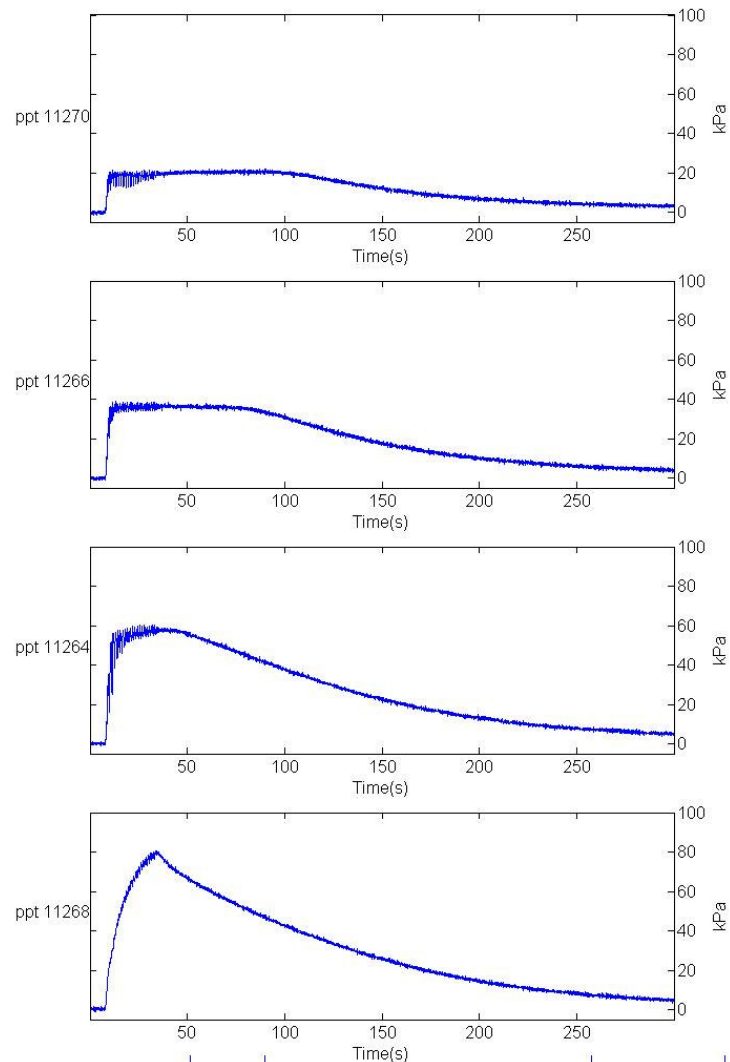
Scales: Prototype  
8th order Butterworth Filter at 500Hz  
Short-Term Time Records

Earthquake

2

Figure No.

## Excess pore pressures at the side and under the base of cemented zone



TEST CZ1F

Scales: Prototype  
8th order Butterworth Filter at 500Hz  
Long-Term Time Records

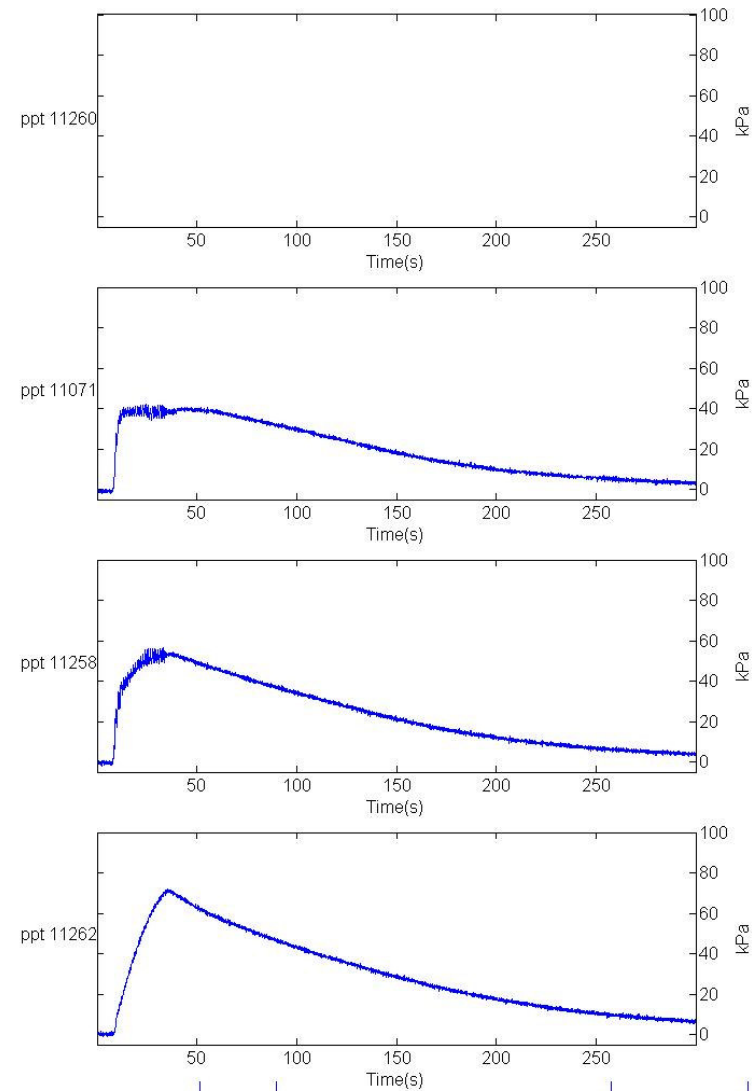
Earthquake

Figure No.

FLIGHT 1

2

## Free field excess pore pressures



TEST CZ1F

Scales: Prototype  
8th order Butterworth Filter at 500Hz  
Long-Term Time Records

Earthquake

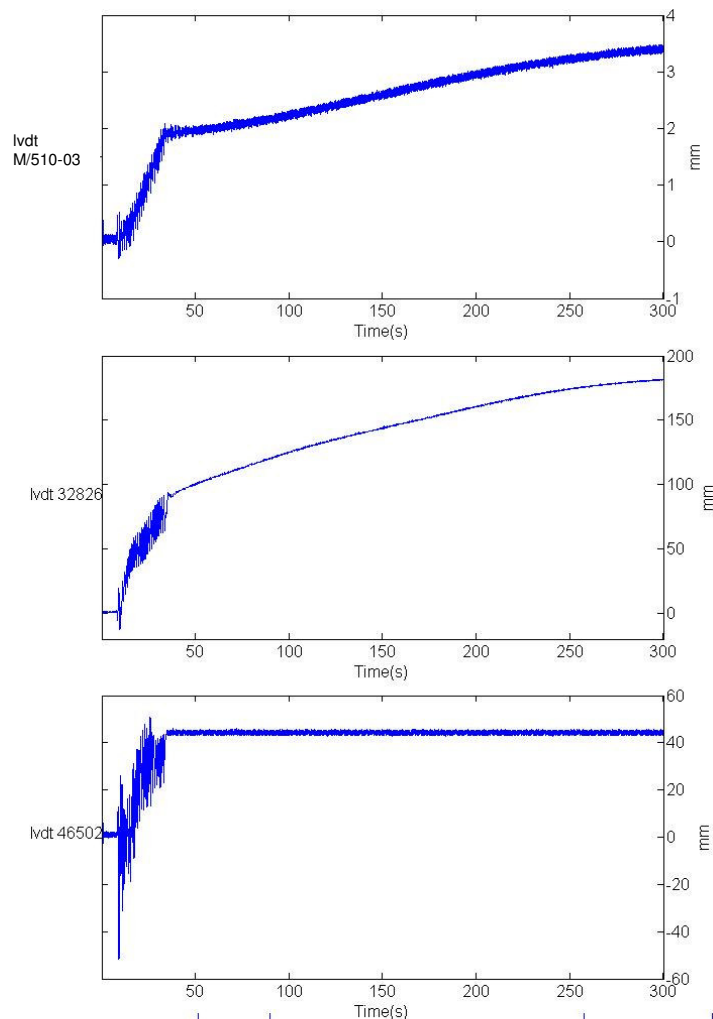
Figure No.

FLIGHT 1

2

## 5.8 Centrifuge test CZ1F, earthquake 3

### Soil and structural displacements



TEST CZ1F

Scales: Prototype  
8th order Butterworth Filter at 500Hz

Earthquake

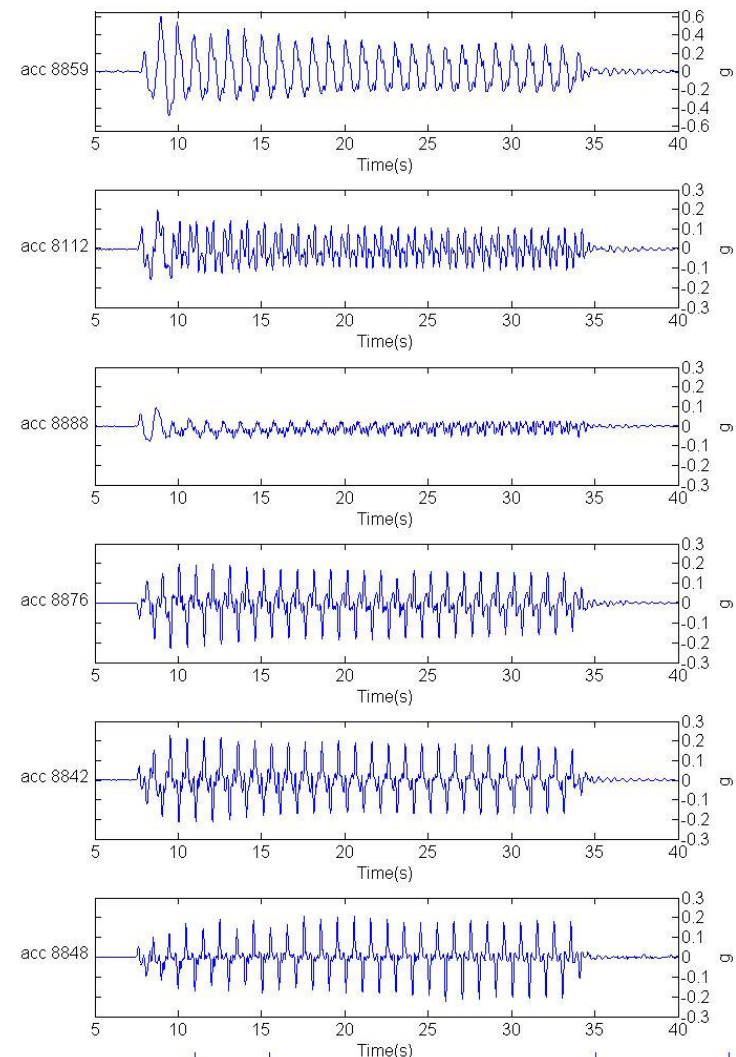
Figure No.

FLIGHT 1

Long-Term Time Records

3

### Accelerations of structure, cemented zone and soil under base of cemented zone



TEST CZ1F

Scales: Prototype  
8th order Butterworth Filter at 500Hz

Earthquake

Figure No.

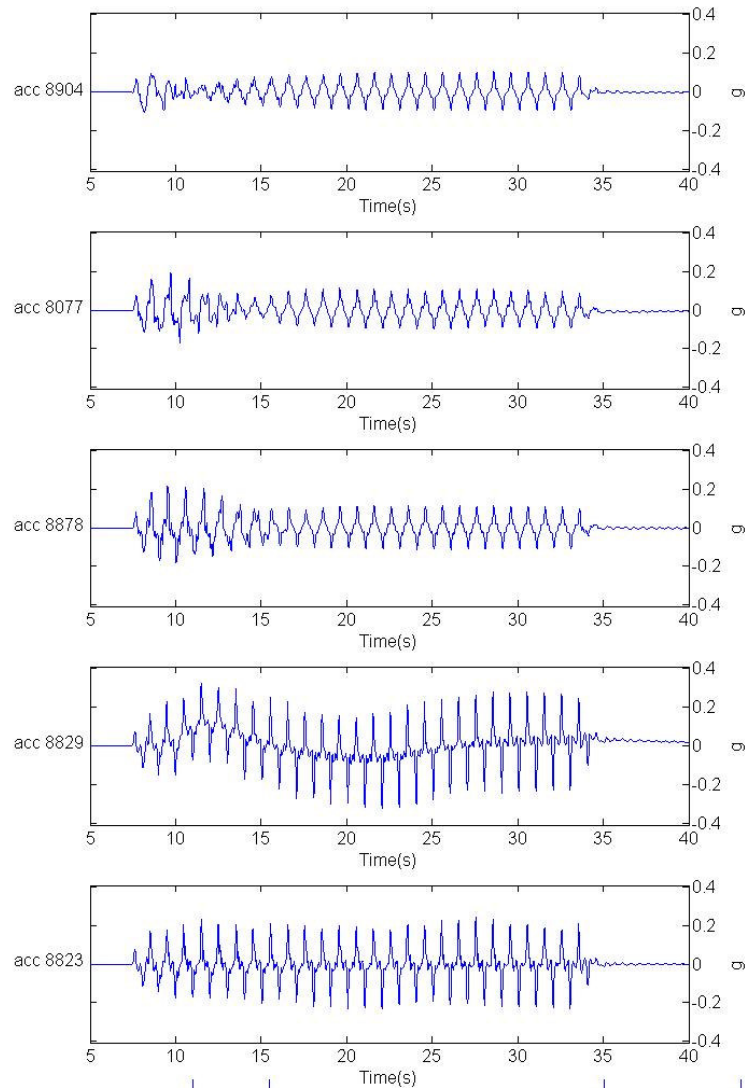
FLIGHT 1

Short-Term Time Records

3



## Free field soil accelerations and box (input) acceleration



TEST CZ1F

FLIGHT 1

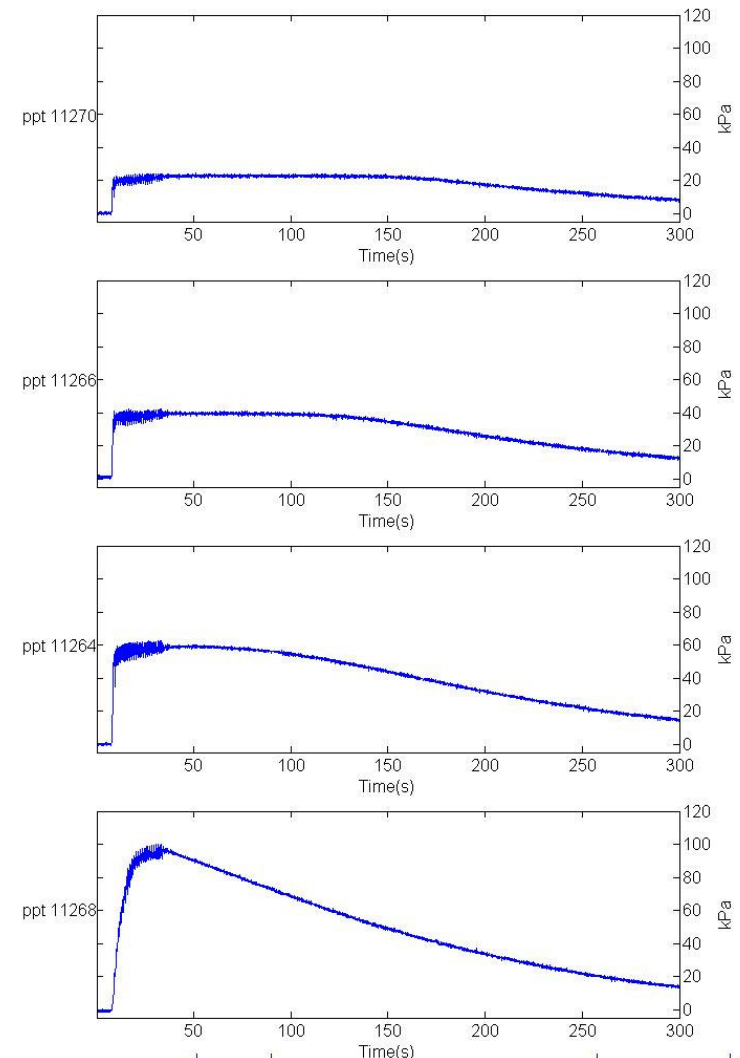
Scales: Prototype  
8th order Butterworth Filter at 500Hz  
Short-Term Time Records

Earthquake

3

Figure No.

## Excess pore pressures at the side and under the base of cemented zone



TEST CZ1F

FLIGHT 1

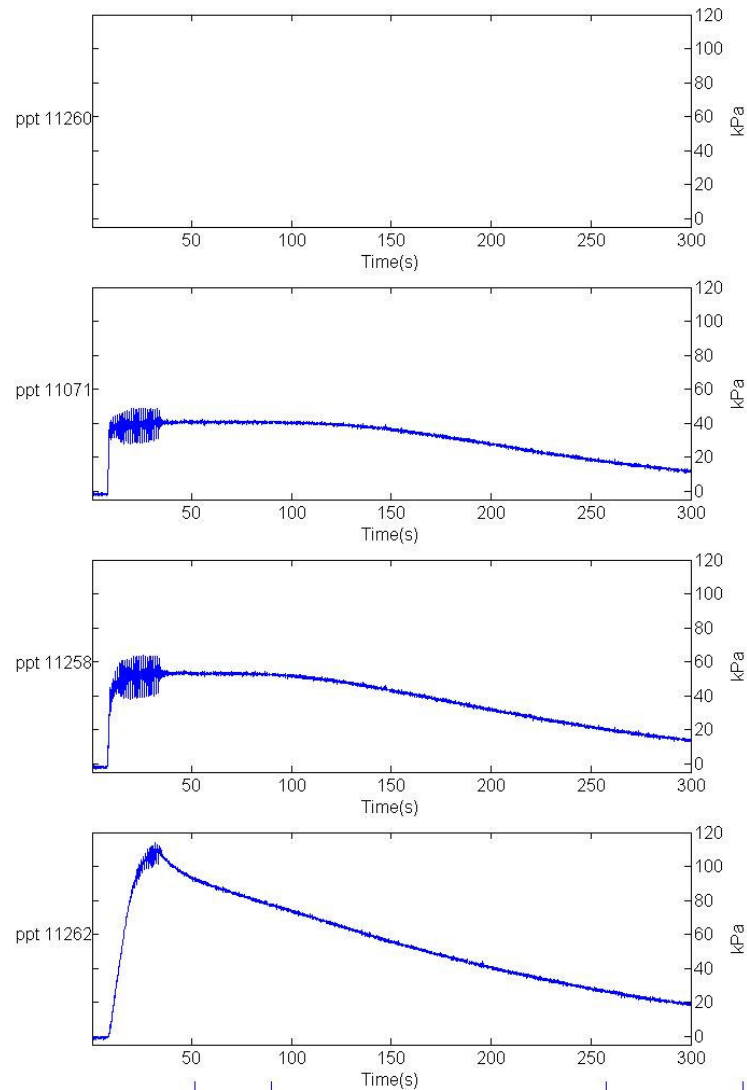
Scales: Prototype  
8th order Butterworth Filter at 500Hz  
Long-Term Time Records

Earthquake

3

Figure No.

## Free field excess pore pressures



TEST CZ1F

FLIGHT 1

Scales: Prototype  
8th order Butterworth Filter at 500Hz  
Long-Term Time Records

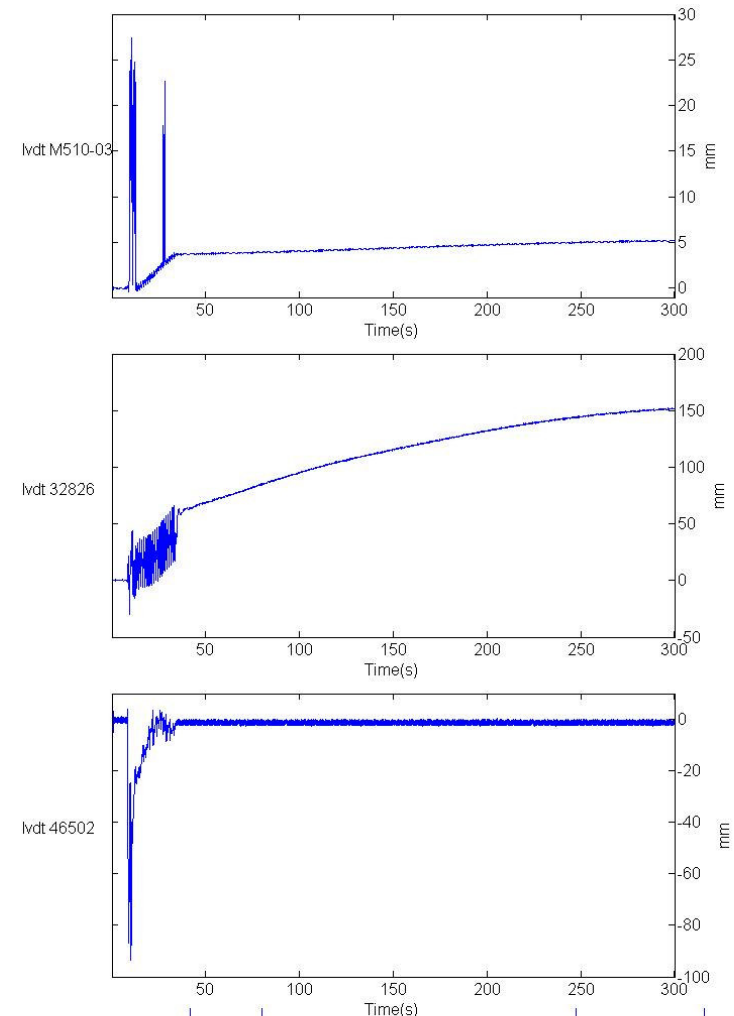
Earthquake

3

Figure No.

## 5.9 Centrifuge test CZ1F, earthquake 4

## Soil and structural displacements



TEST CZ1F

FLIGHT 1

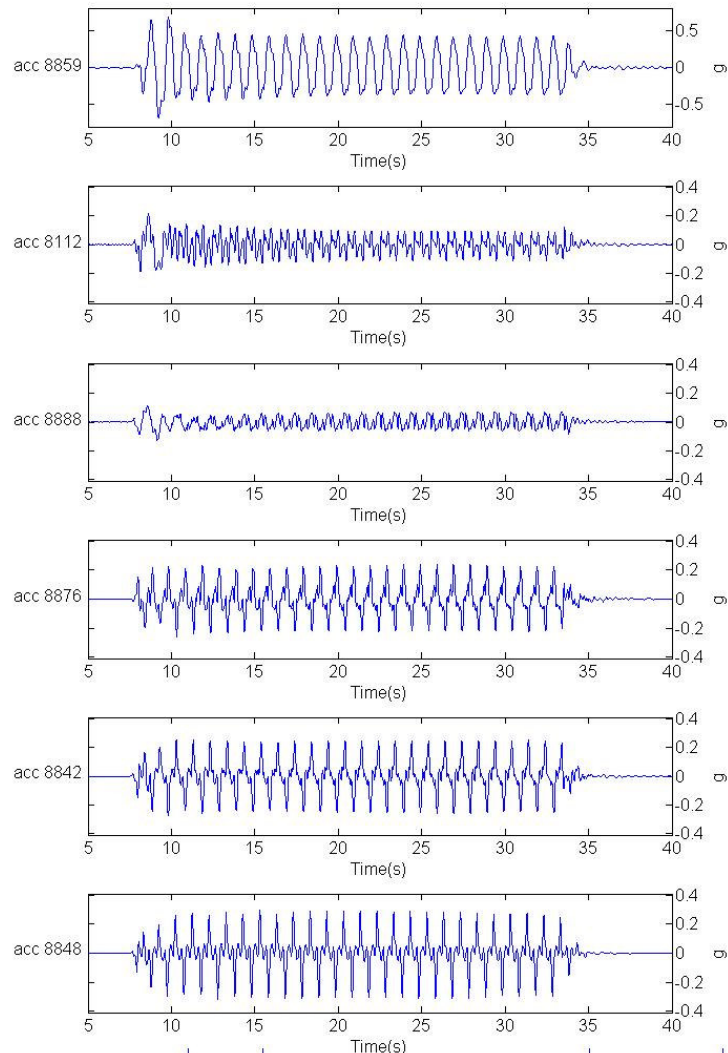
Scales: Prototype  
8th order Butterworth Filter at 500Hz  
Long-Term Time Records

Earthquake

4

Figure No.

### Accelerations of structure, cemented zone and soil under base of cemented zone



TEST CZ1F

FLIGHT 1

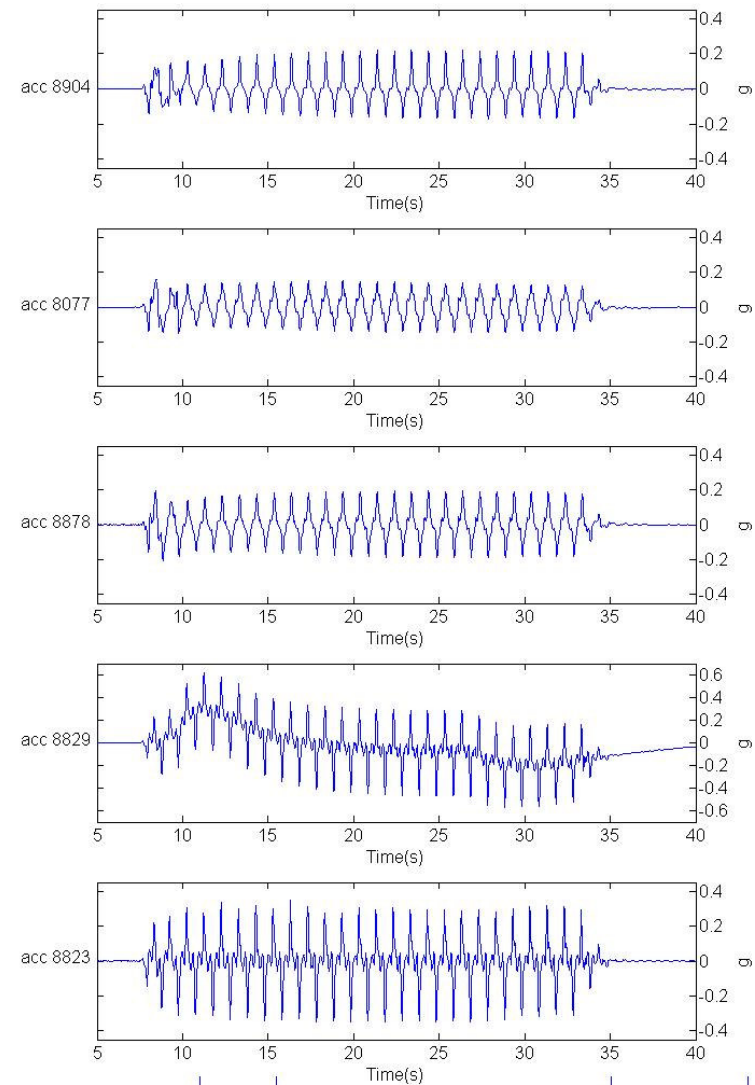
Scales: Prototype  
8th order Butterworth Filter at 500Hz  
Short-Term Time Records

Earthquake

4

Figure No.

### Free field soil accelerations and box (input) acceleration



TEST CZ1F

FLIGHT 1

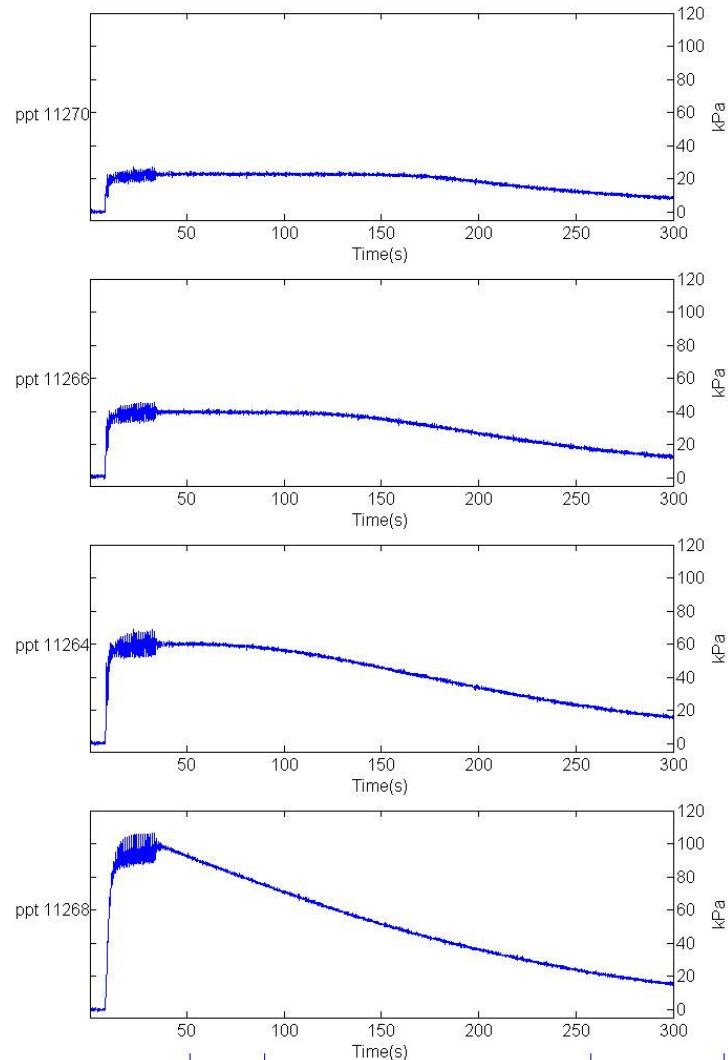
Scales: Prototype  
8th order Butterworth Filter at 500Hz  
Short-Term Time Records

Earthquake

4

Figure No.

## Excess pore pressures at the side and under the base of cemented zone



TEST CZ1F

Scales: Prototype  
8th order Butterworth Filter at 500Hz  
Long-Term Time Records

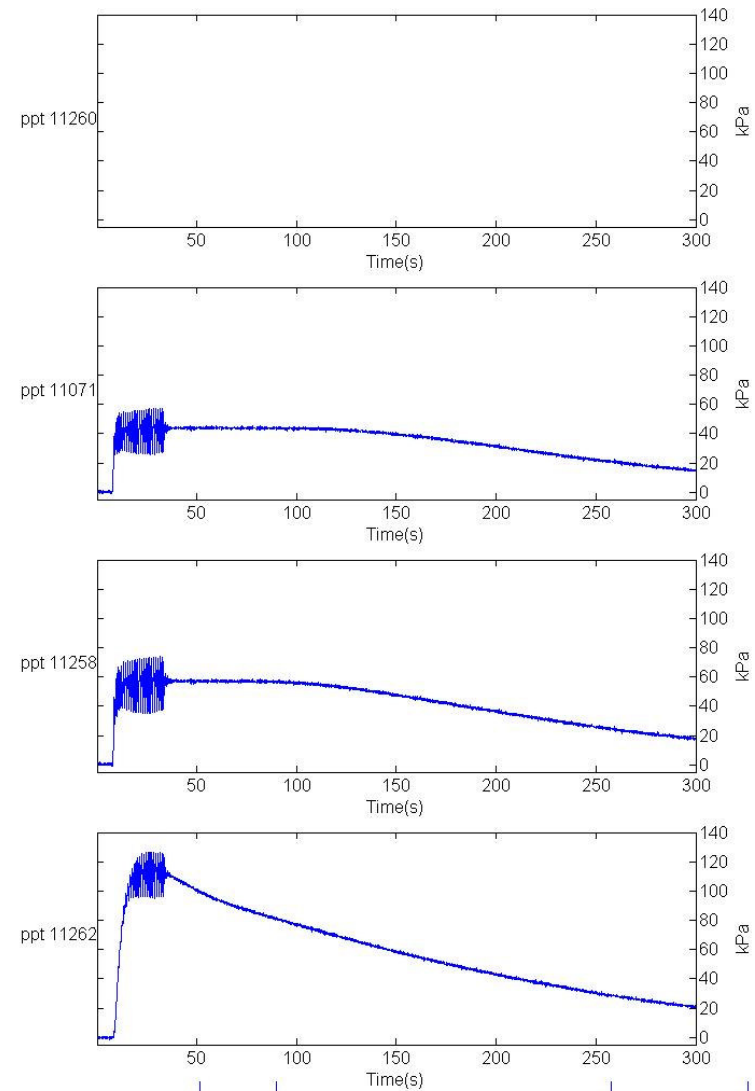
Earthquake

Figure No.

FLIGHT 1

4

## Free field excess pore pressures



TEST CZ1F

Scales: Prototype  
8th order Butterworth Filter at 500Hz  
Long-Term Time Records

Earthquake

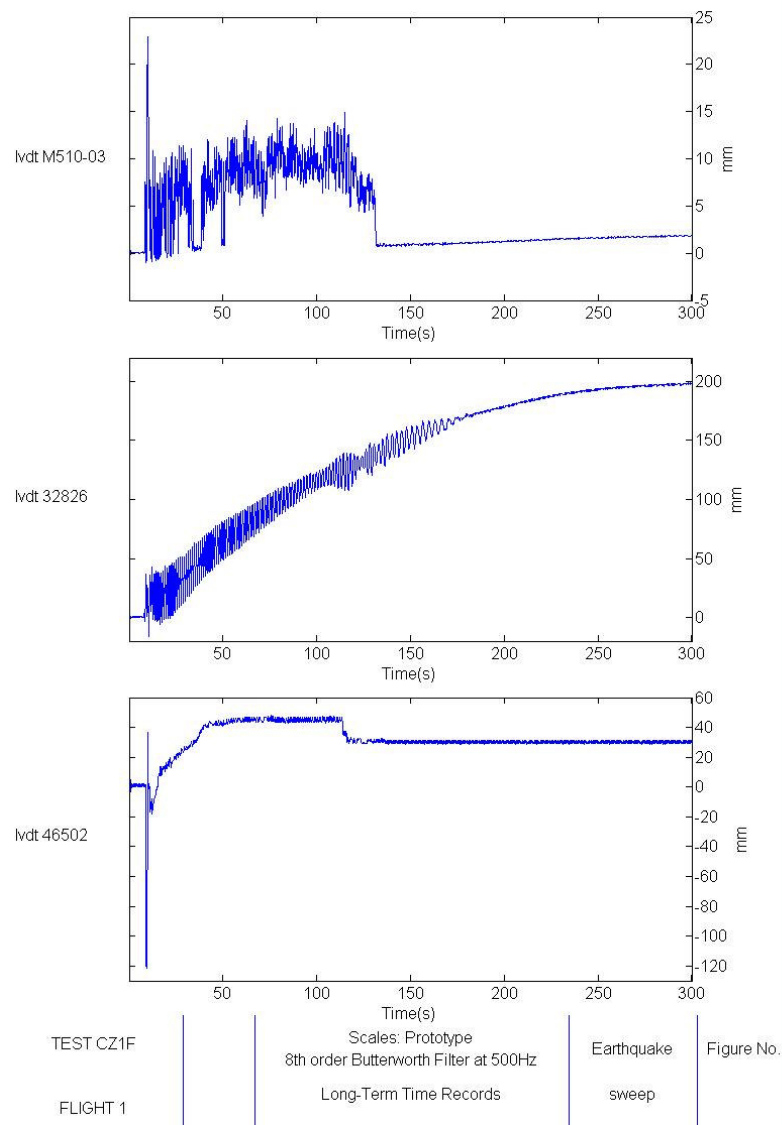
Figure No.

FLIGHT 1

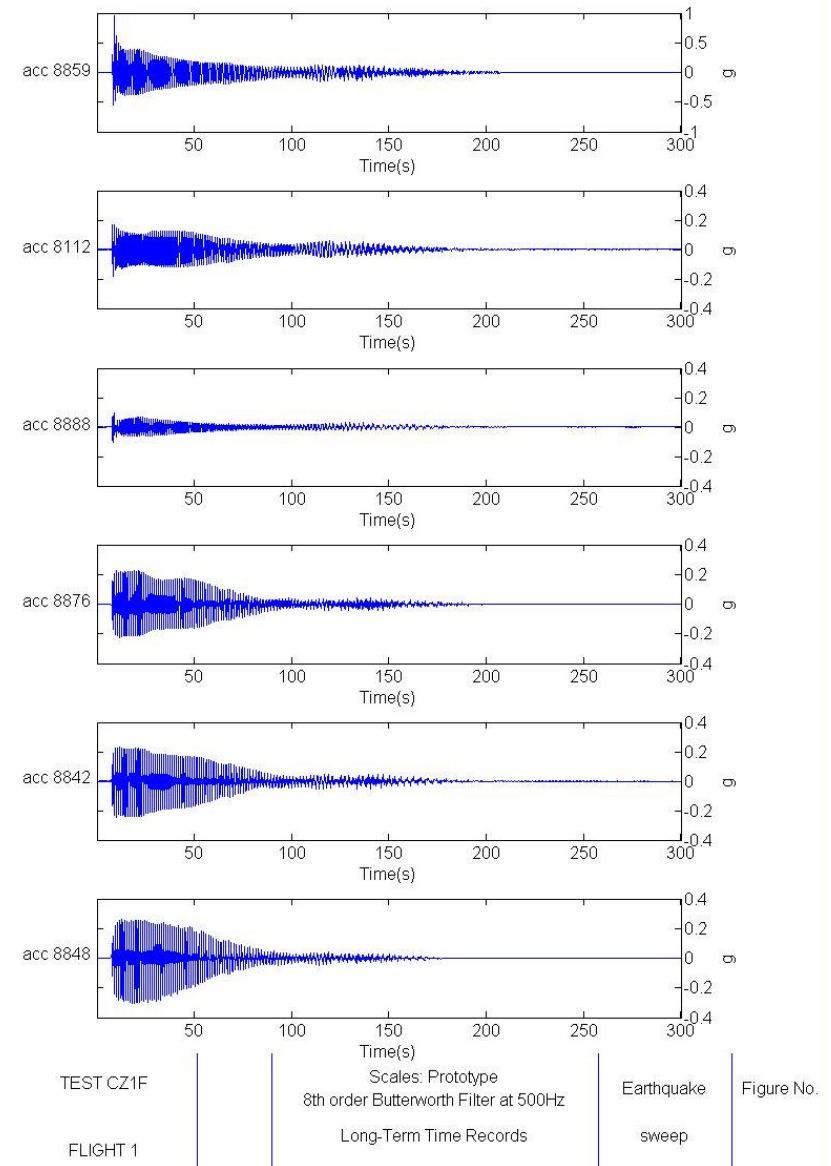
4

## 5.10 Centrifuge test CZ1F, frequency sweep earthquake

### Soil and structural displacements

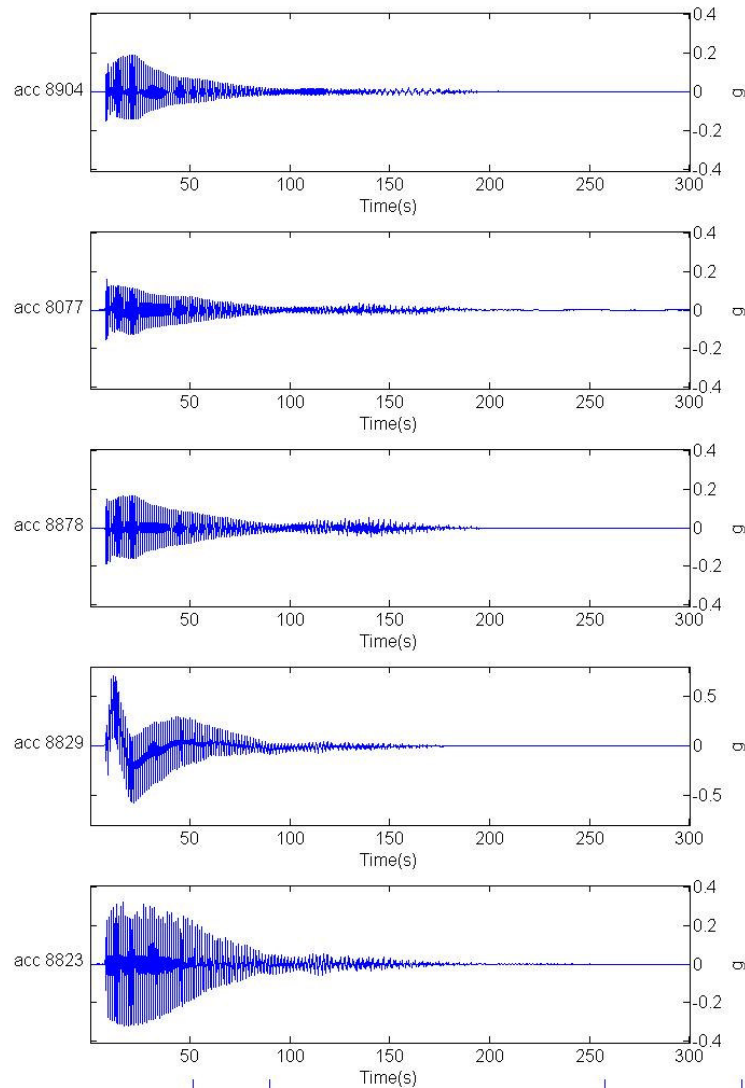


### Accelerations of structure, cemented zone and soil under base of cemented zone





## Free field soil accelerations and box (input) acceleration



TEST CZ1F

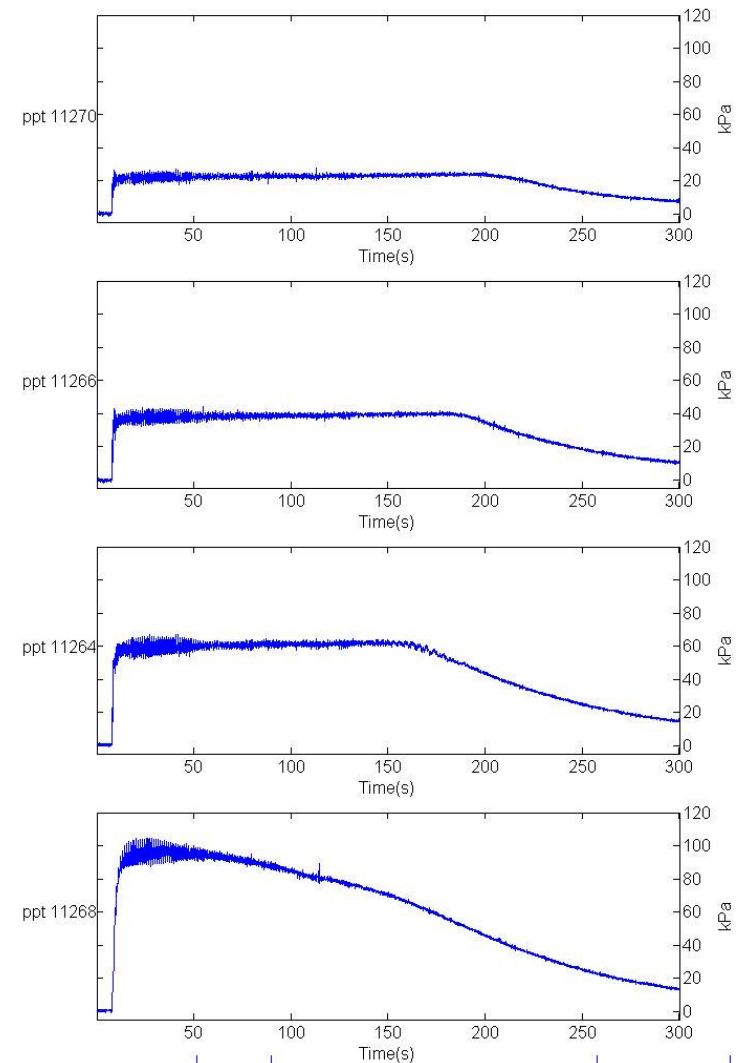
FLIGHT 1

Scales: Prototype  
8th order Butterworth Filter at 500Hz  
Long-Term Time Records

Earthquake  
sweep

Figure No.

## Excess pore pressures at the side and under the base of cemented zone



TEST CZ1F

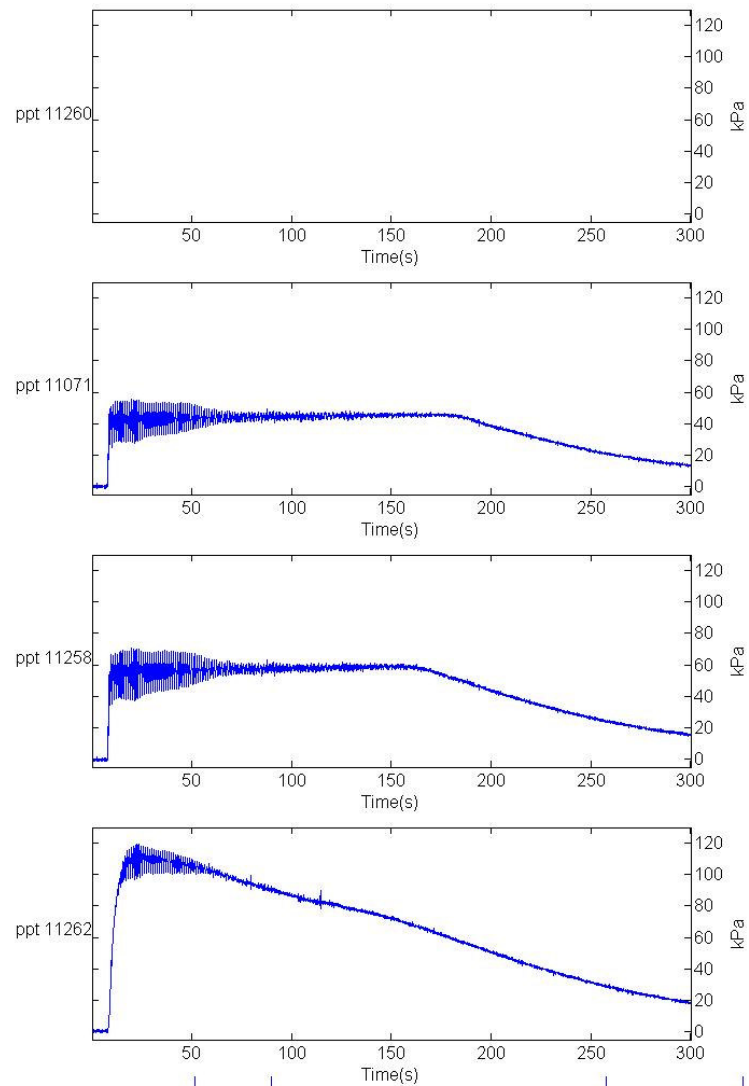
FLIGHT 1

Scales: Prototype  
8th order Butterworth Filter at 500Hz  
Long-Term Time Records

Earthquake  
sweep

Figure No.

## Free field excess pore pressures



TEST CZ1F

FLIGHT 1

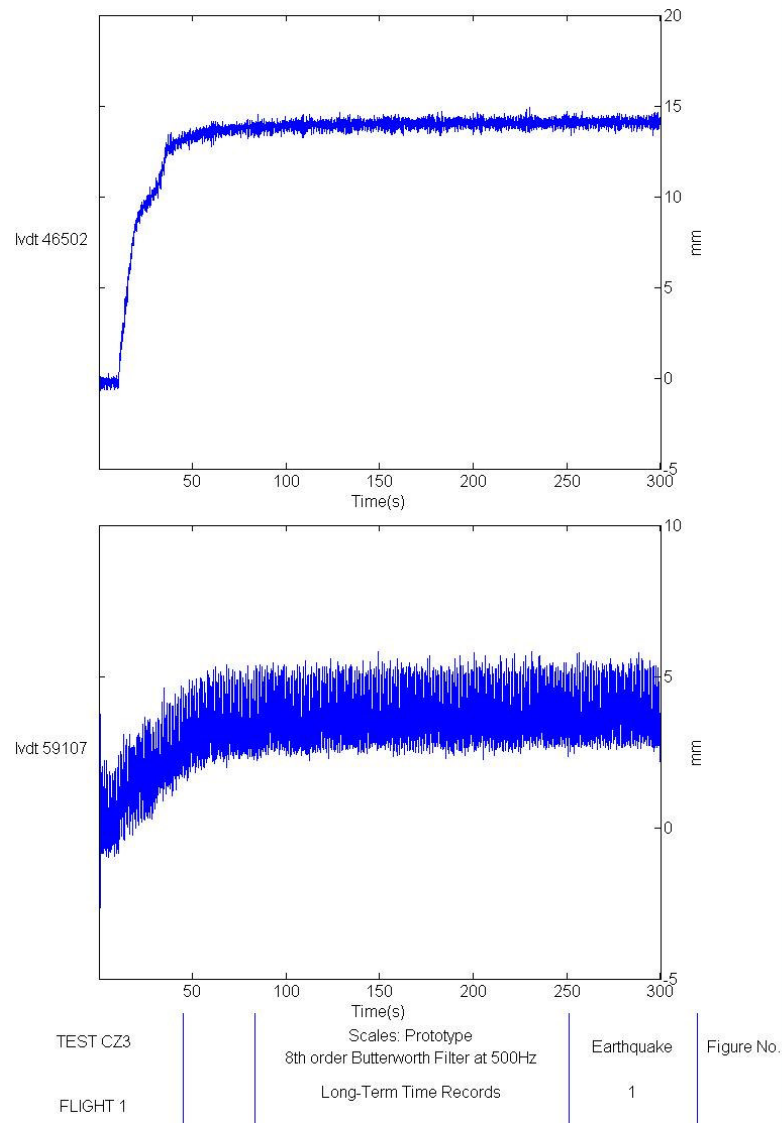
Scales: Prototype  
8th order Butterworth Filter at 500Hz  
Long-Term Time Records

Earthquake  
sweep

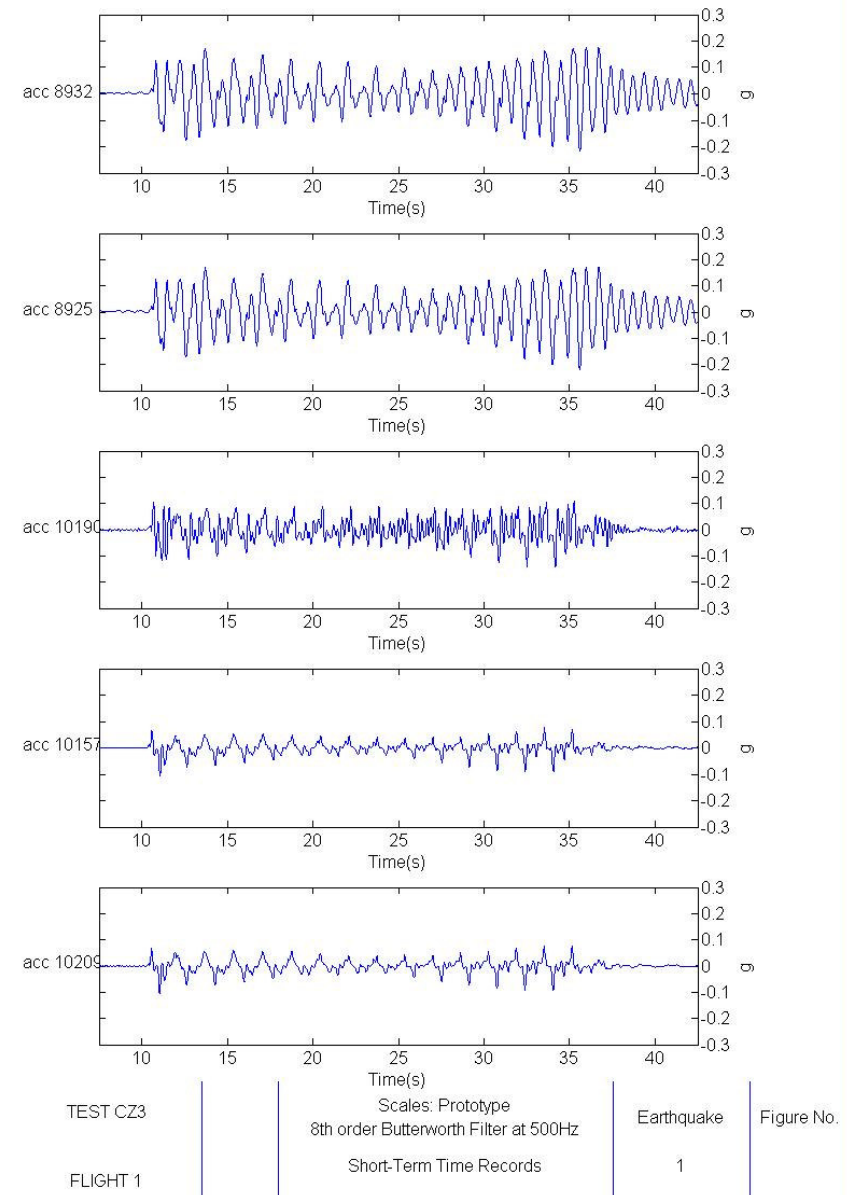
Figure No.

### 5.11 Centrifuge test CZ3, earthquake 1

#### Soil and structural displacements

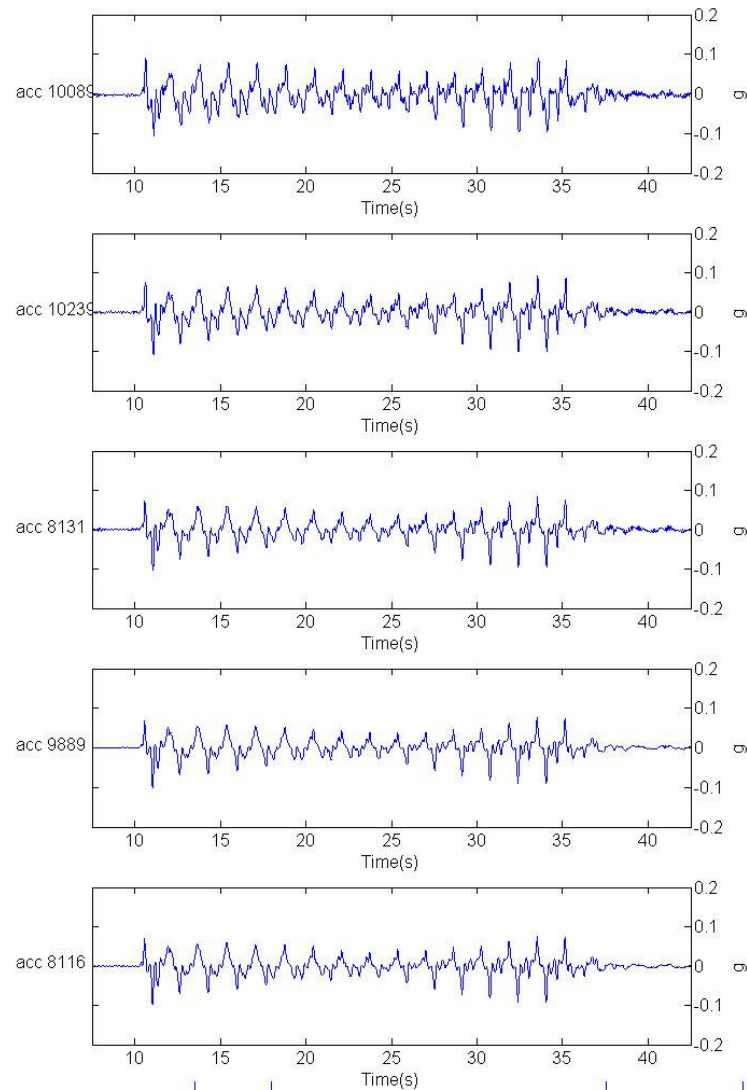


#### Accelerations on structure and under base of cemented zone





## Free field soil accelerations and box (input) acceleration



TEST CZ3

Scales: Prototype  
8th order Butterworth Filter at 500Hz

Earthquake

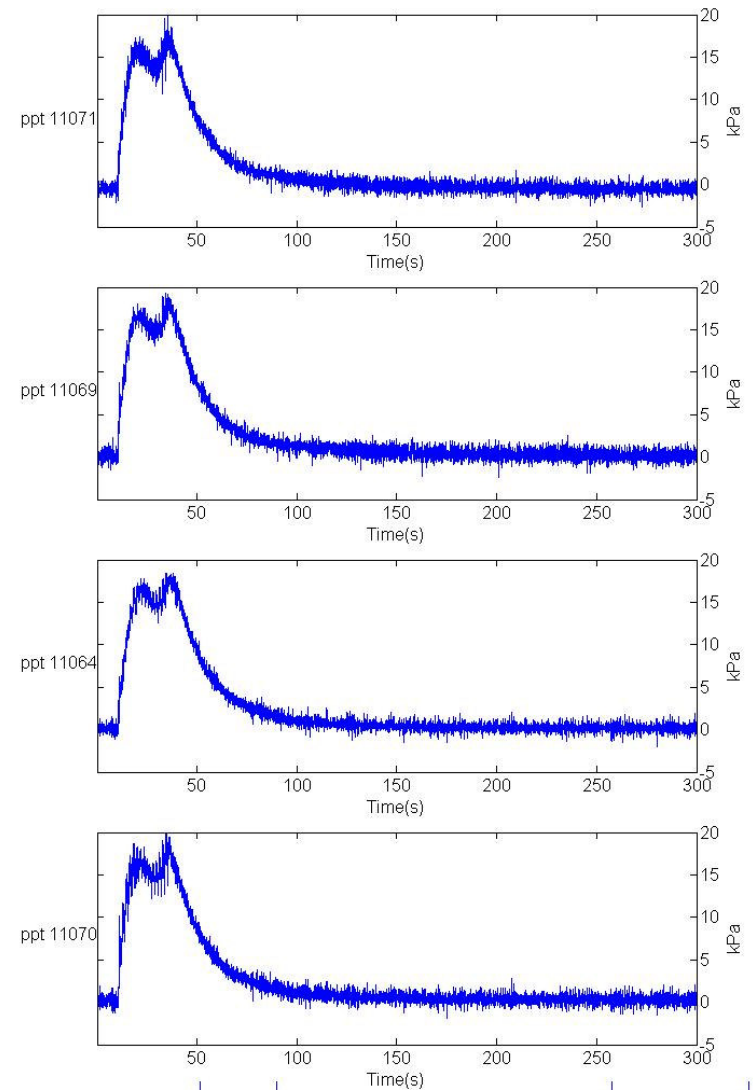
Figure No.

FLIGHT 1

Short-Term Time Records

1

## Excess pore pressures under base of cemented zone



TEST CZ3

Scales: Prototype  
8th order Butterworth Filter at 500Hz

Earthquake

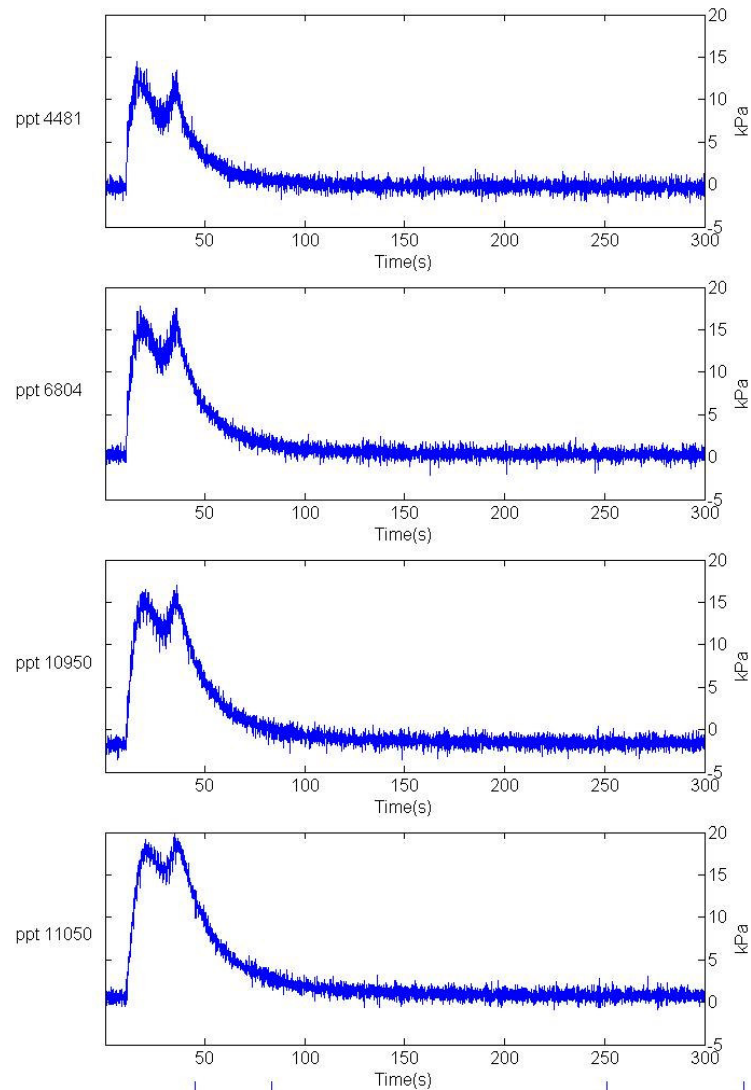
Figure No.

FLIGHT 1

Long-Term Time Records

1

## Free field excess pore pressures



TEST CZ3

Scales: Prototype  
8th order Butterworth Filter at 500Hz

Earthquake

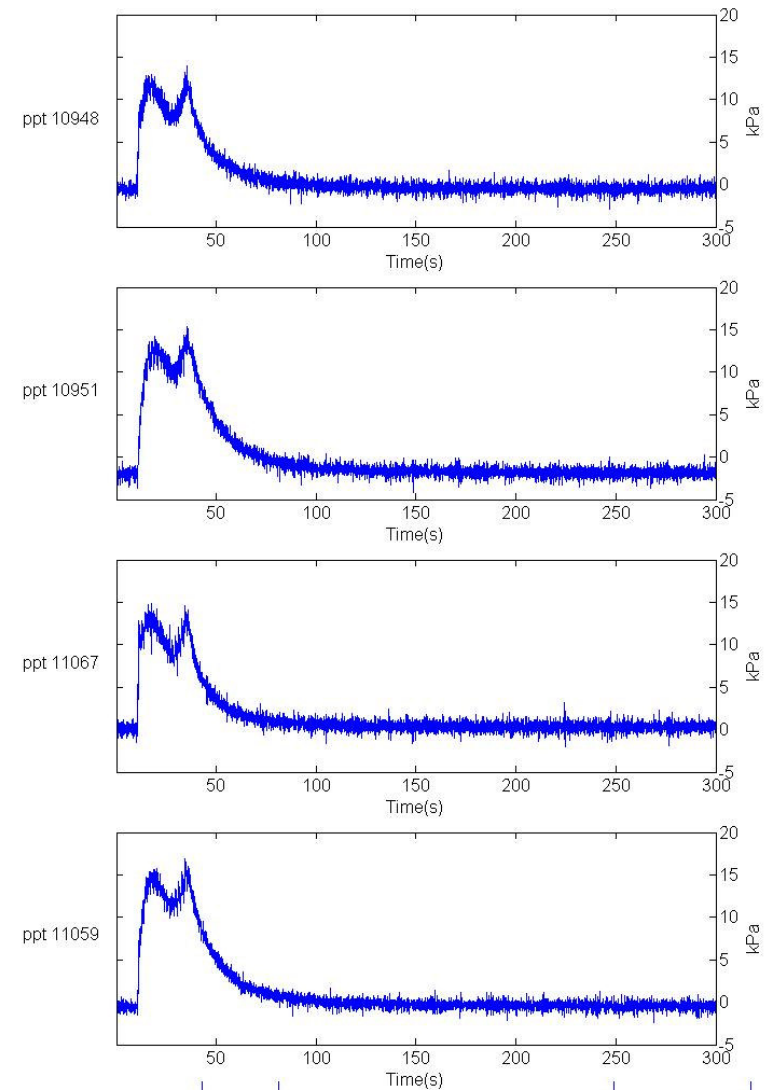
Figure No.

FLIGHT 1

Long-Term Time Records

1

## Excess pore pressures at side of cemented zone



TEST CZ3

Scales: Prototype  
8th order Butterworth Filter at 500Hz

Earthquake

Figure No.

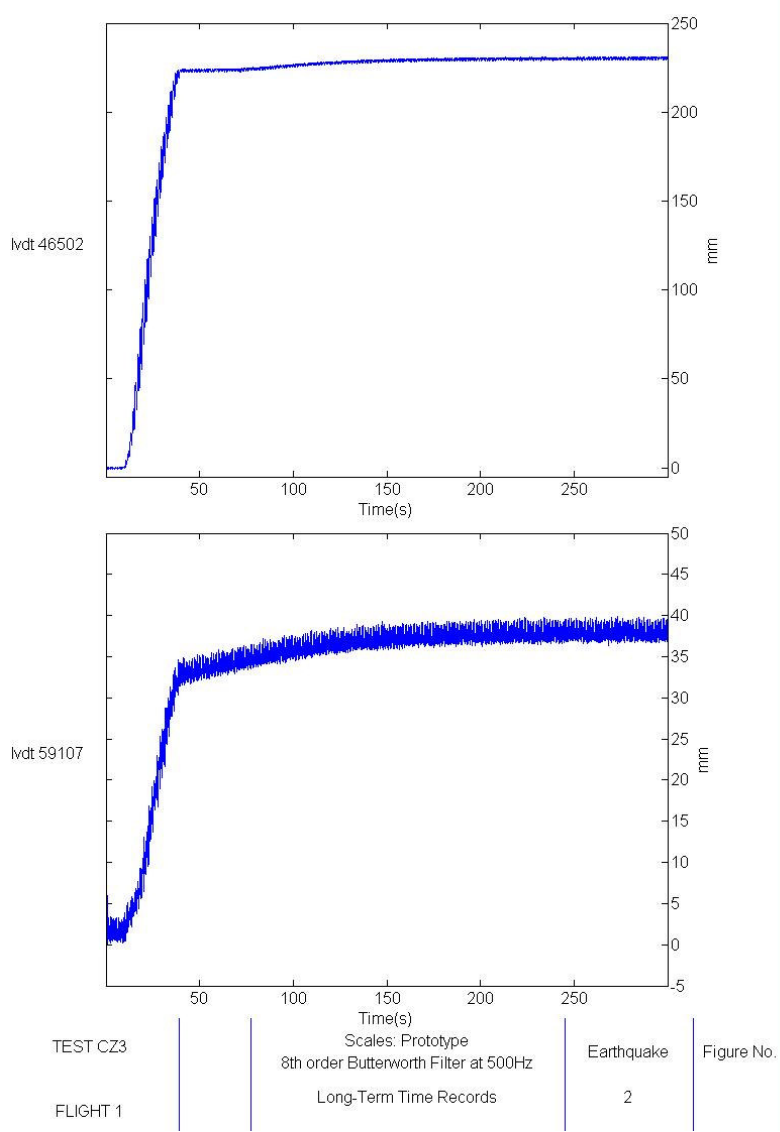
FLIGHT 1

Long-Term Time Records

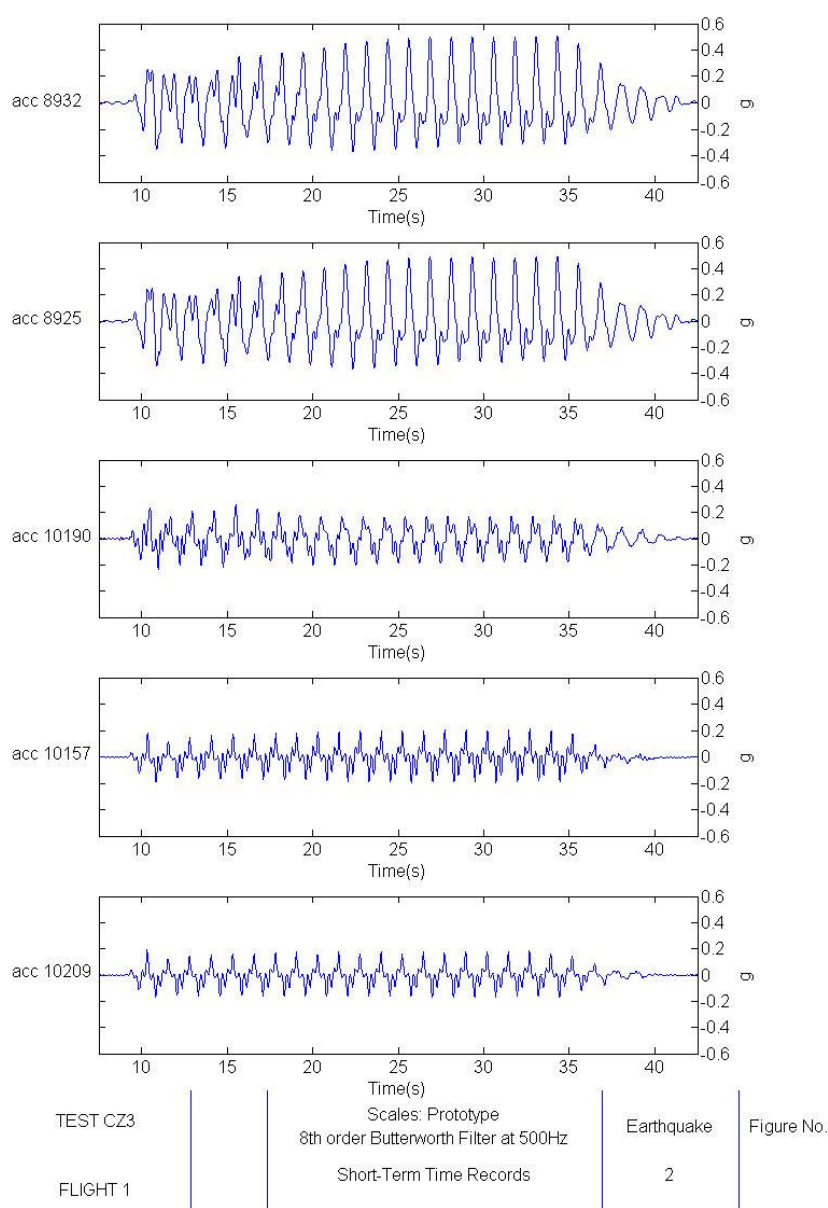
1

5.12 Centrifuge test CZ3, earthquake 2

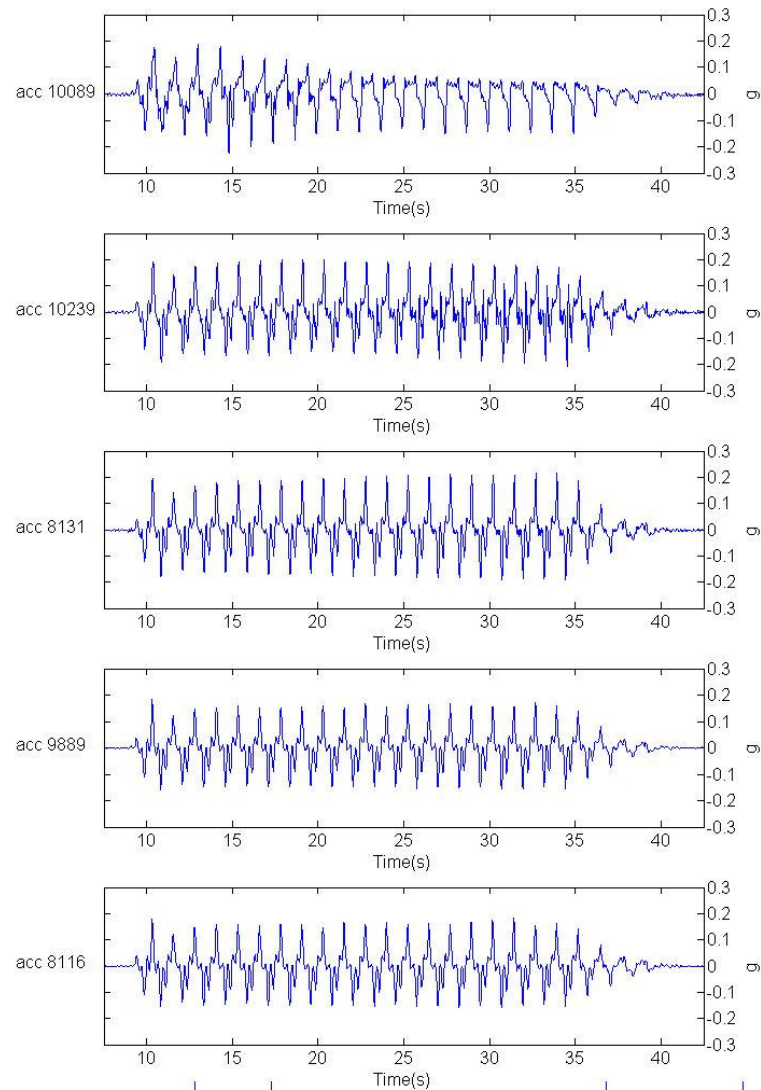
Soil and structural displacements



Accelerations on structure and under base of cemented zone



## Free field soil accelerations and box (input) acceleration



TEST CZ3

Scales: Prototype  
8th order Butterworth Filter at 500Hz

Earthquake

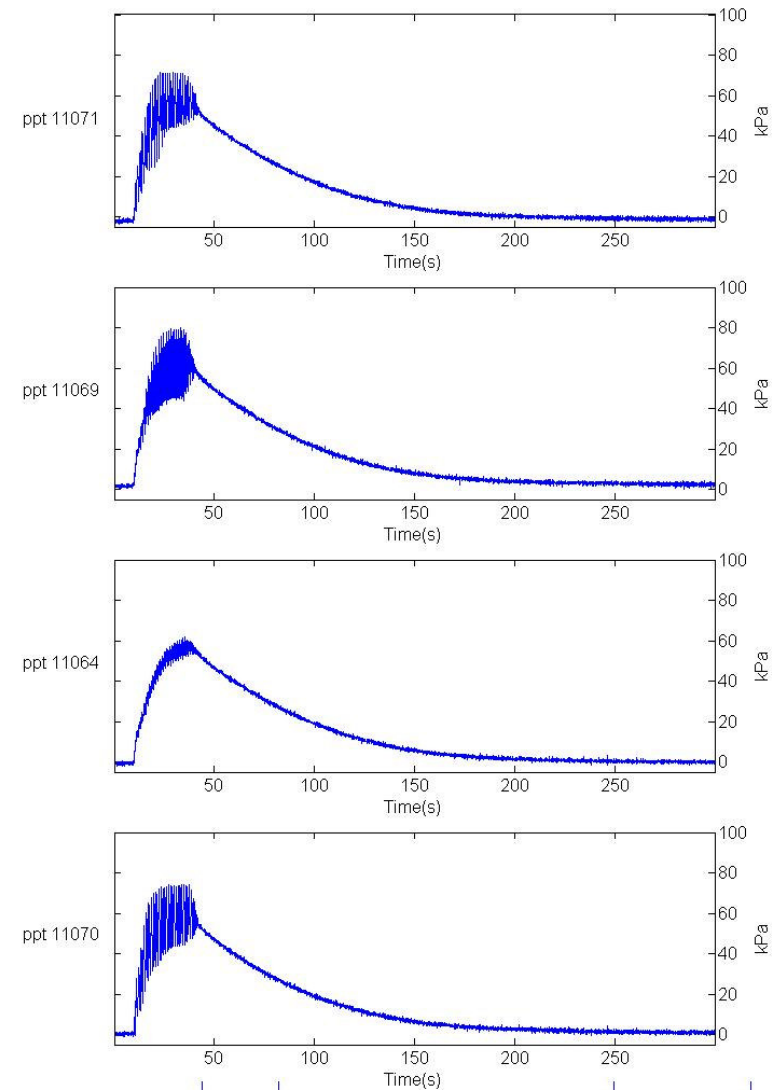
Figure No.

FLIGHT 1

Short-Term Time Records

2

## Excess pore pressures under base of cemented zone



TEST CZ3

Scales: Prototype  
8th order Butterworth Filter at 500Hz

Earthquake

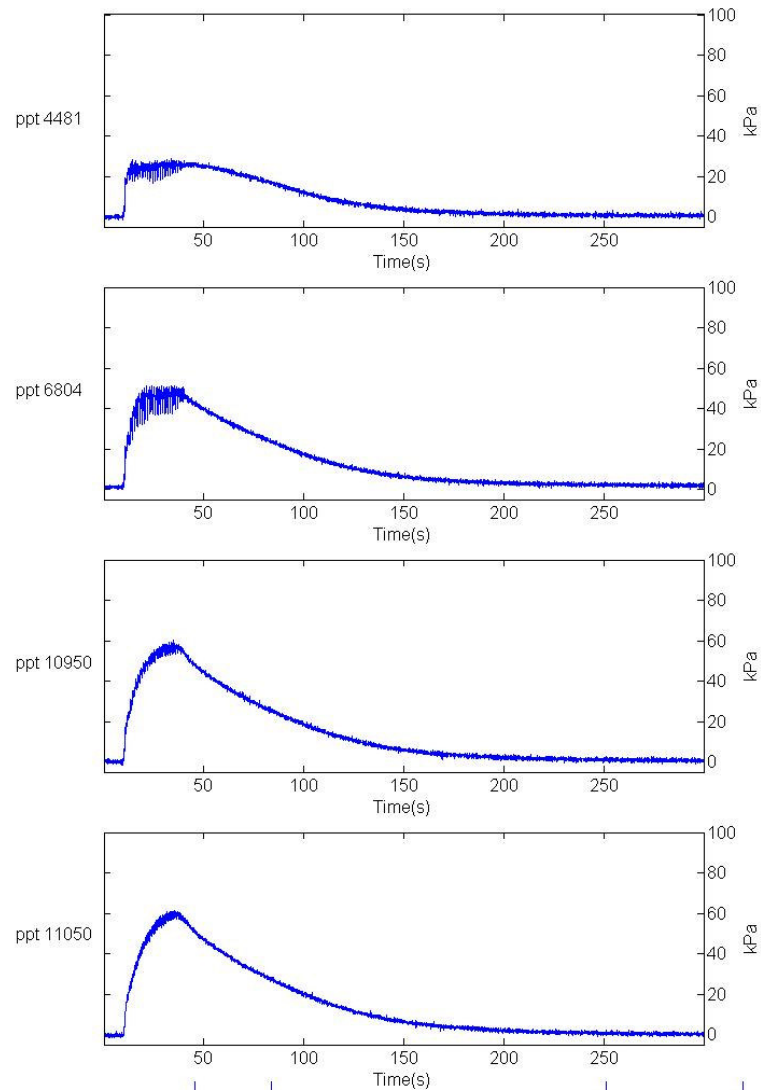
Figure No.

FLIGHT 1

Long-Term Time Records

2

## Free field excess pore pressures



TEST CZ3

Scales: Prototype  
8th order Butterworth Filter at 500Hz

Earthquake

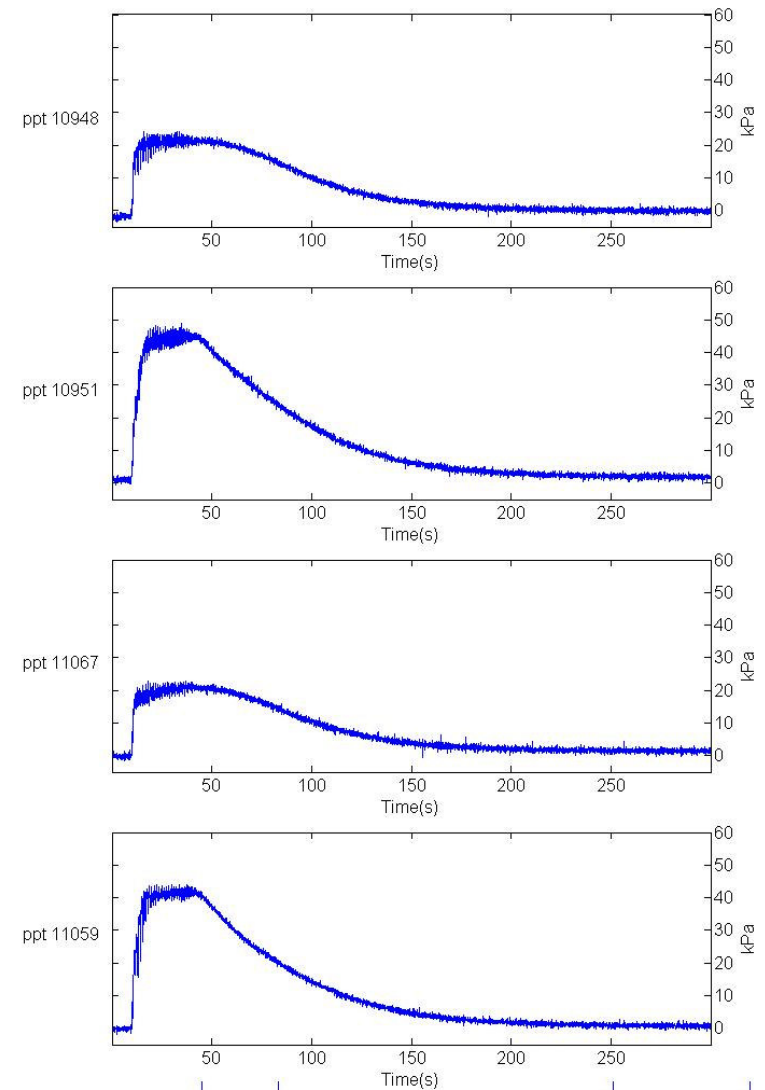
Figure No.

FLIGHT 1

Long-Term Time Records

2

## Excess pore pressures at side of cemented zone



TEST CZ3

Scales: Prototype  
8th order Butterworth Filter at 500Hz

Earthquake

Figure No.

FLIGHT 1

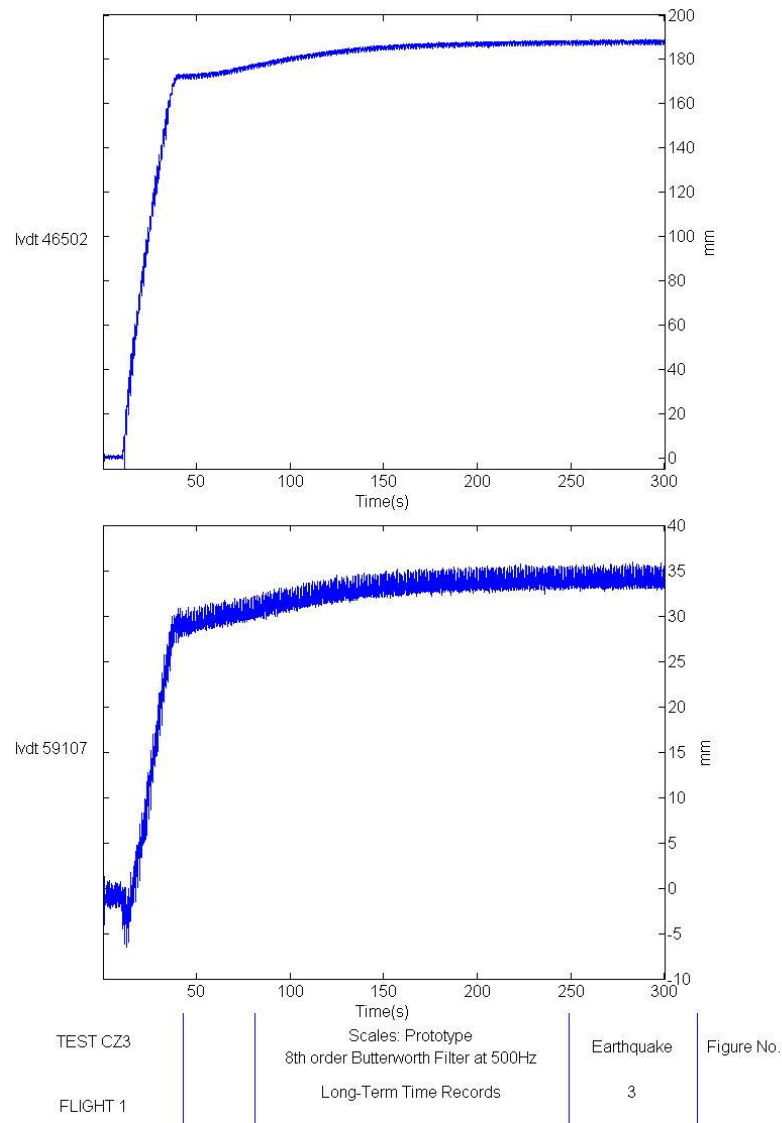
Long-Term Time Records

2

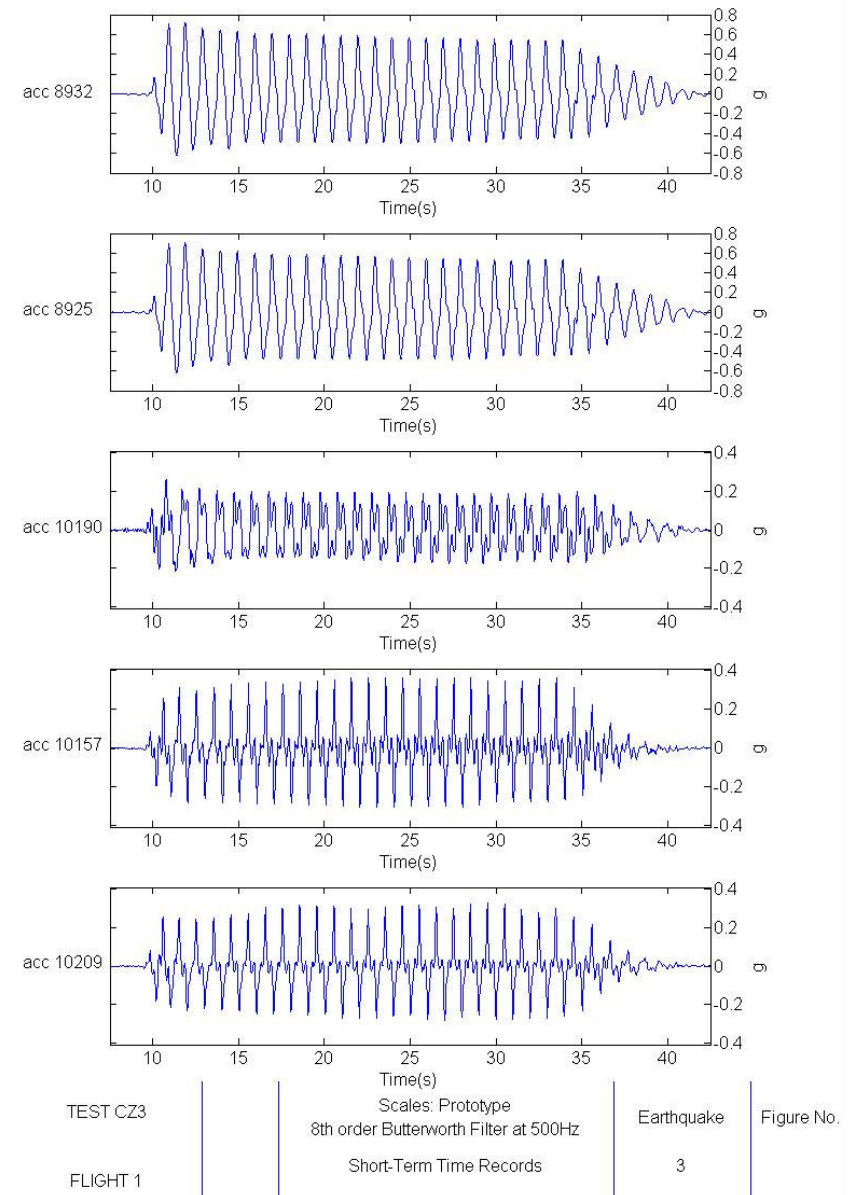


### 5.13 Centrifuge test CZ3, earthquake 3

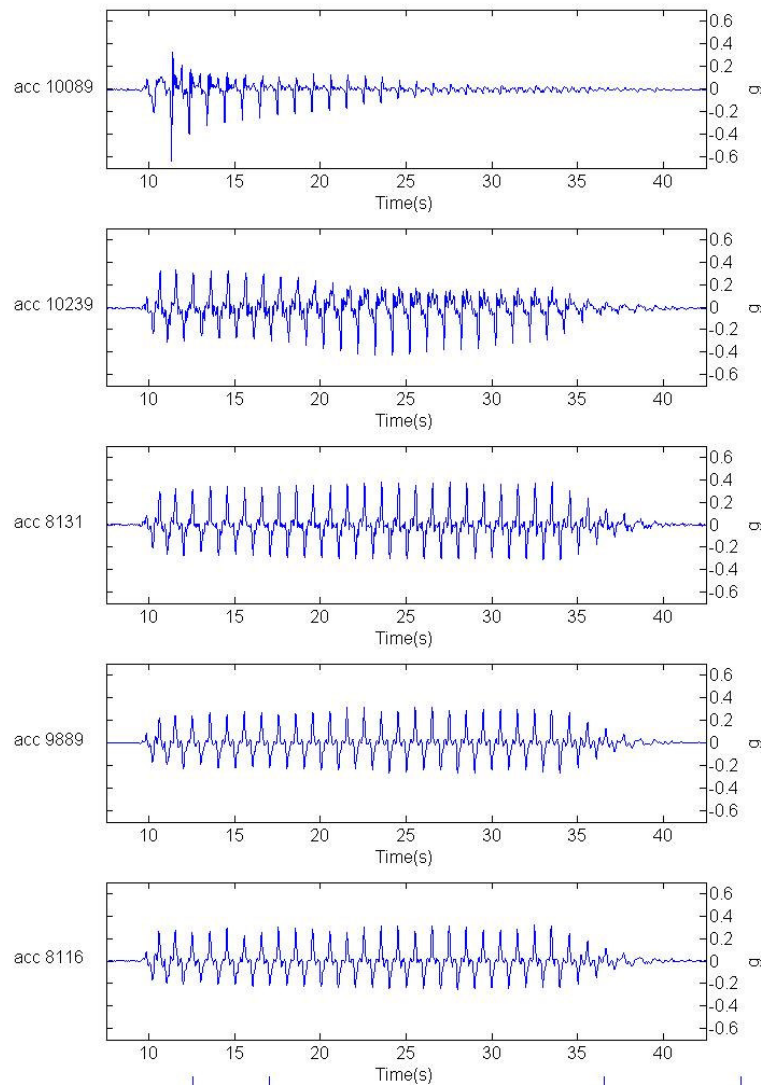
#### Soil and structural displacements



#### Accelerations on structure and under base of cemented zone



## Free field soil accelerations and box (input) acceleration



TEST CZ3

Scales: Prototype  
8th order Butterworth Filter at 500Hz

Earthquake

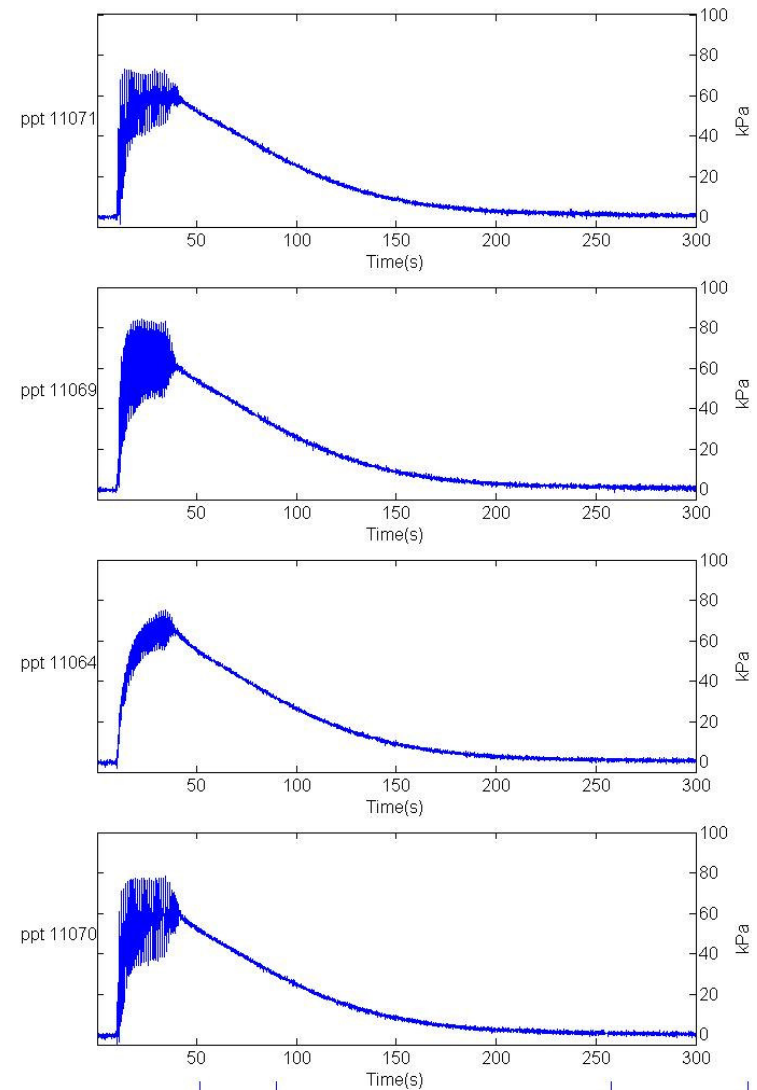
Figure No.

FLIGHT 1

Short-Term Time Records

3

## Excess pore pressures under base of cemented zone



TEST CZ3

Scales: Prototype  
8th order Butterworth Filter at 500Hz

Earthquake

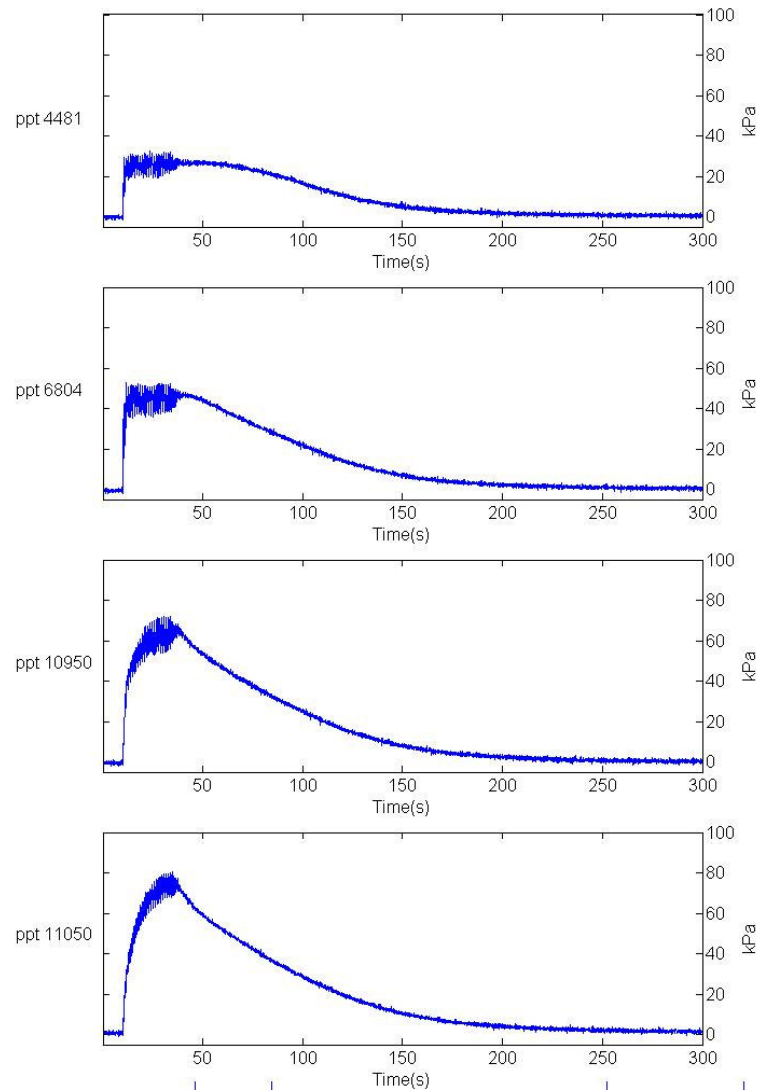
Figure No.

FLIGHT 1

Long-Term Time Records

3

## Free field excess pore pressures



TEST CZ3

Scales: Prototype  
8th order Butterworth Filter at 500Hz

Earthquake

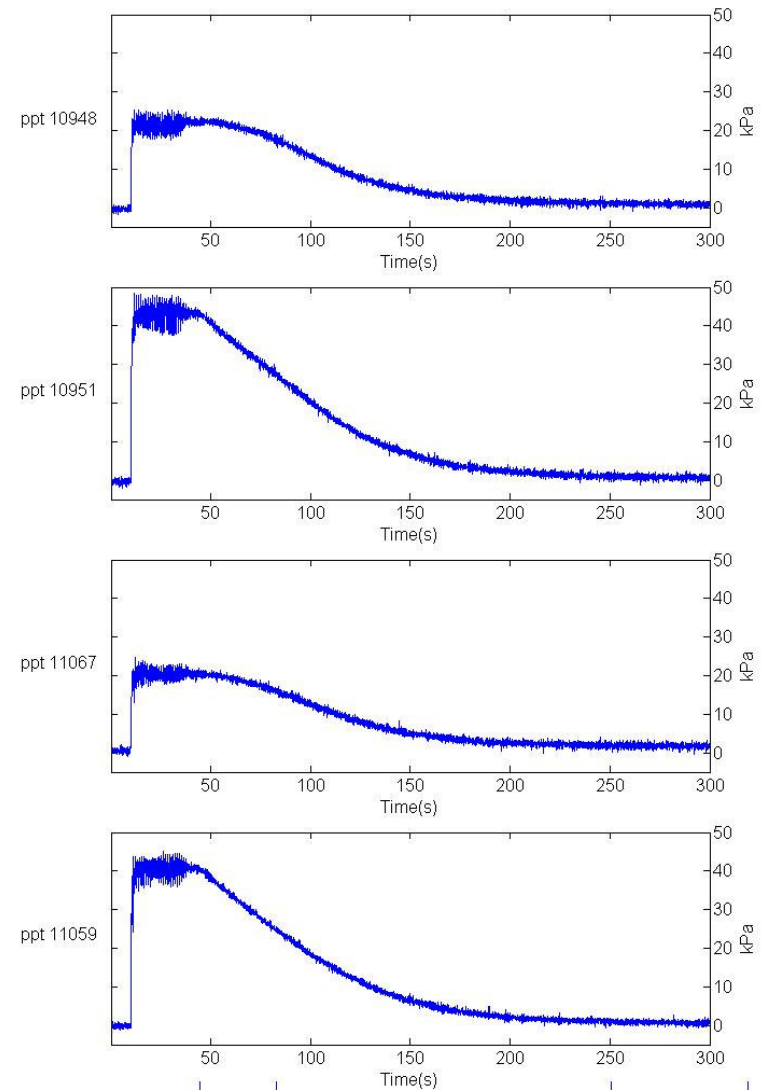
Figure No.

FLIGHT 1

Long-Term Time Records

3

## Excess pore pressures at side of cemented zone



TEST CZ3

Scales: Prototype  
8th order Butterworth Filter at 500Hz

Earthquake

Figure No.

FLIGHT 1

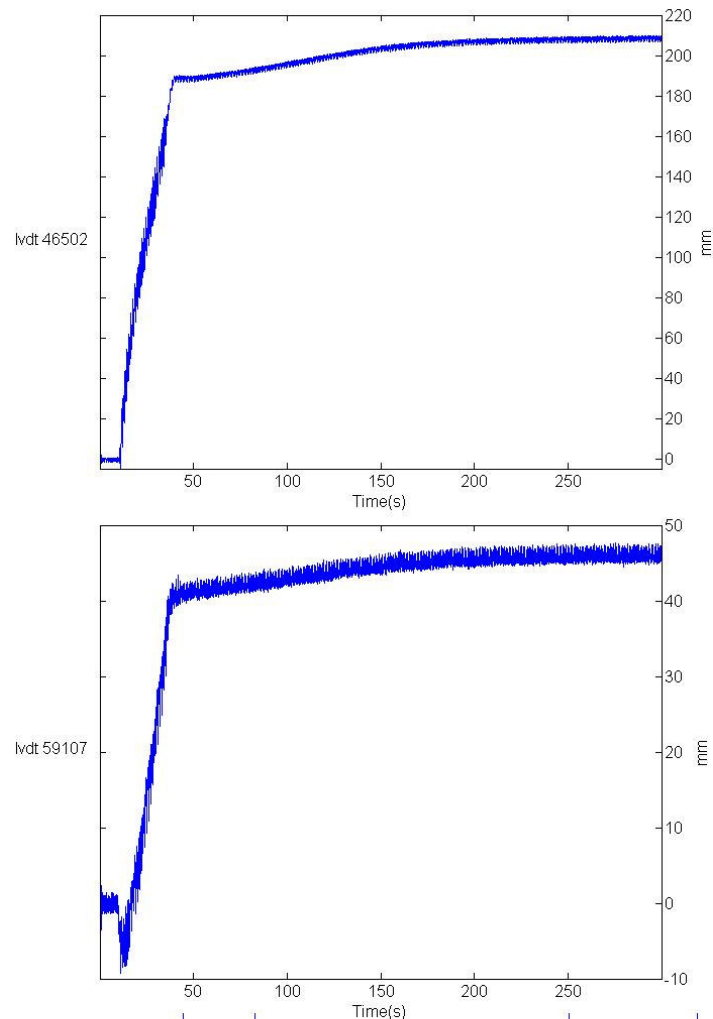
Long-Term Time Records

3



### 5.14 Centrifuge test CZ3, earthquake 4

#### Soil and structural displacements



TEST CZ3

Scales: Prototype  
8th order Butterworth Filter at 500Hz

Earthquake

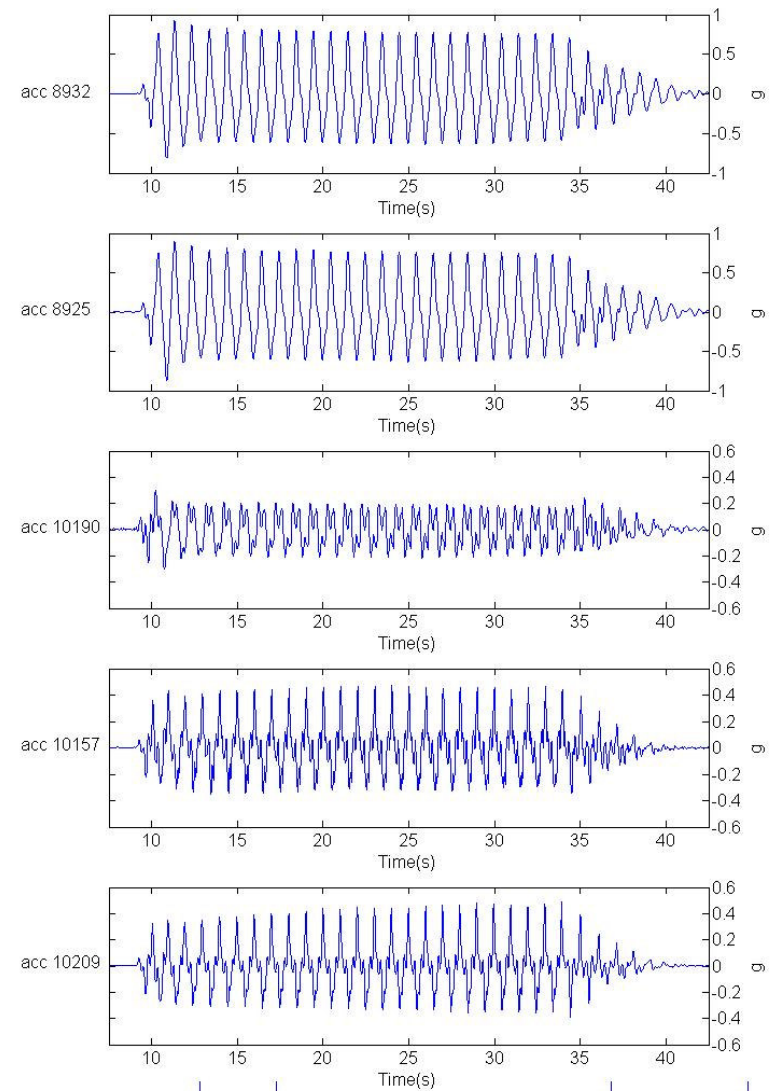
Figure No.

FLIGHT 1

Long-Term Time Records

4

#### Accelerations on structure and under base of cemented zone



TEST CZ3

Scales: Prototype  
8th order Butterworth Filter at 500Hz

Earthquake

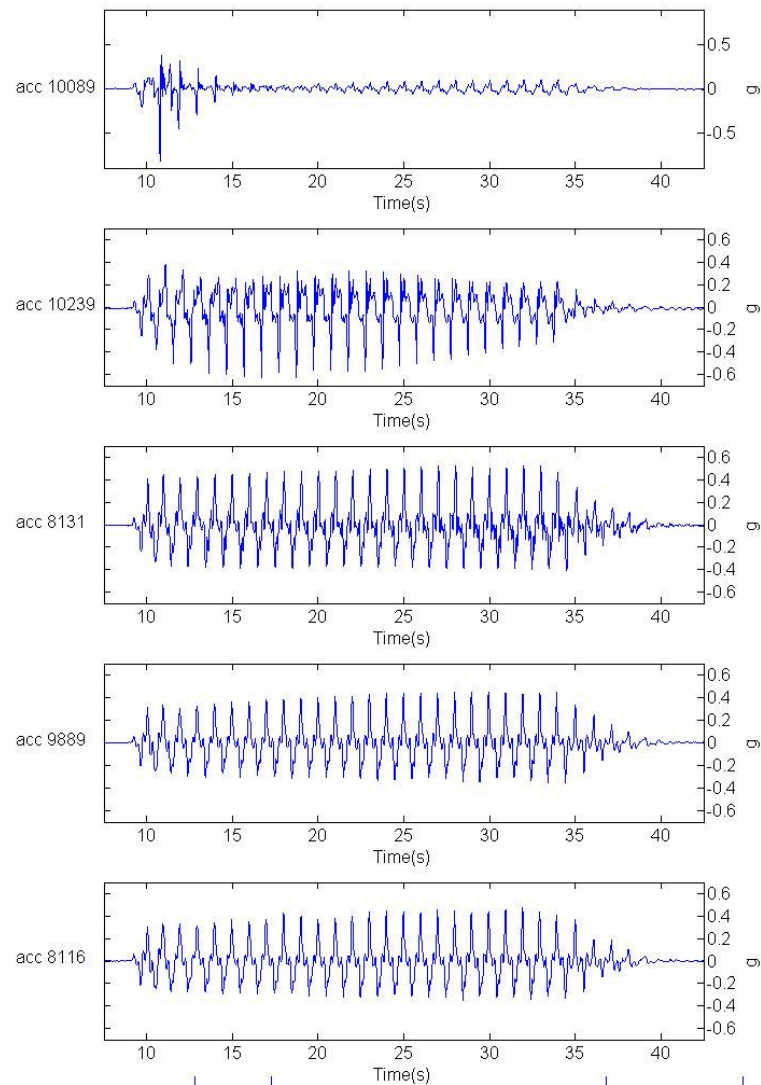
Figure No.

FLIGHT 1

Short-Term Time Records

4

## Free field soil accelerations and box (input) acceleration



TEST CZ3

Scales: Prototype  
8th order Butterworth Filter at 500Hz

Earthquake

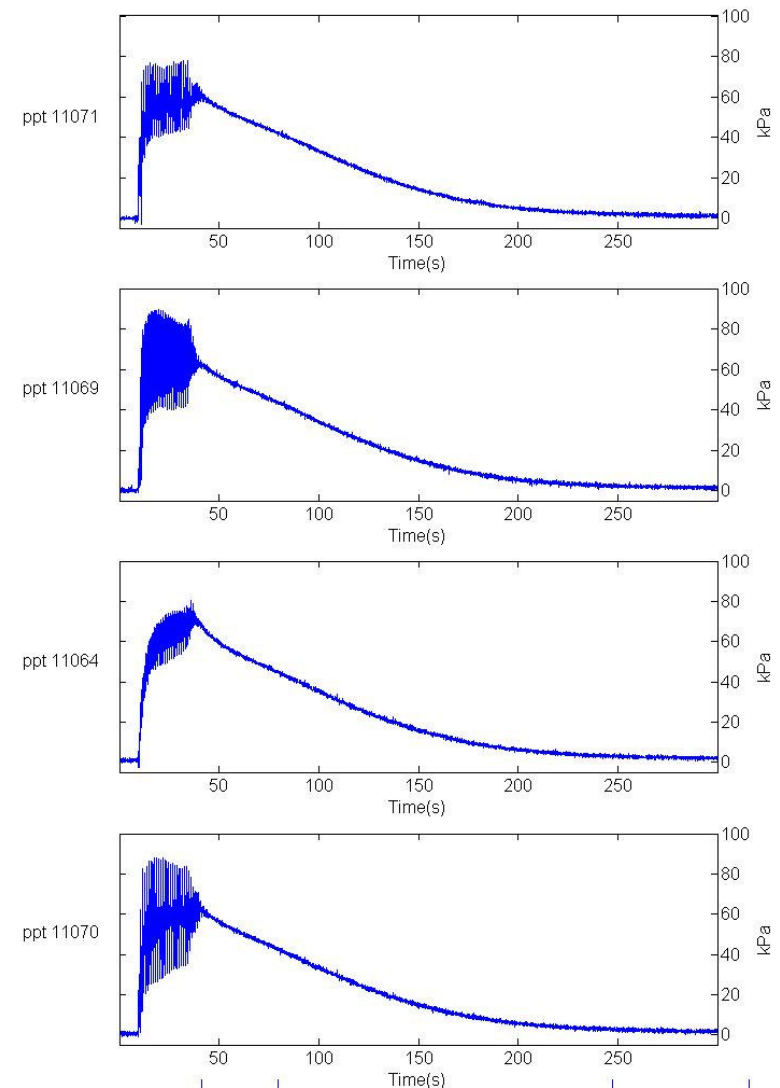
Figure No.

FLIGHT 1

Short-Term Time Records

4

## Excess pore pressures under base of cemented zone



TEST CZ3

Scales: Prototype  
8th order Butterworth Filter at 500Hz

Earthquake

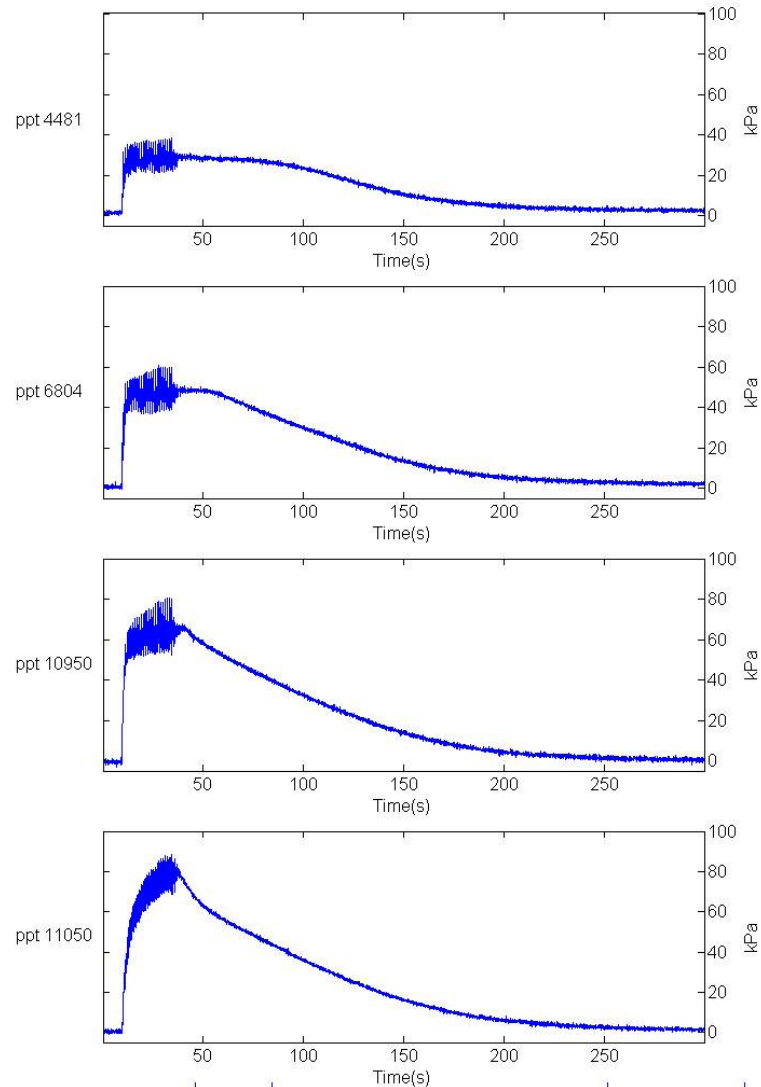
Figure No.

FLIGHT 1

Long-Term Time Records

4

## Free field excess pore pressures



TEST CZ3

Scales: Prototype  
8th order Butterworth Filter at 500Hz

Earthquake

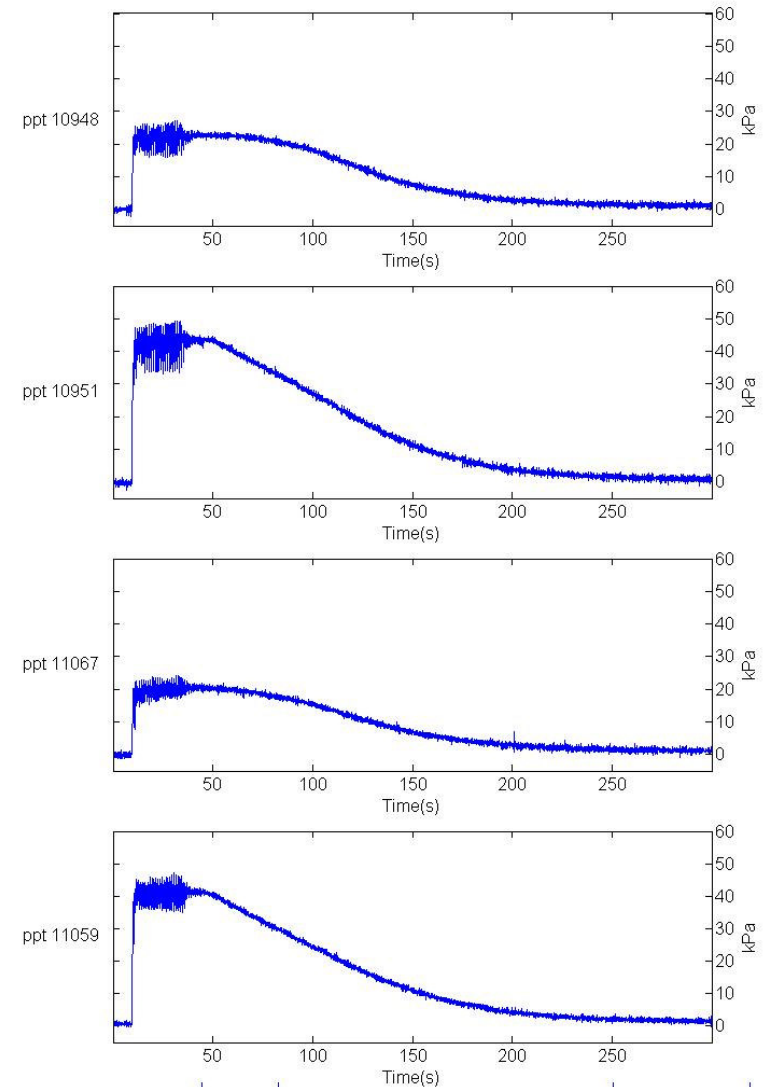
Figure No.

FLIGHT 1

Long-Term Time Records

4

## Excess pore pressures at side of cemented zone



TEST CZ3

Scales: Prototype  
8th order Butterworth Filter at 500Hz

Earthquake

Figure No.

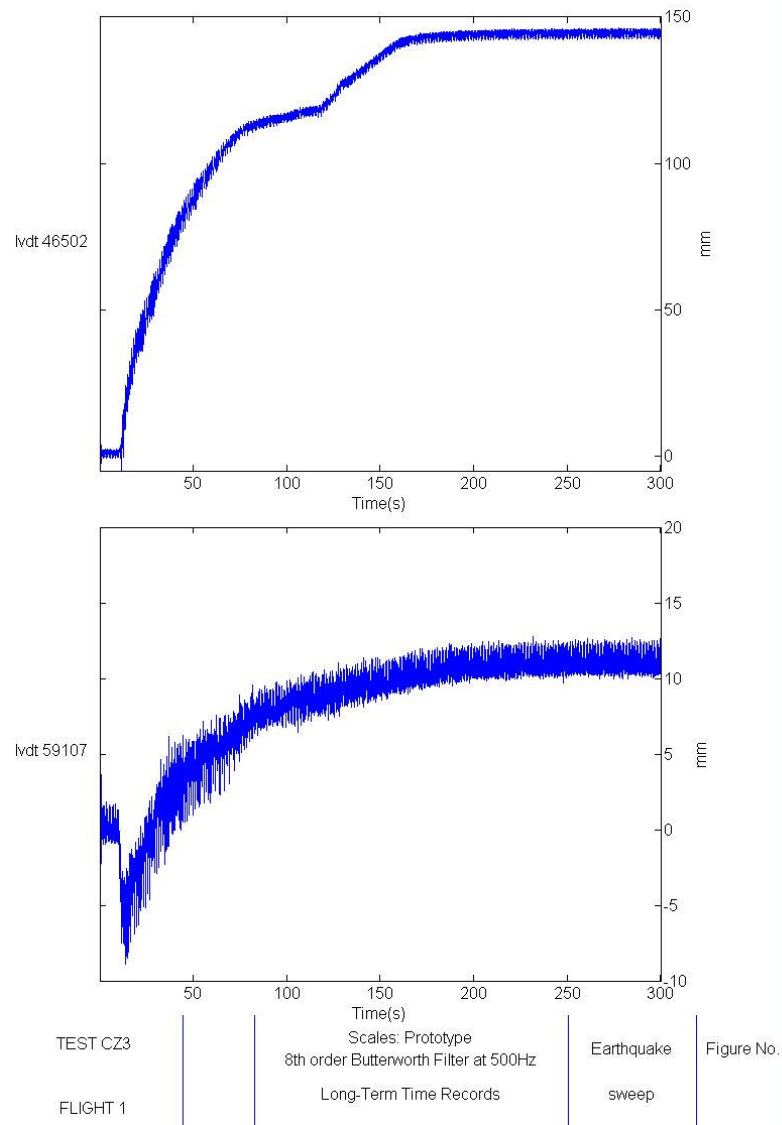
FLIGHT 1

Long-Term Time Records

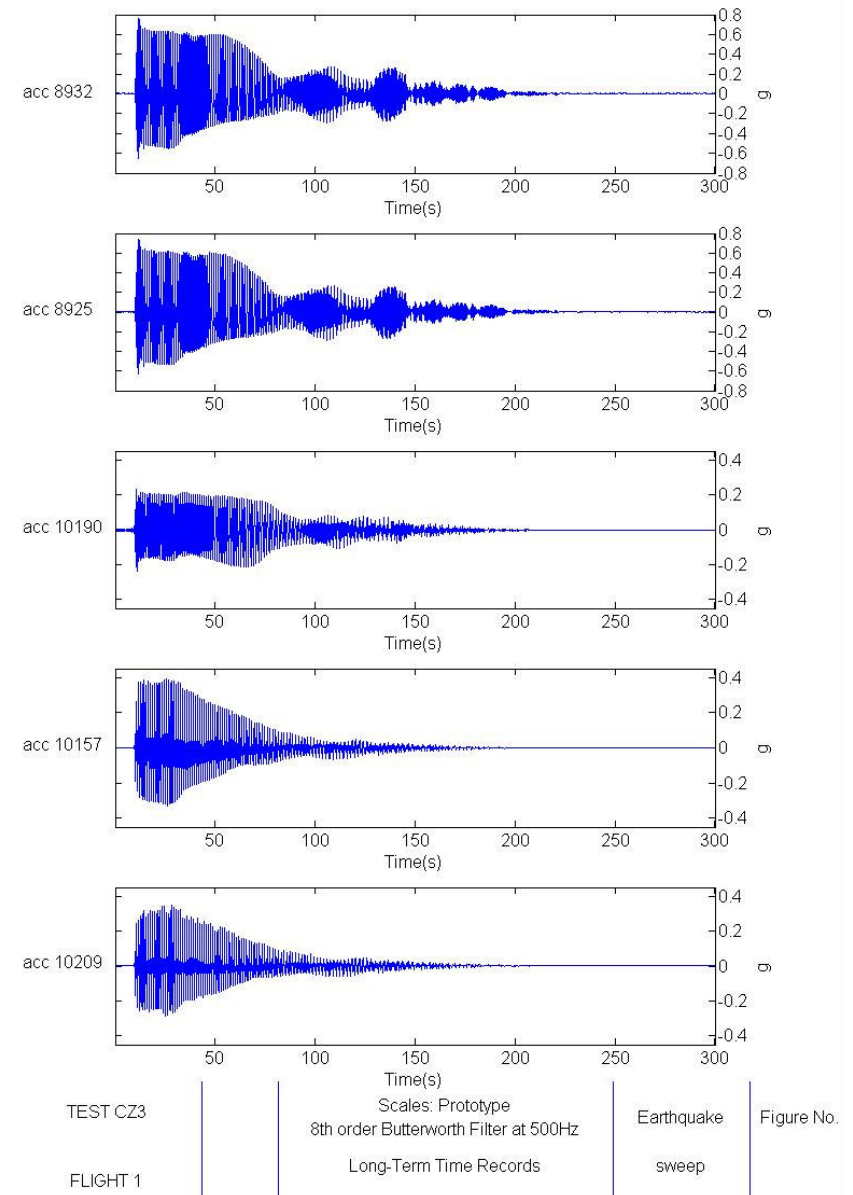
4

### 5.15 Centrifuge test CZ3, frequency sweep earthquake

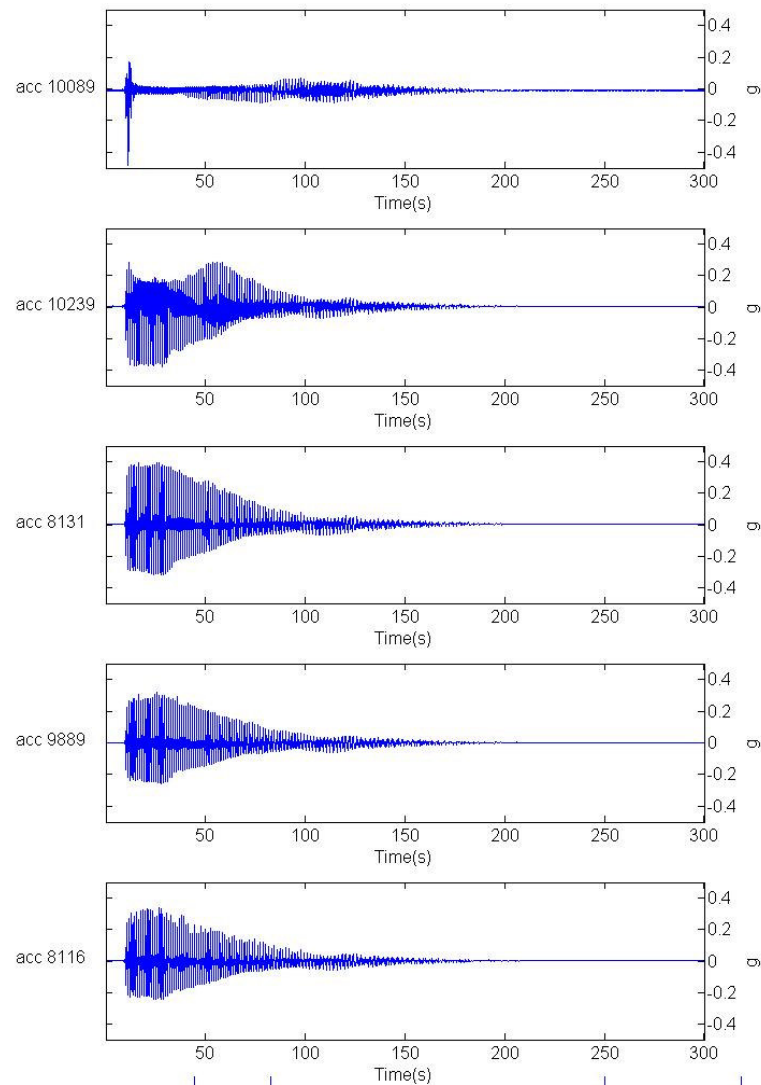
#### Soil and structural displacements



#### Accelerations on structure and under base of cemented zone



Free field soil accelerations and box (input) acceleration



TEST CZ3

Scales: Prototype  
8th order Butterworth Filter at 500Hz

Earthquake

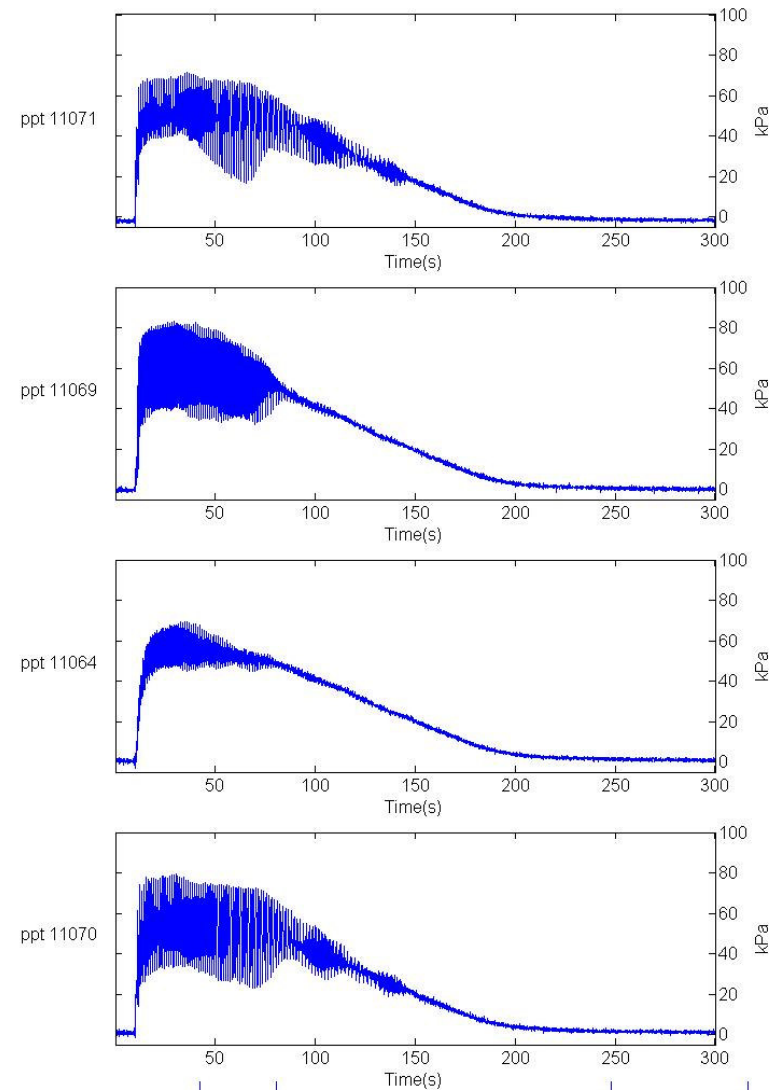
Figure No.

FLIGHT 1

Long-Term Time Records

sweep

Excess pore pressures under base of cemented zone



TEST CZ3

Scales: Prototype  
8th order Butterworth Filter at 500Hz

Earthquake

Figure No.

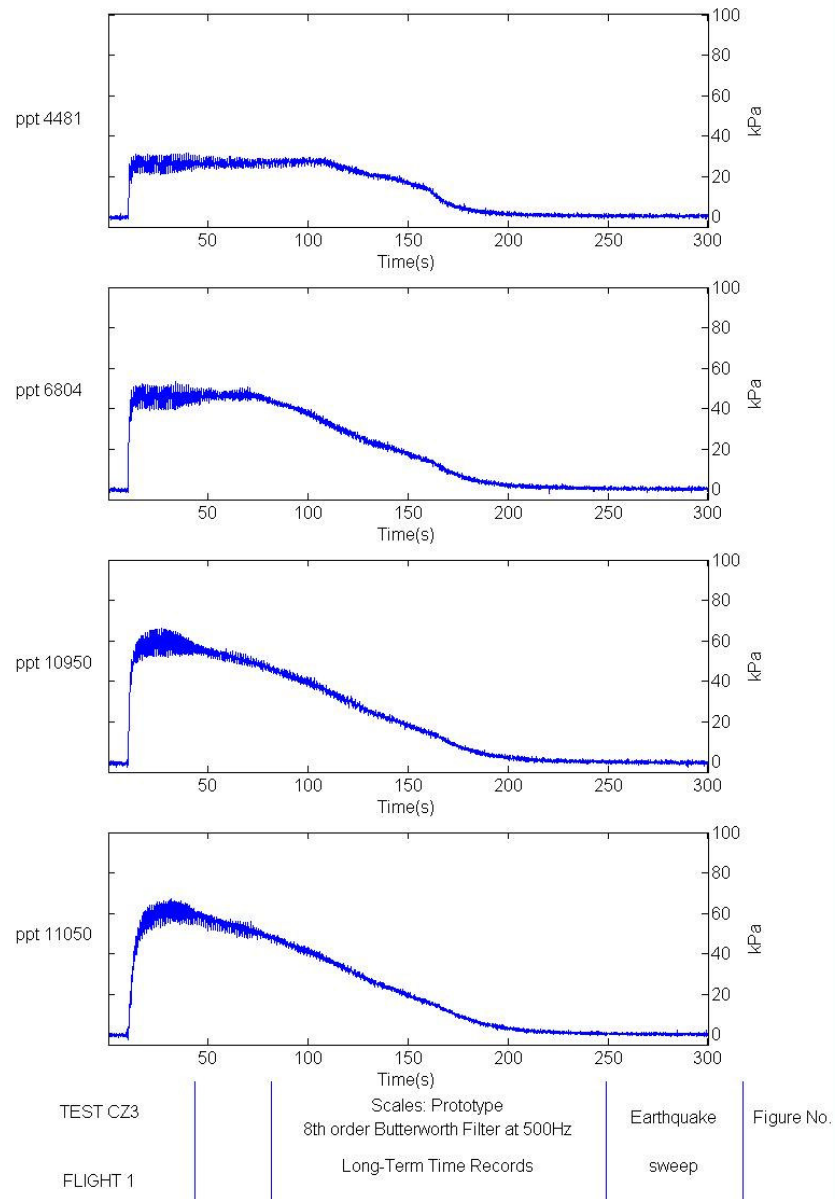
FLIGHT 1

Long-Term Time Records

sweep



## Free field excess pore pressures



## Excess pore pressures at side of cemented zone

