Seismic behaviour of Municipal Solid Waste (MSW)- Data report on centrifuge tests IT02, IT03 and IT09

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1 Introduction

Seismic behaviour of landfills is a major concern as landfill failures can lead to ground water contamination and other geo-environmental disasters. Study into the seismic behaviour of waste landfills has often been limited to numerical analysis due to the difficulties associated with dealing with real waste in experiments. Hence present understanding of seismic behaviour of MSW landfills is mainly based on parametric studies carried out using numerical packages (i.e SHAKE91) and few recorded earthquakes.

This report presents the development of a generic model waste which can be used in centrifuge experiments to model both the static and dynamic behaviour of MSW. Important physical properties of the model waste such as unit weight, compressibility, shear strength and moisture content were tested and shown to agree well with typical values reported in the literature for the MSW. A series of dynamic centrifuge tests were performed on the model waste, in which the model waste was subjected to several earthquakes of varying intensity and frequency. This model waste was then used in dynamic centrifuge tests to understand the seismic performance of "above *and below ground fill*" type and "*area fill*" type MSW landfills (Thusyanthan 2005).

This data report presents results from dynamic centrifuge tests IT02, IT03 and IT09. The landfills modelled in the dynamic centrifuge test were municipal solid waste (MSW) landfills. Detailed analysis of the data provided in this report is given in Thusyanthan (2005)- Ph.D thesis, University of Cambridge, UK.

2 Modelling municipal solid waste

Municipal Solid Waste (MSW) is usually highly heterogeneous and variable in its content. Thus the use of real MSW in centrifuge experiments has many concerns such as the dependence of centrifuge test results on the source and age of the MSW and hence the question of repeatability. A model waste, whose properties closely match to those of a typical MSW, has been developed using a mixture of peat, E-grade kaolin clay and fraction-E fine sand.

Preliminary development involved producing 3 mixtures (A, B & C). The ratio of peat : clay : sand by weight in mixtures A, B and C were 2:1:1, 1:1:1 and 1:2:1 respectively. Unit weight,

compressibility and shear strength characteristics of the mixtures were experimentally determined. Even though all three mixtures had the potential to be used as model MSW, consideration of easy of handling dominated the choice and mixture B was chosen as the model MSW to be used in centrifuge experiments.

3 Model preparation and testing

3.1 Model IT02

Fig. 1 shows the cross section of centrifuge model IT02. The dynamic centrifuge test on model waste was performed in an equivalent shear beam (ESB) container. The model waste was placed into the container in layers of 50 mm thickness and each layer was compacted by static load to give a compacted unit weight of 9 kN/m^3. Accelerometers (Accs) were placed in each layer as shown in Fig. 1. A miniature air hammer (Ghosh & Madabhushi, 2002), which is capable of inducing small amplitude shear waves, was placed at the base of the container near Acc.1. A linearly variable displacement transducer (LVDT) was mounted on top of the container to measure the settlement of the model waste during swing up and during the test. The depth of the completed model was 200 mm. This represents 10 m of MSW at prototype scale in centrifuge test at 50g.

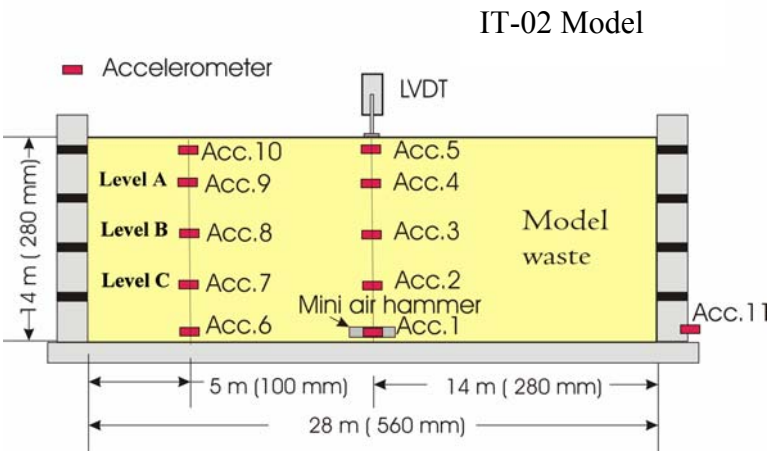


Fig. 1 Cross sections of centrifuge model IT02.

The completed model was swung up to 50g in stages of 10g, 20g and 40g. At 50g, the miniature air hammer was activated for a short period and the accelerometer signals recorded at a sampling frequency of 30 kHz. Following this, seven model earthquakes of varying intensity and magnitude were fired using the SAM earthquake actuator. Table 1 provides details of the simulated earthquakes.

Table 1 Simulated earthquake loadings in test IT02, prototype scale [model scale].

Model Earthquake Number	Driving frequency (Hz)	Duration (s)	Maximum base acceleration-Acc.1(g)
E.1	0.6 [30]	15 [0.3]	0.075 [3.76]
E.2	0.8 [40]	15 [0.3]	0.123 [6.13]
E.3	1 [50]	15 [0.3]	0.178 [8.9]
E.4	1 [50]	15 [0.3]	0.135 [6.79]
E.5	1 [50]	15 [0.3]	0.236 [11.8]
E.6	1 [50]	15 [0.3]	0.284 [14.2]
E.7	1 [50]	25 [0.5]	0.148 [7.41]

3.2 Model IT03

The schematic layout of the landfill model and instrumentation is shown in Fig. 2. At 50g, the centrifuge model simulates a prototype MSW depth of 7 m founded on a 2 m deep sand foundation. The centrifuge model was prepared in stages as described in the previous section.

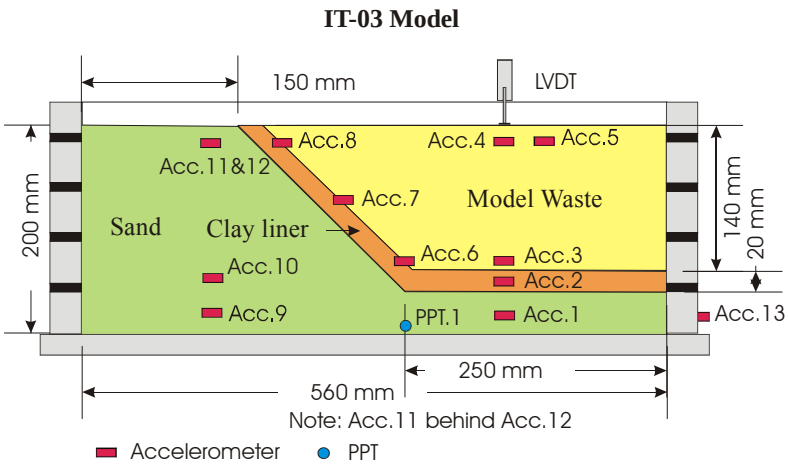
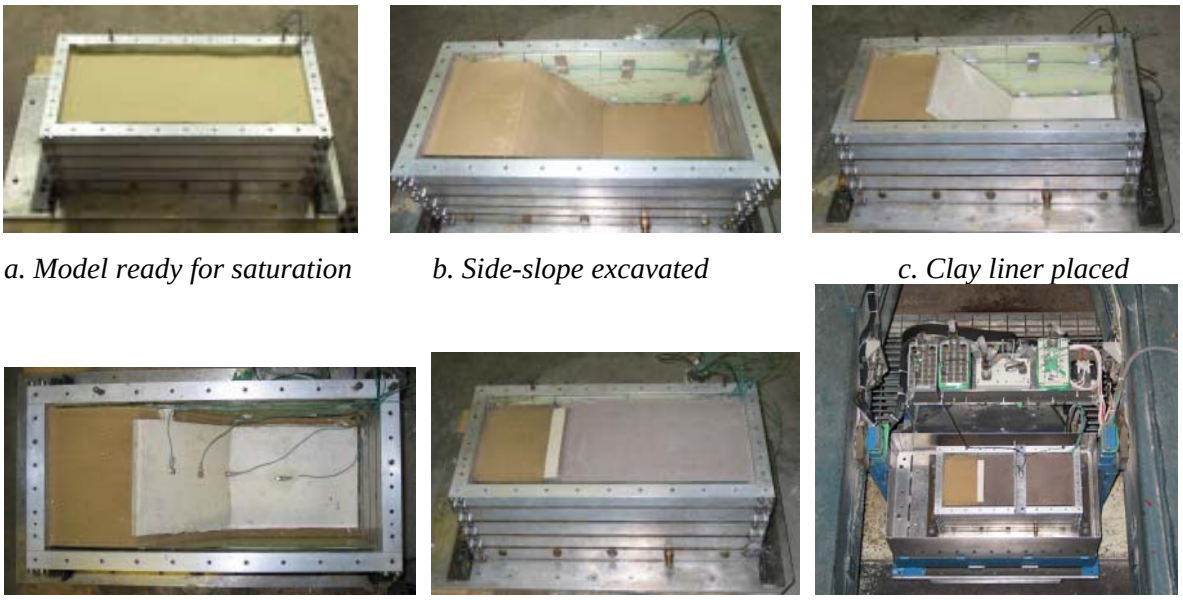


Fig. 2 Cross section of the centrifuge model IT03.

A LVDT was mounted on the top of the container to measure the model waste settlement during swing-up (increase of centrifuge acceleration) and during the earthquake loading. Fig. 3(a) to (e) shows the model preparation sequence.



a. Model ready for saturation *b. Side-slope excavated* *c. Clay liner placed*

d. Accelerometers placed on clay liner *e. Completed model* *f. Model loaded in centrifuge*

Fig. 3 model preparation sequence.

The completed landfill model was loaded into the centrifuge and was swung-up to 50g in stages of 10g, 20g and 40g. At 50g, seven earthquakes of varying intensity and magnitude were applied to the model by the SAM earthquake actuator. Table 2 provides the details of the applied model earthquakes.

Table 2 Simulated earthquake loadings in test IT03, prototype scale [model scale].

Model Earthquake Number	Driving frequency (Hz)	Duration (s)	Maximum base acceleration-Acc.1(g)
E.1	0.6 [30]	15 [0.3]	0.098 [4.9]
E.2	0.8 [40]	15 [0.3]	0.124 [6.2]
E.3	1 [50]	15 [0.3]	0.176 [8.8]
E.4	1 [50]	15 [0.3]	0.158 [7.9]
E.5	1 [50]	15 [0.3]	0.284 [14.2]
E.6	1 [50]	15 [0.3]	0.331 [16.5]
E.7	1 [50]	15 [0.3]	0.334 [16.7]

3.3 Model IT09

Fig. 4 shows the cross section of the centrifuge model IT09. The model waste was prepared in layers of 25 mm thickness, and each layer was compacted by a static load to produce a unit weight of 9 kN/m^3.

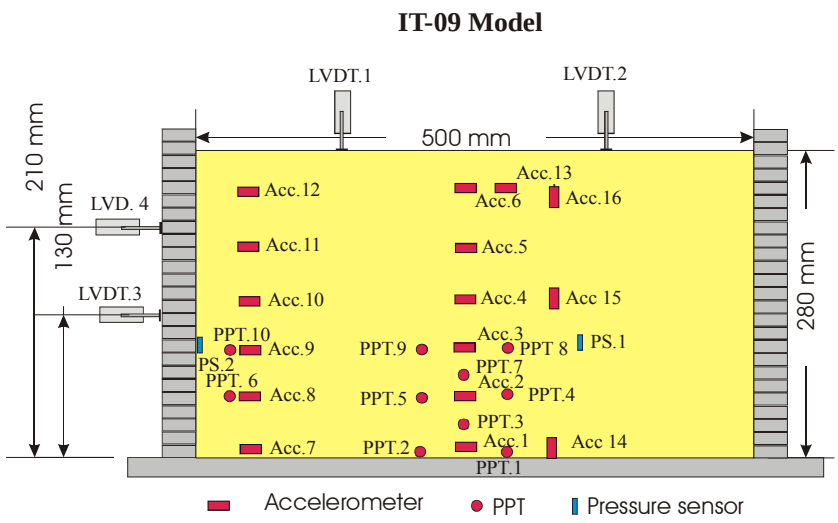


Fig. 4 Centrifuge model IT09 (dimensions in model scale).

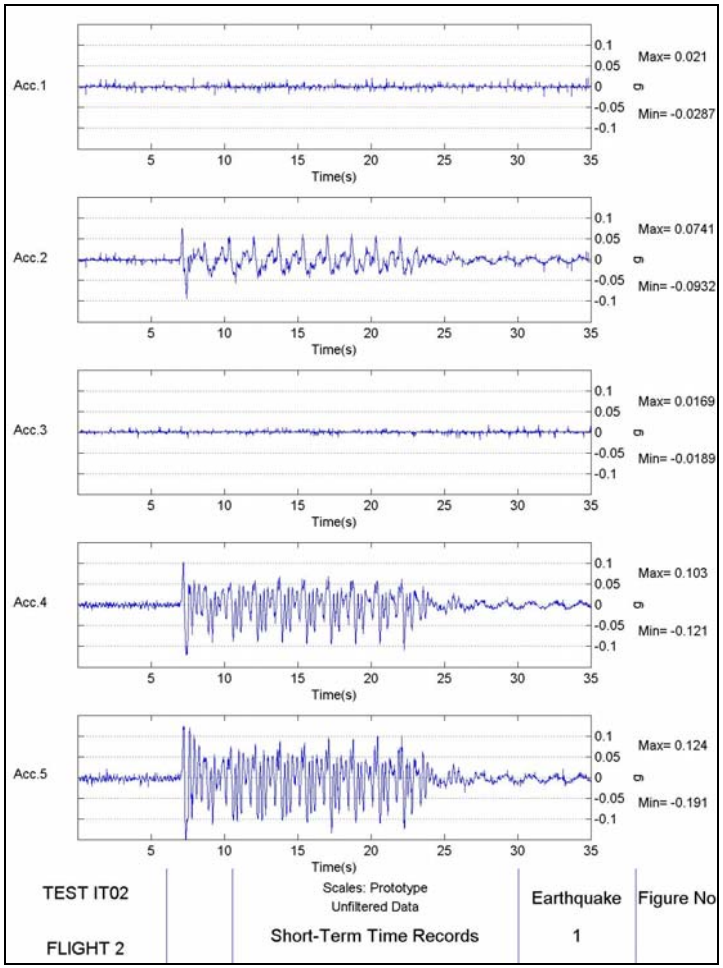
Table 3 shows the earthquake loadings applied to the model IT09. The model was first taken to 50g and a frequency sweep earthquake (E.1) was applied. The model was then swung to 80g where four more model earthquakes were applied.

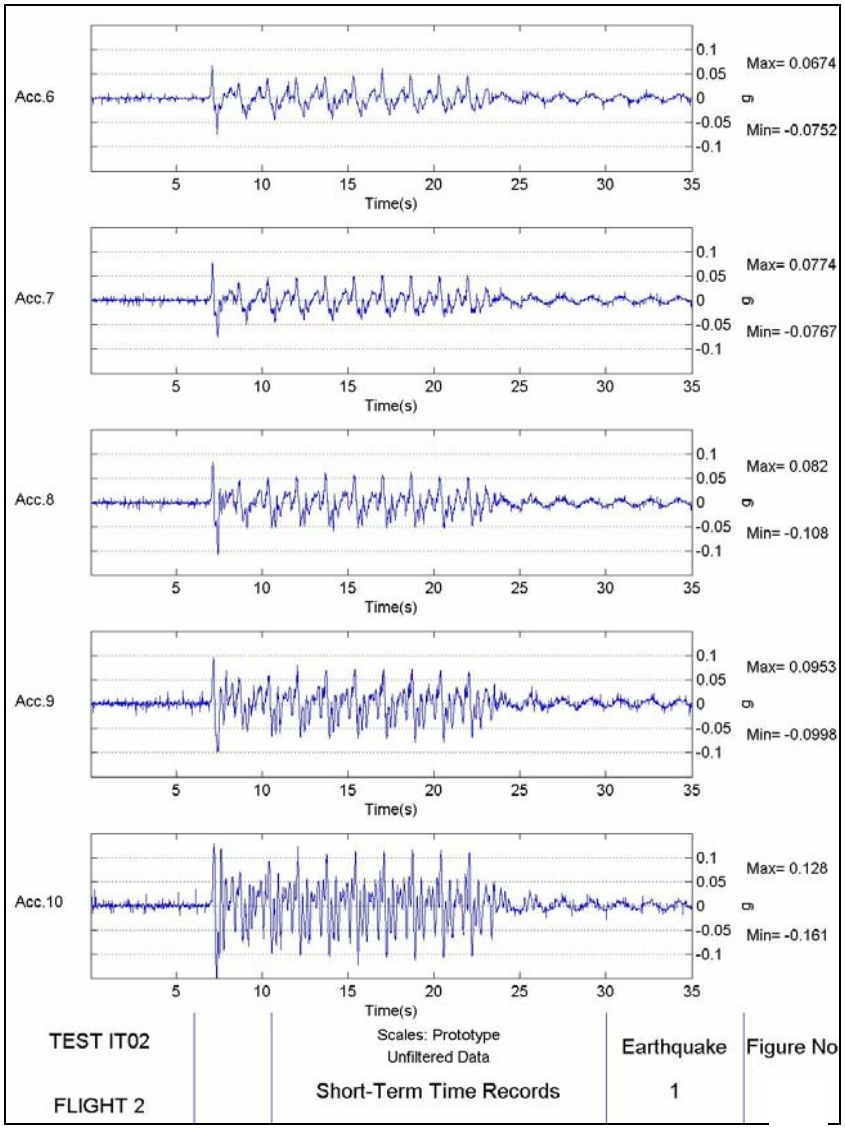
Table 3 Applied earthquakes loadings in test IT09, prototype scale [model scale].

Model Earthquake Number	Driving frequency (Hz)	Duration (s)	Maximum base acceleration-Acc.1(g)
E.1	1→0 [50 → 0]	~200 [~ 4]	0.200 [10]
E.2, E.3, E.4 & E.5 were applied at 80g			
E.2	0.625 [50]	24 [0.3]	0.097 [7.77]
E.3	0.625 [50]	24 [0.3]	0.122 [9.73]
E.4	0.625 [50]	24 [0.3]	0.161 [12.9]
E.5	0.625→0 [50 → 0]	~320 [~ 4]	0.126 [10.1]

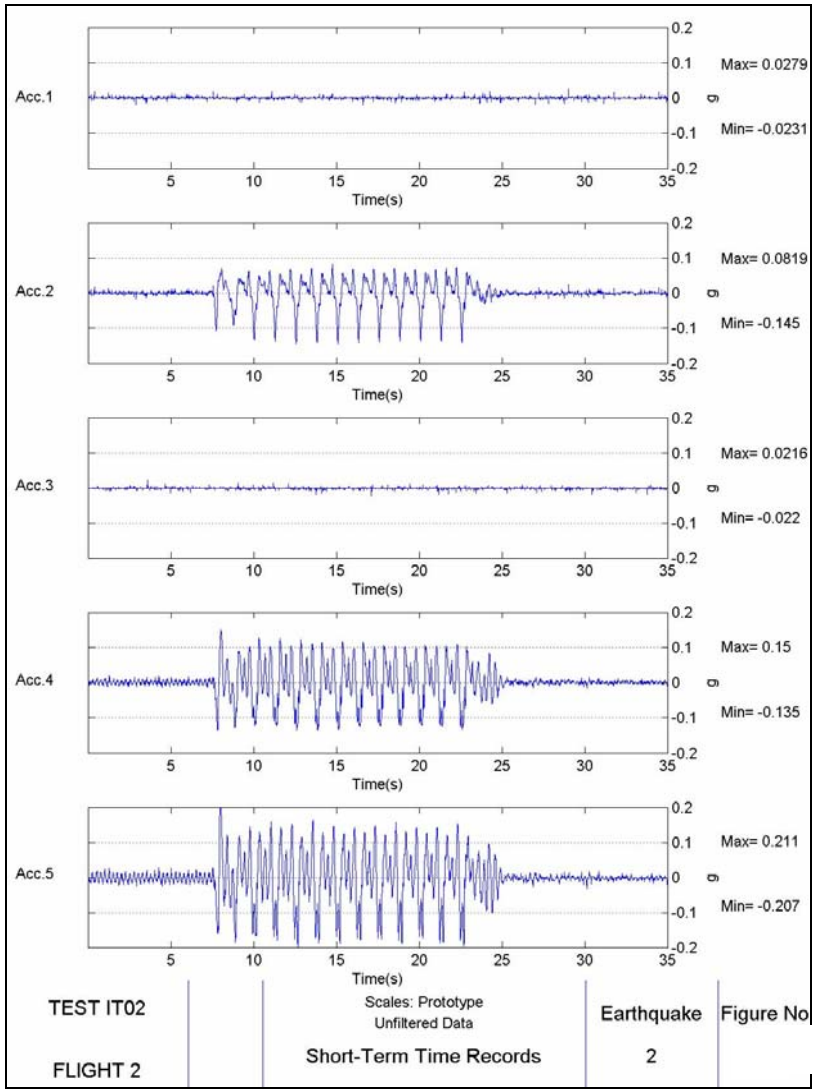
4 Results

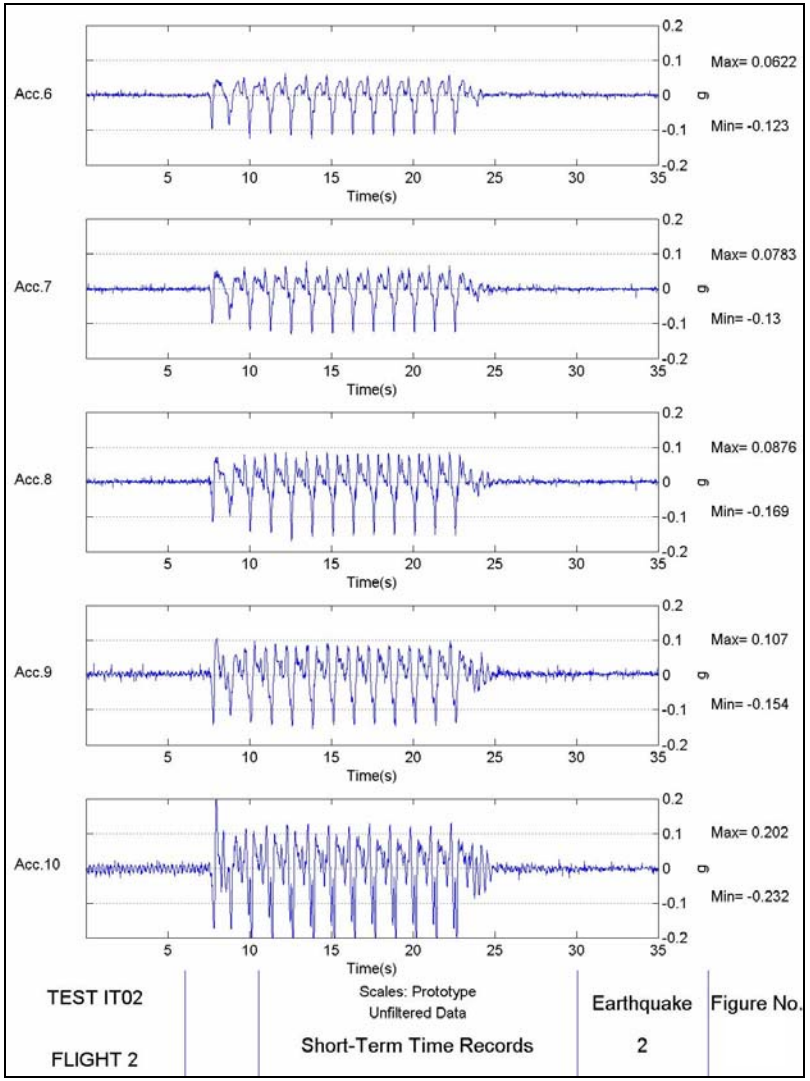
4.1 Data from IT02, Earthquake 1.





4.2 Data from IT02, Earthquake 2





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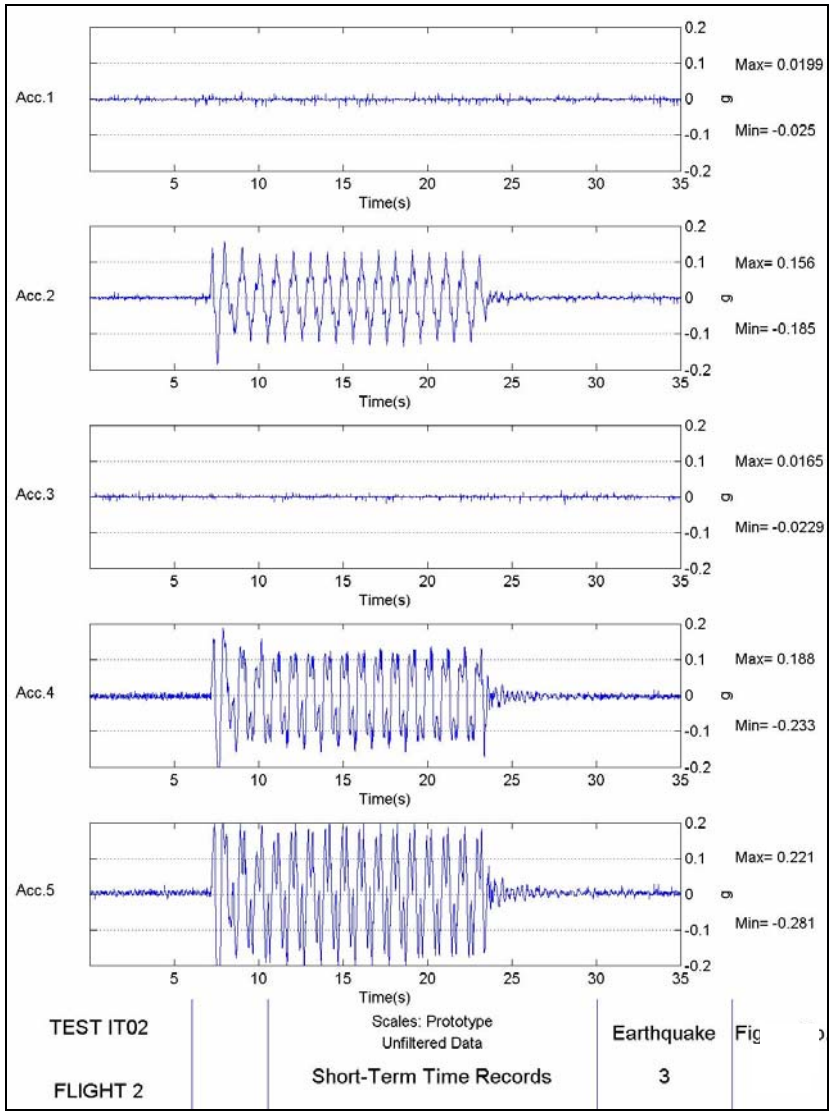

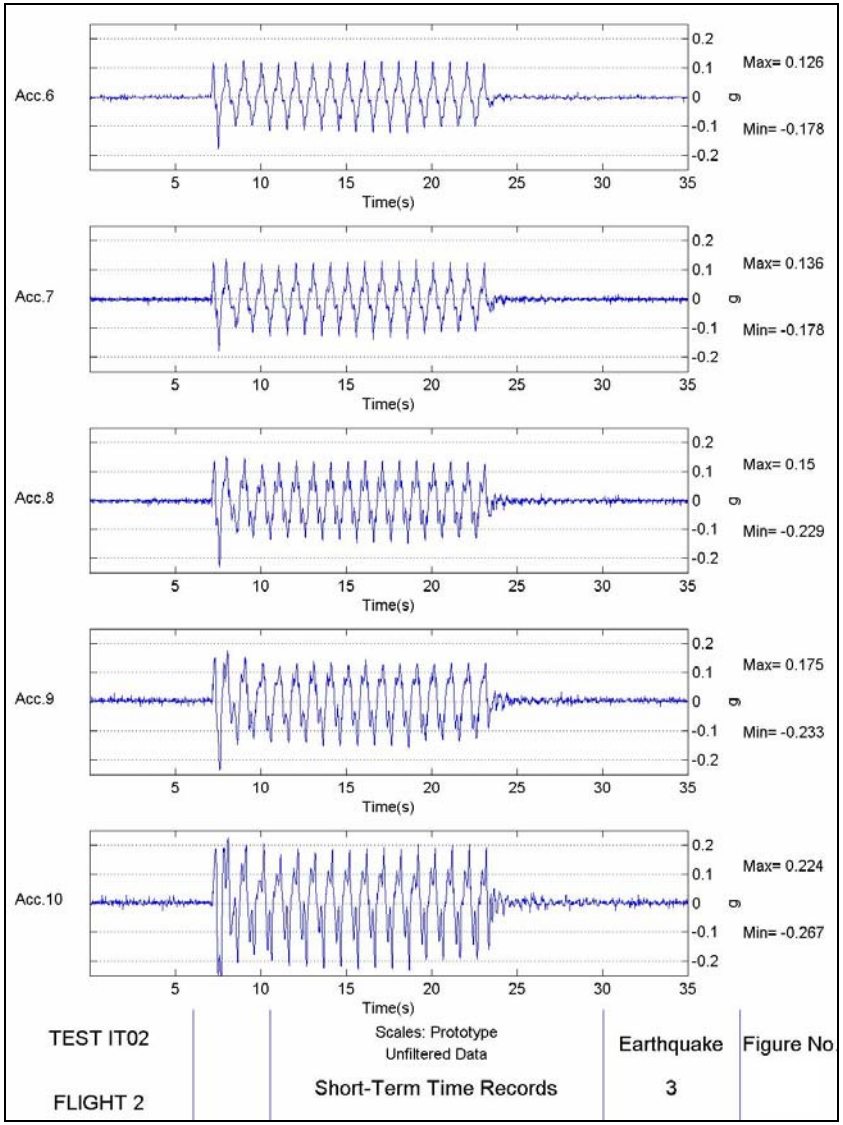

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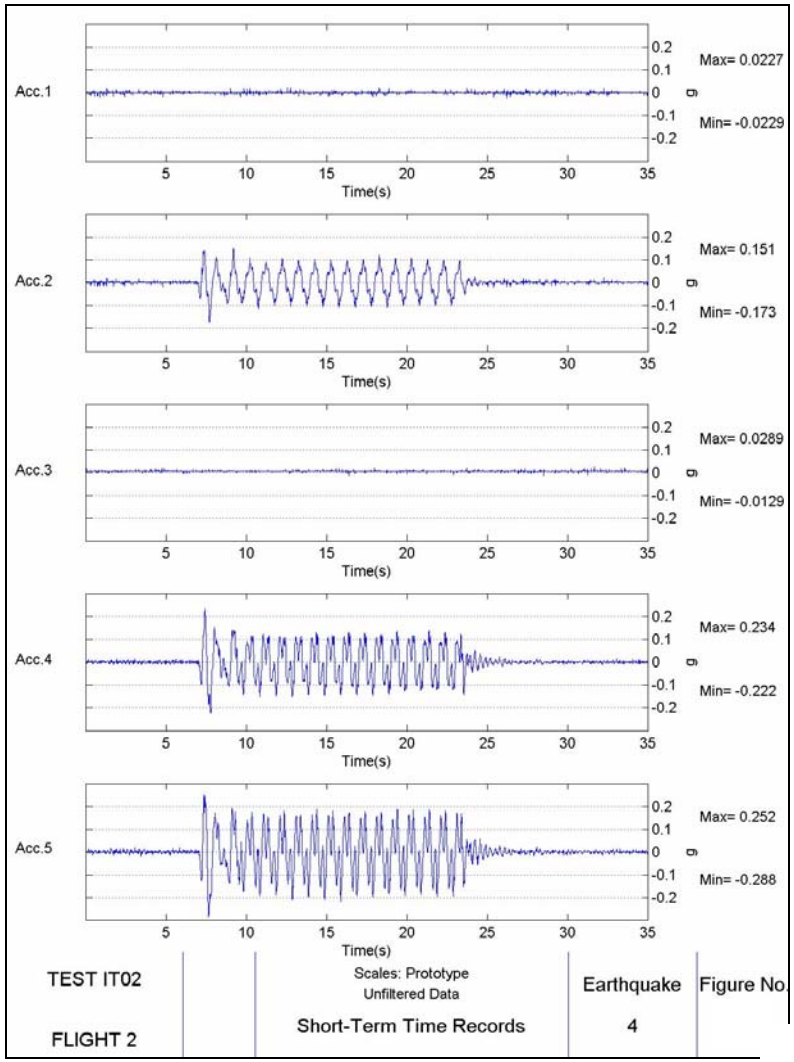

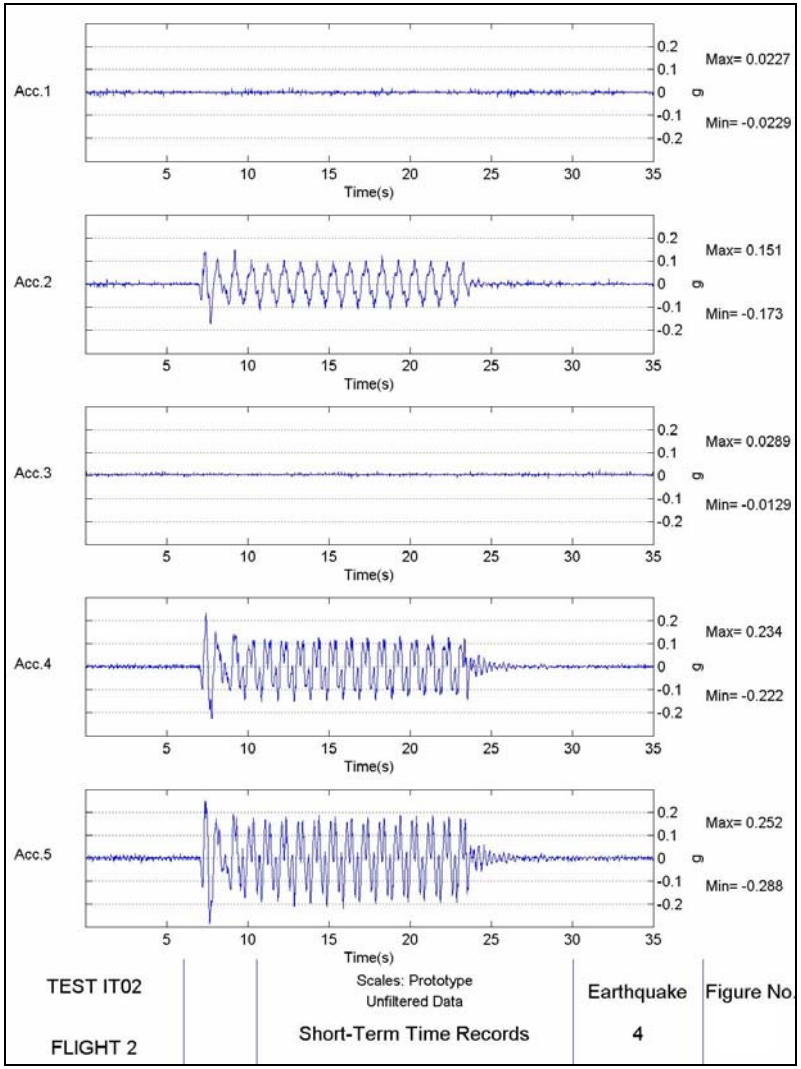

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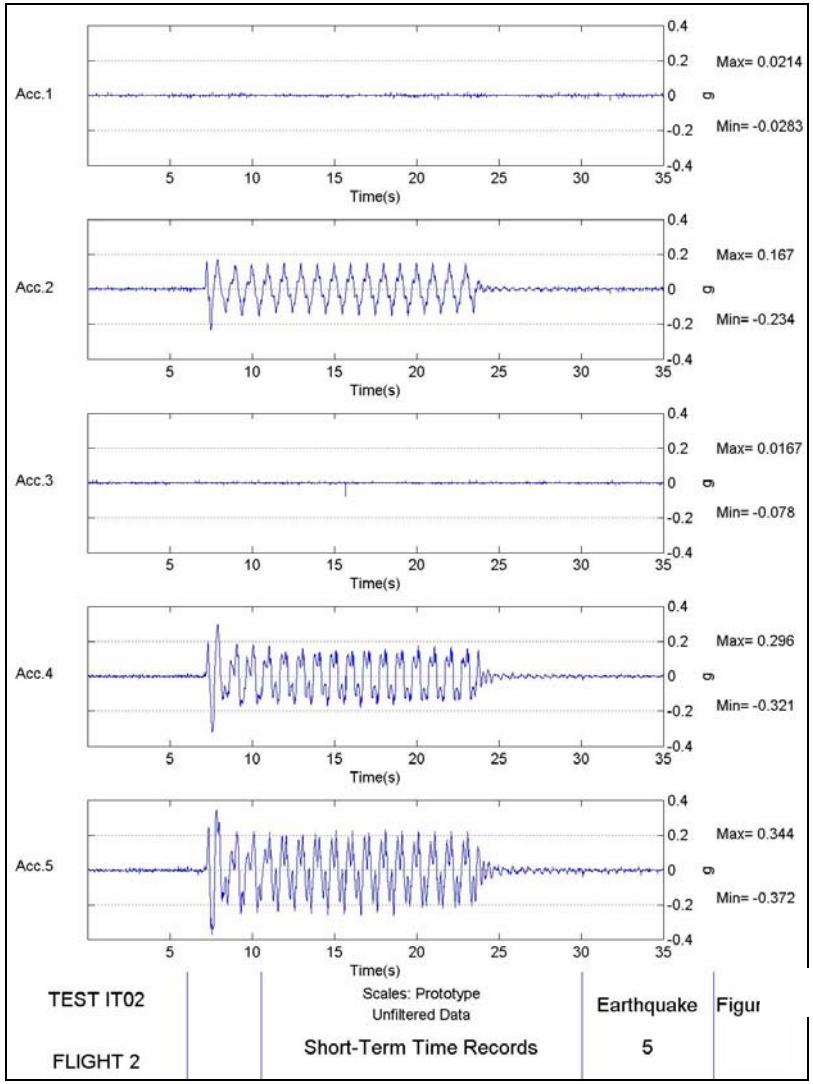

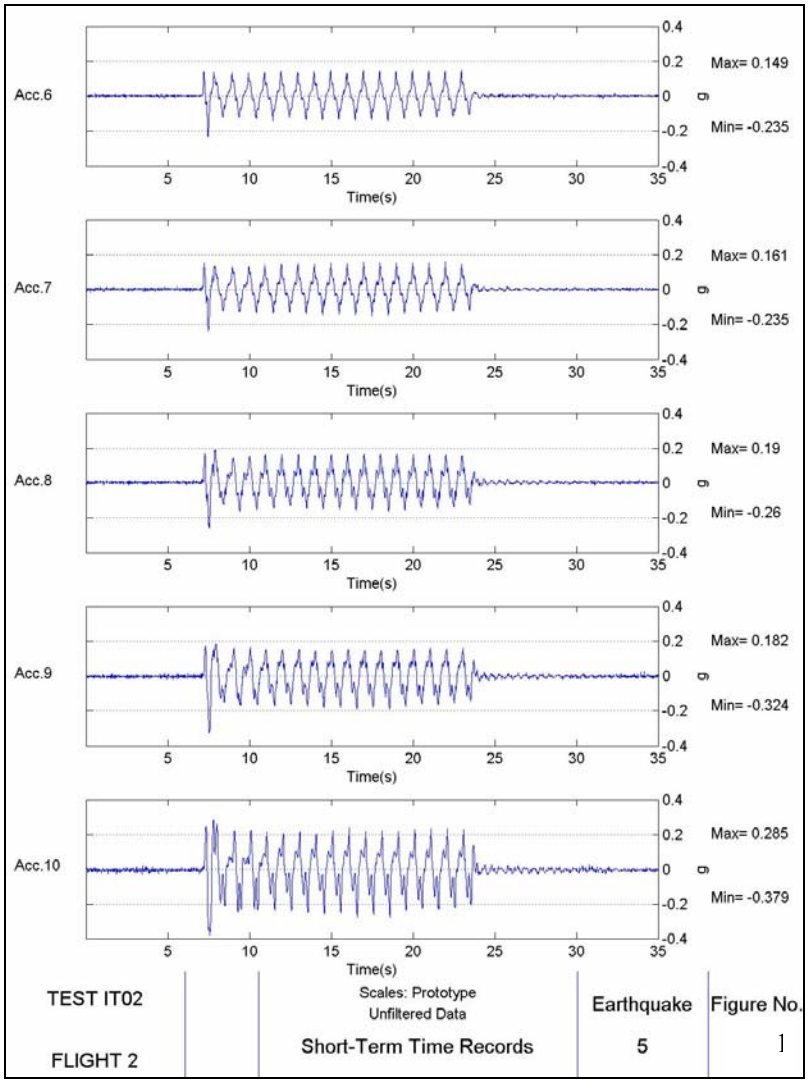

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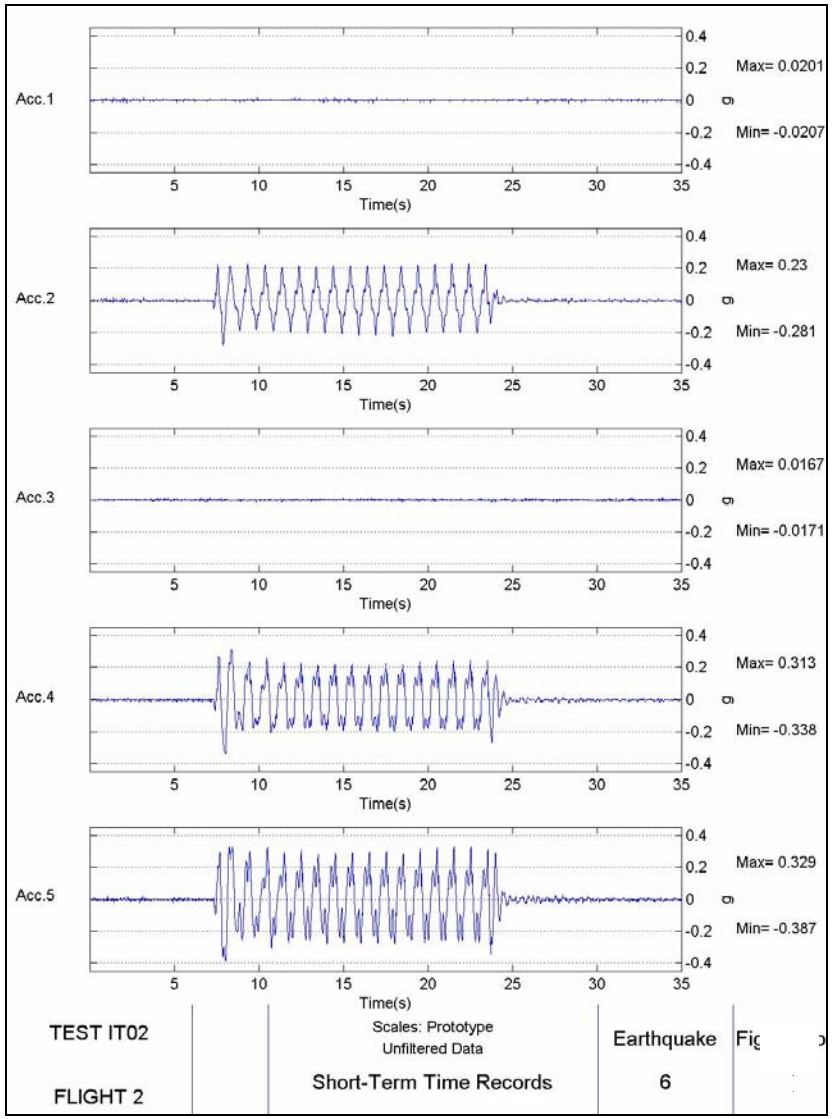

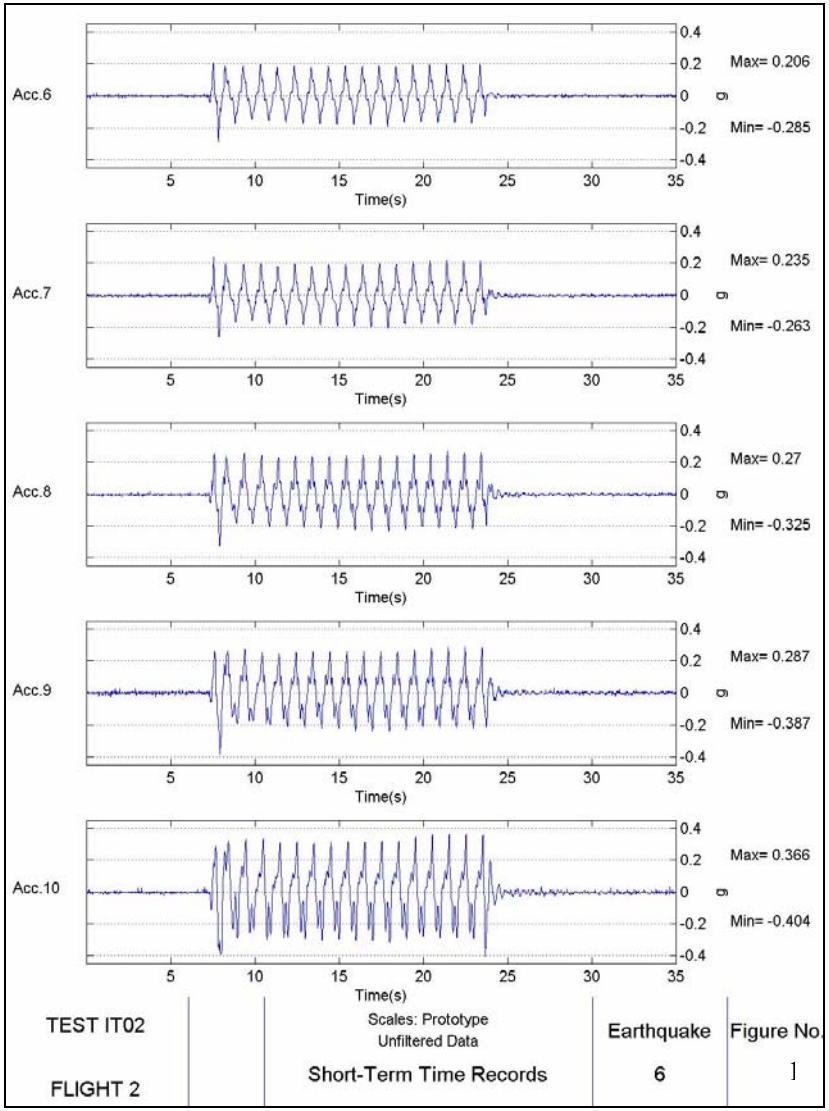

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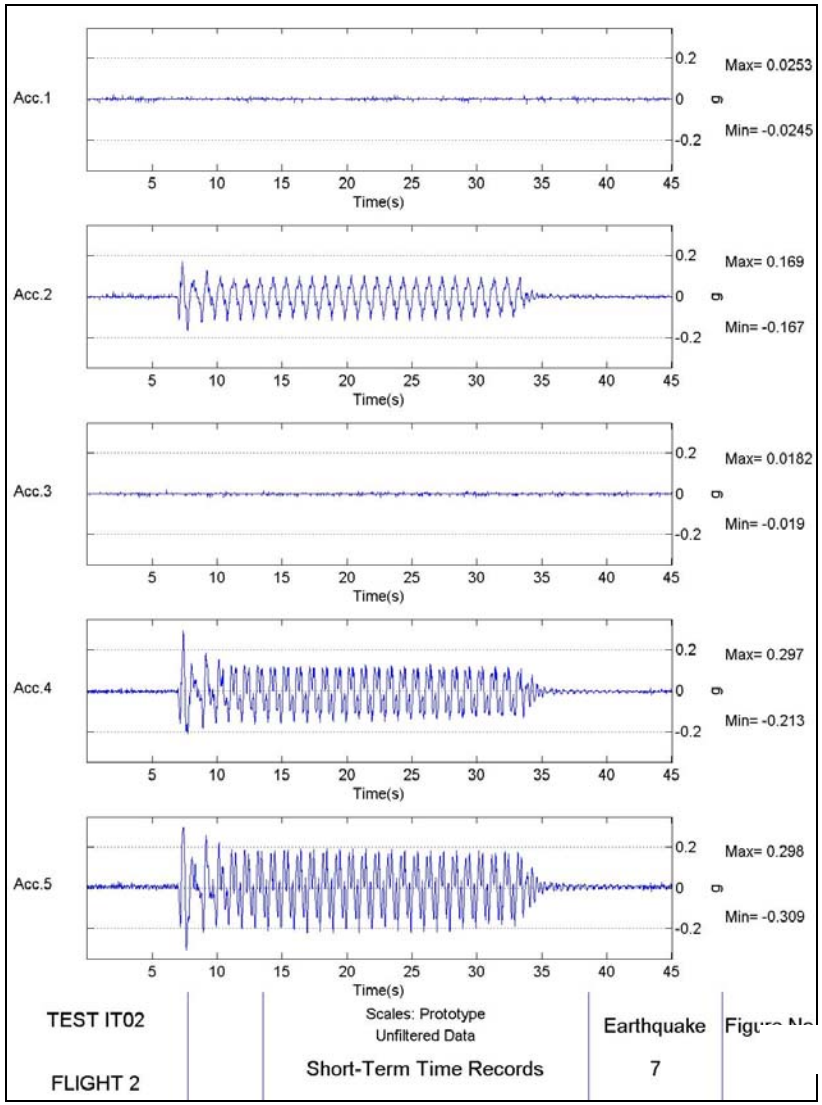
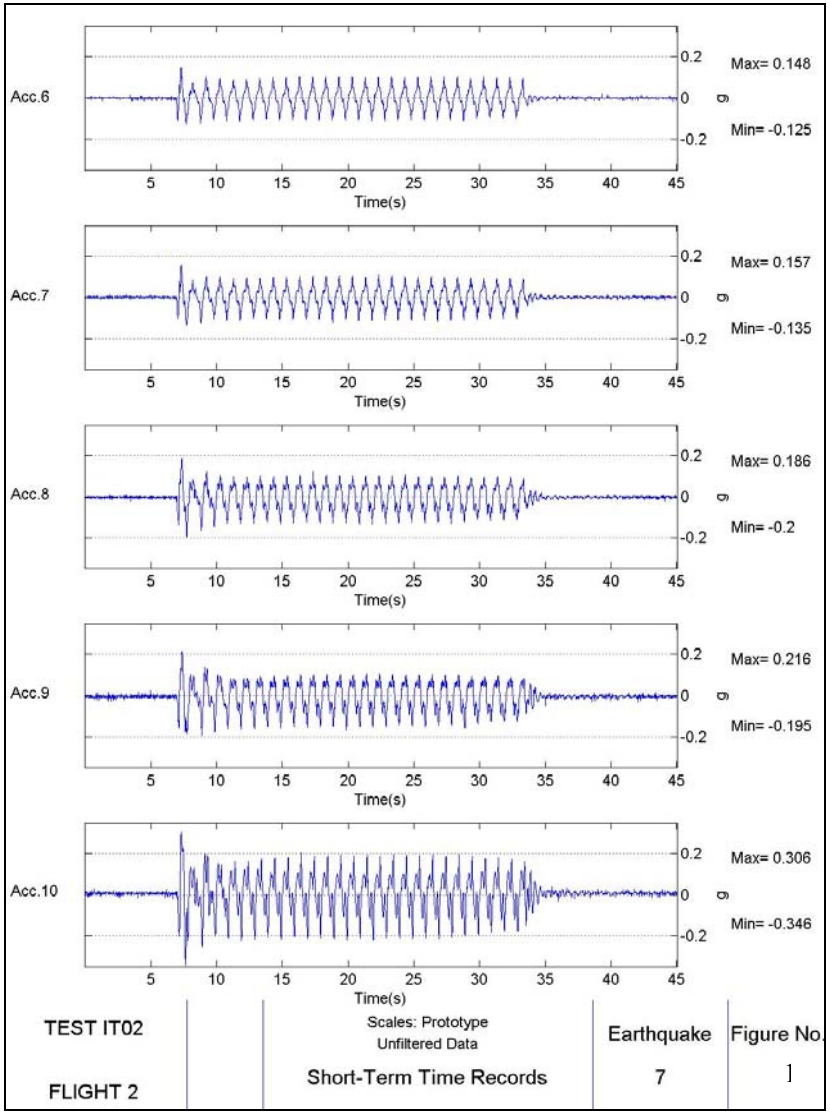
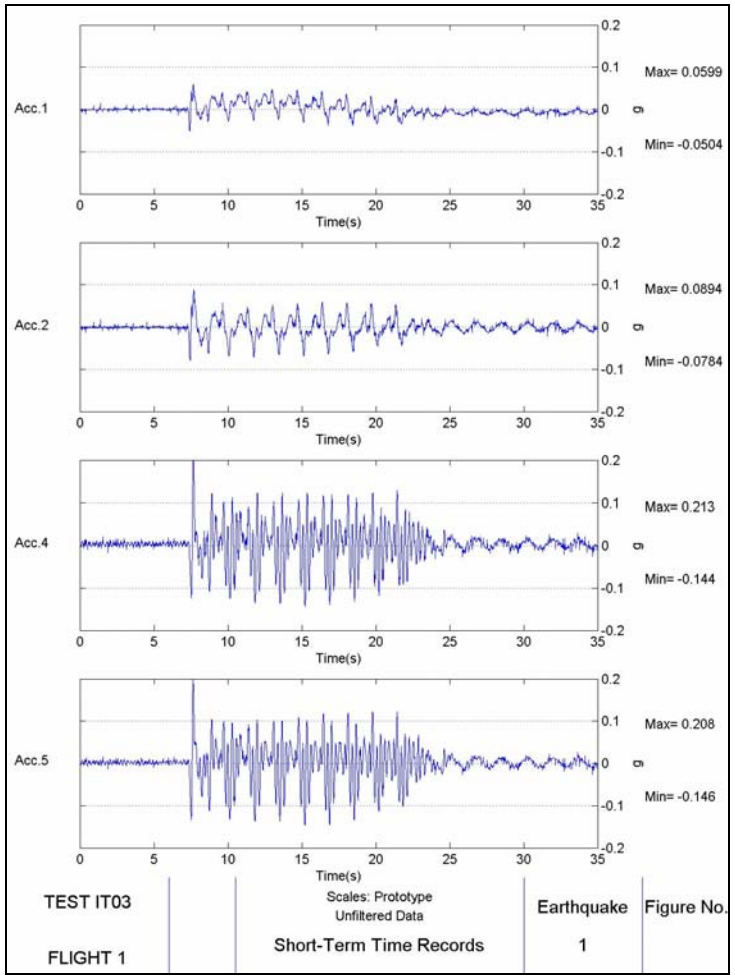
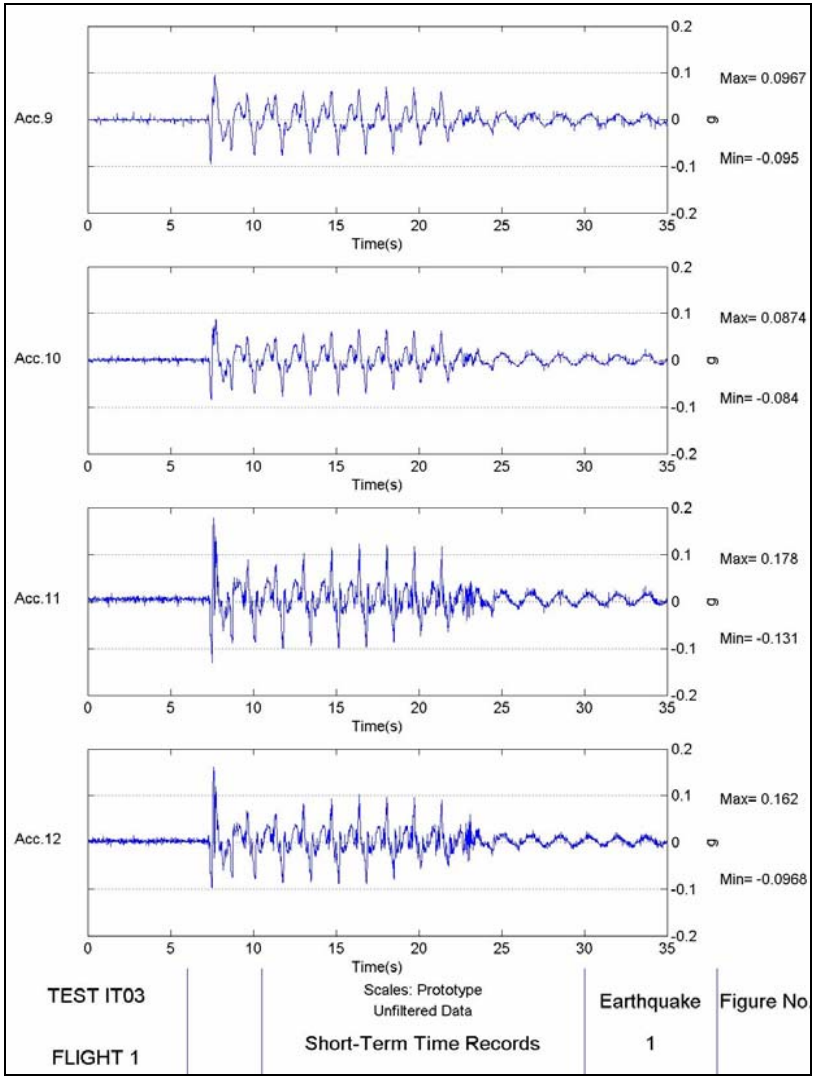




5 Data from Test IT03.

5.1 Data from IT03, Earthquake 1





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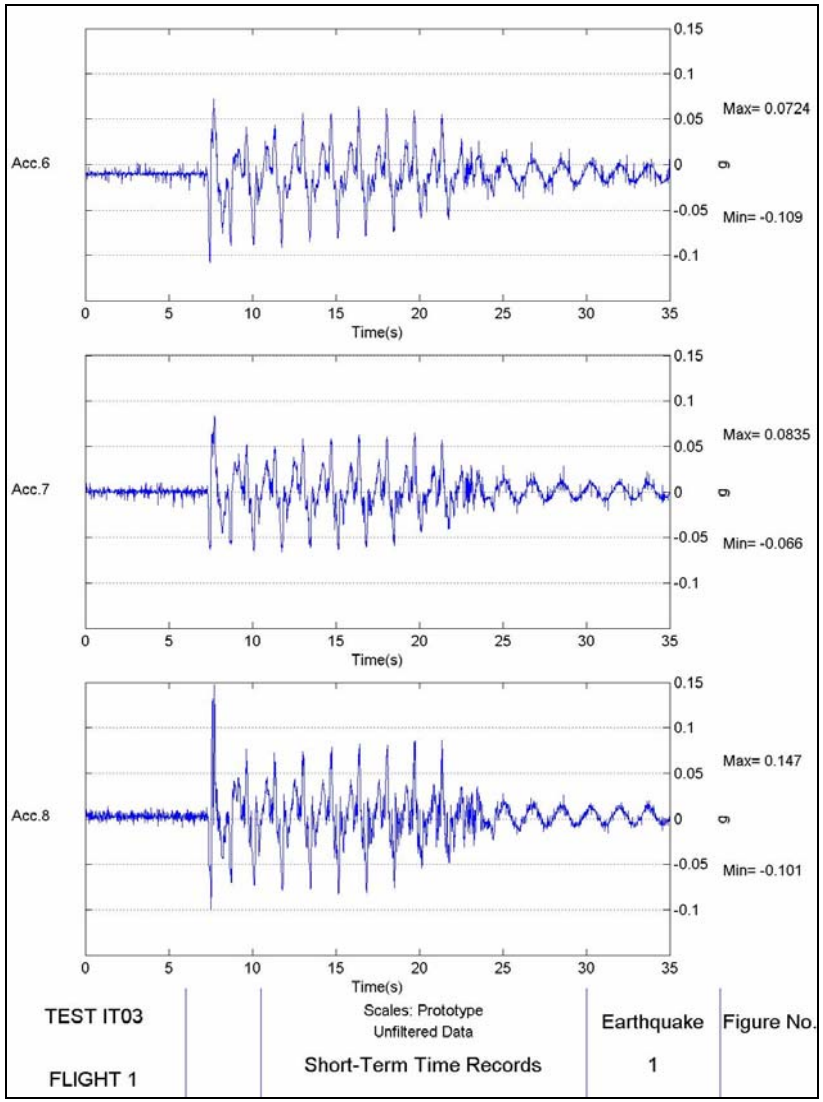

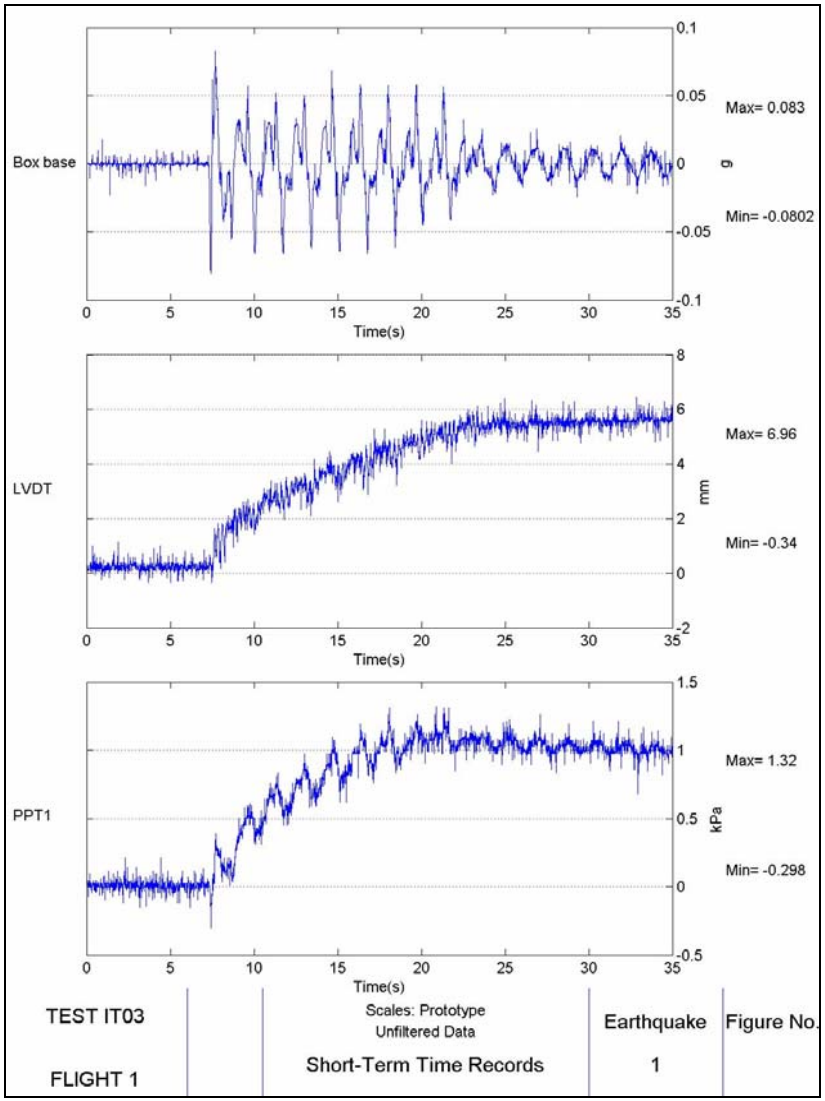

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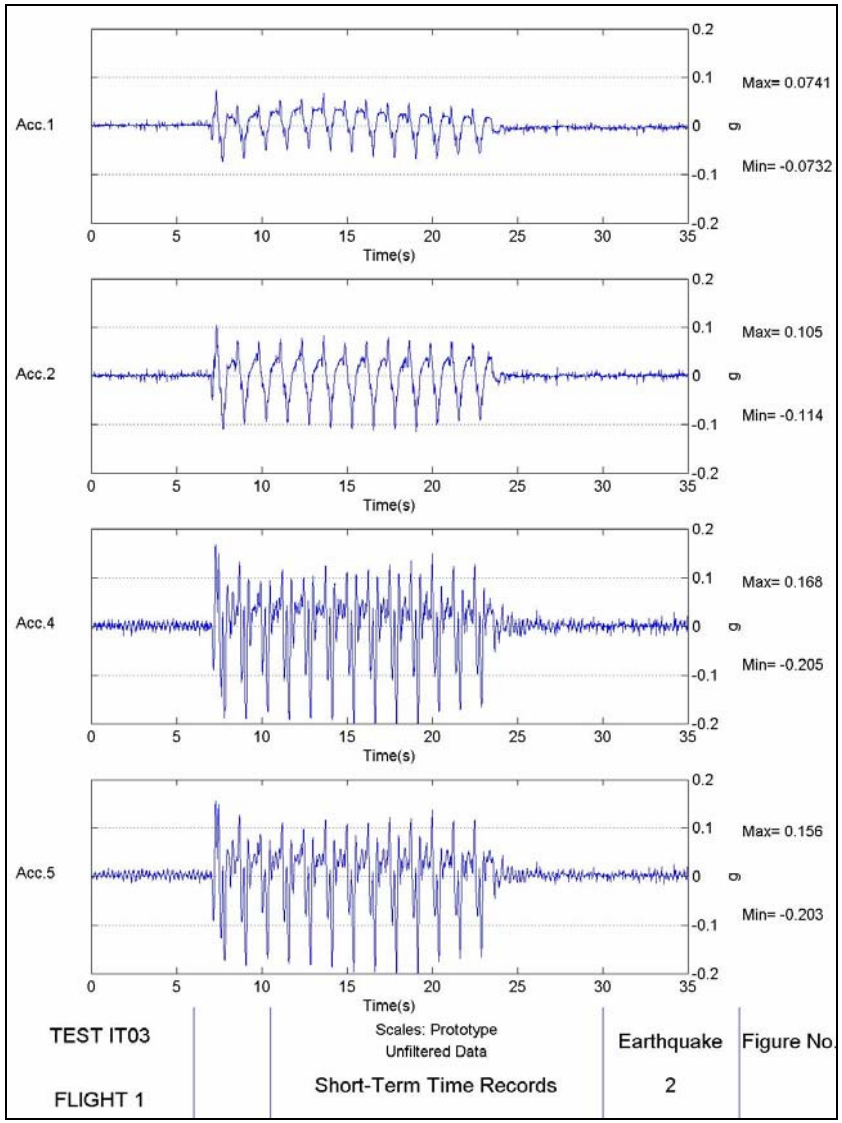

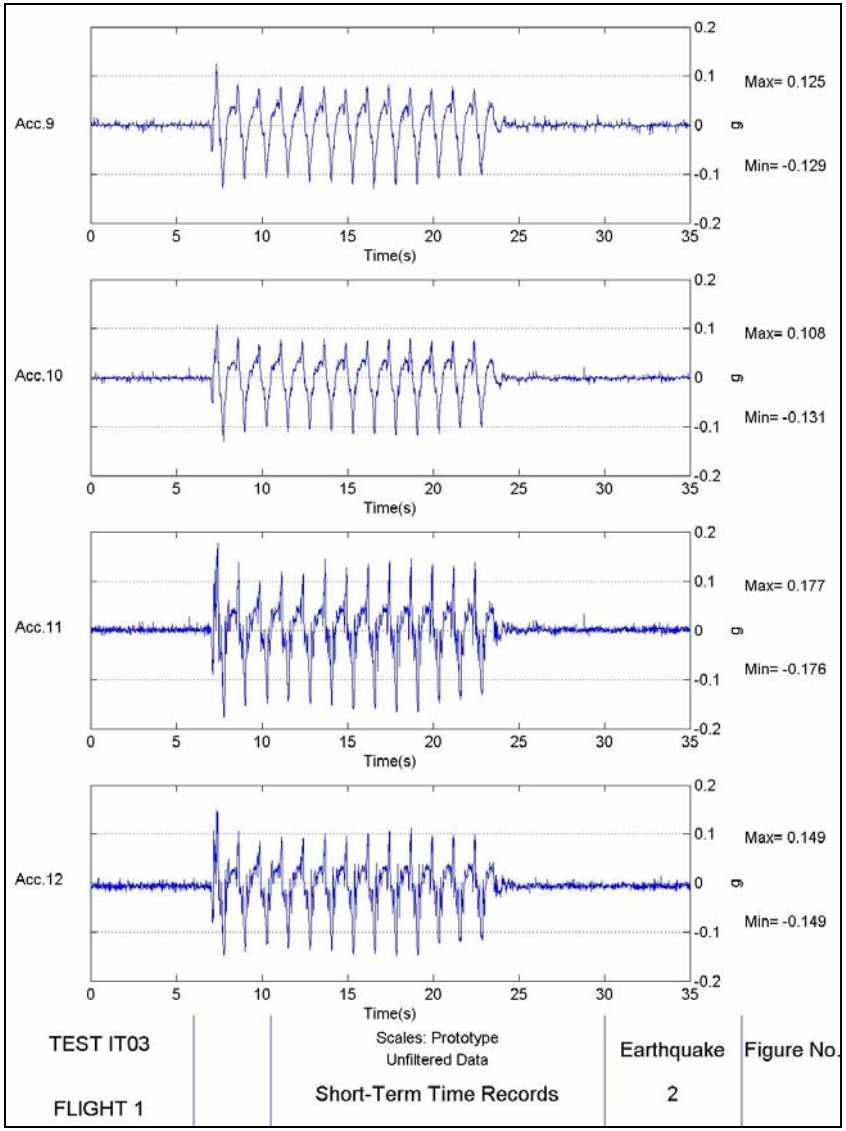

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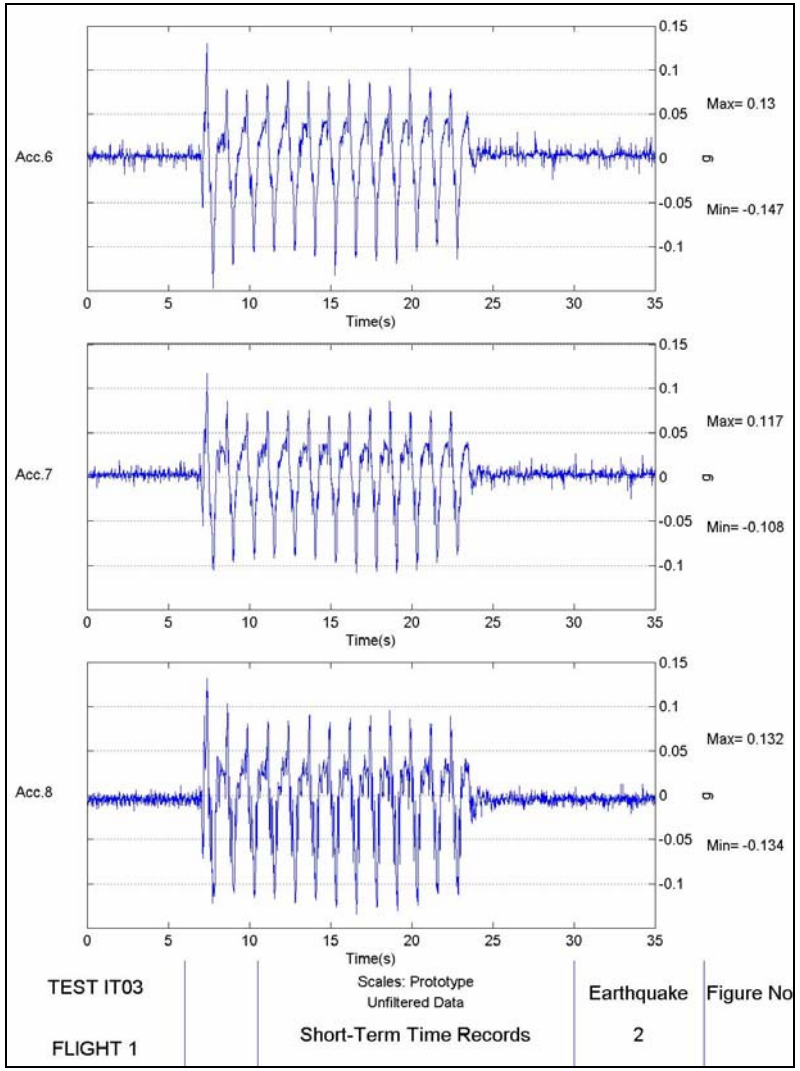

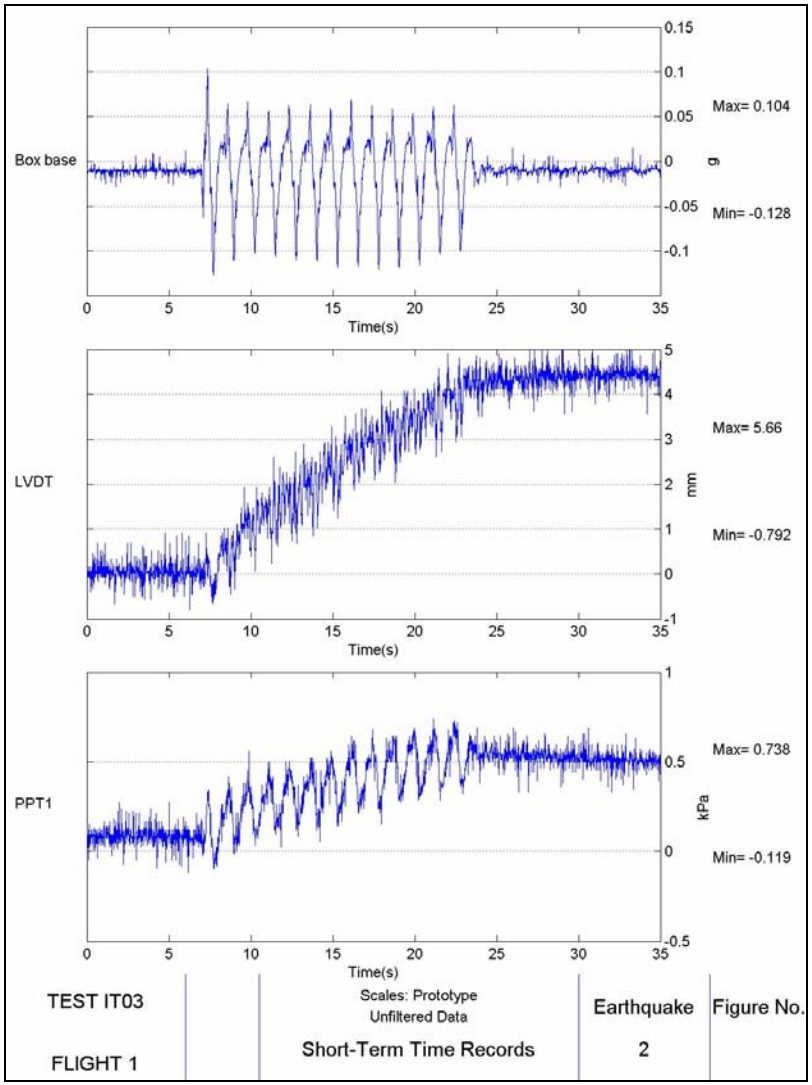

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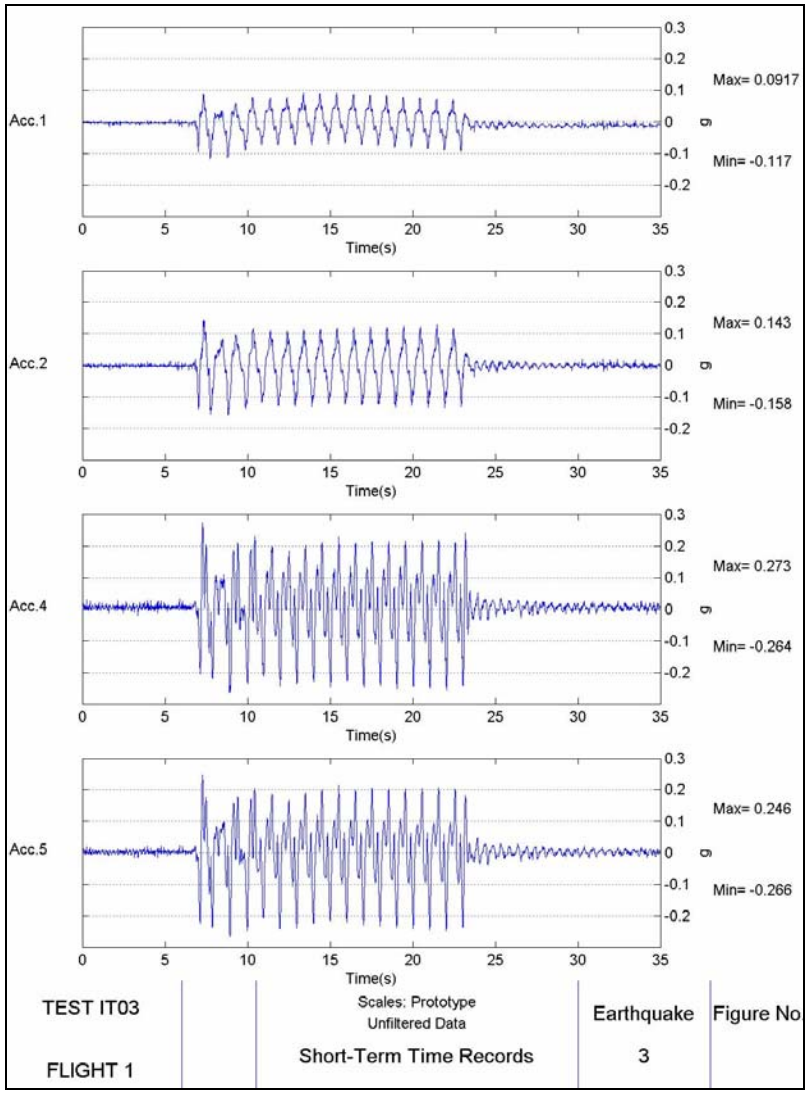

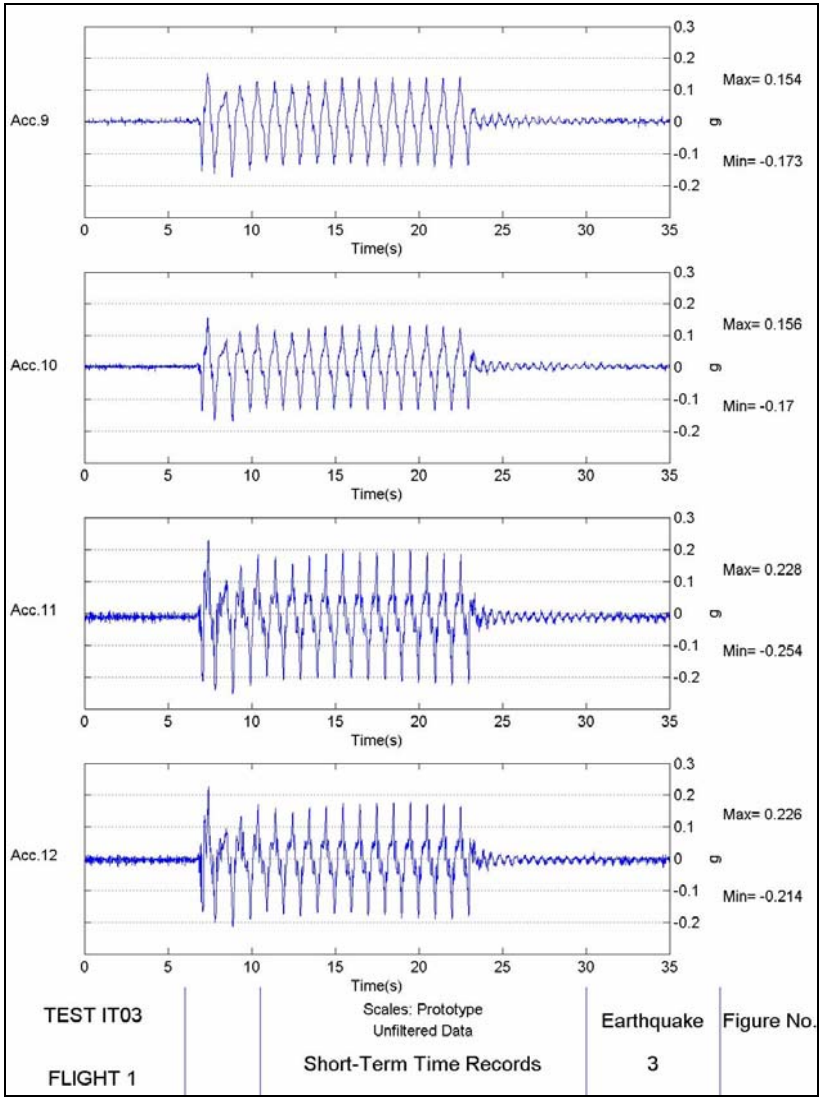

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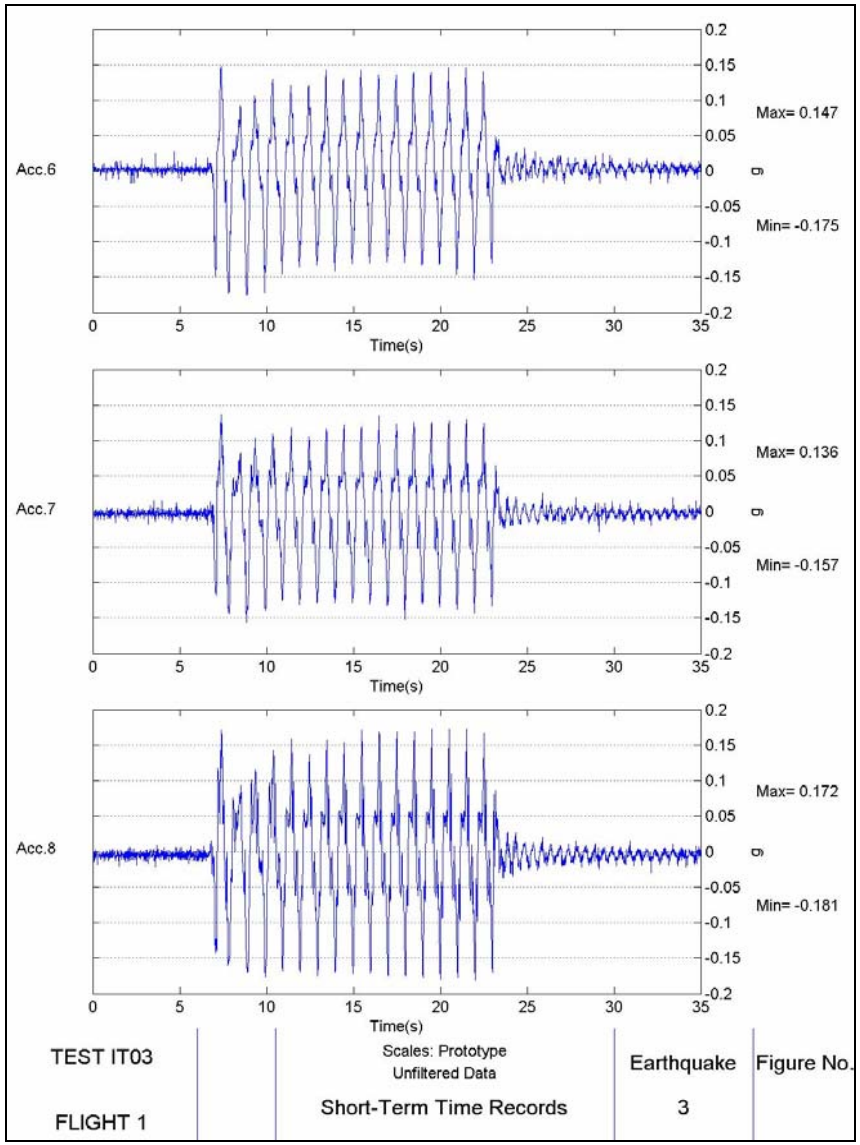

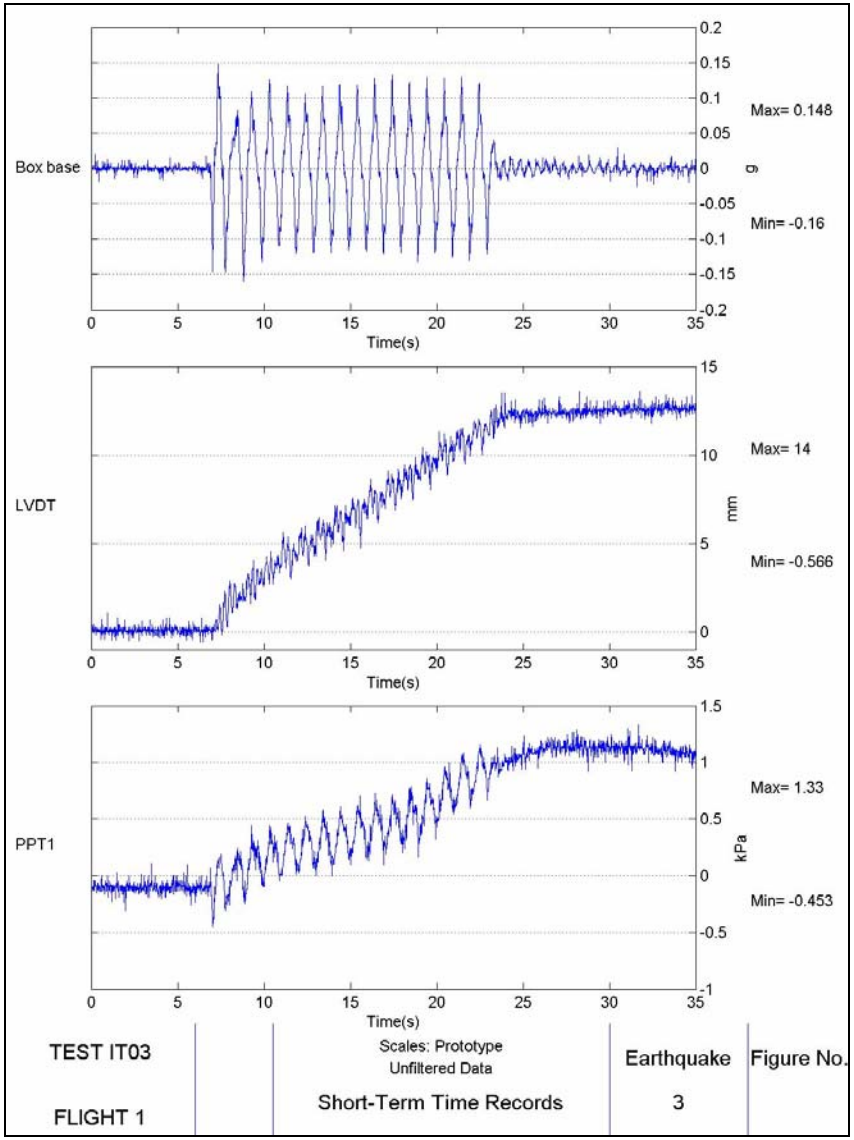

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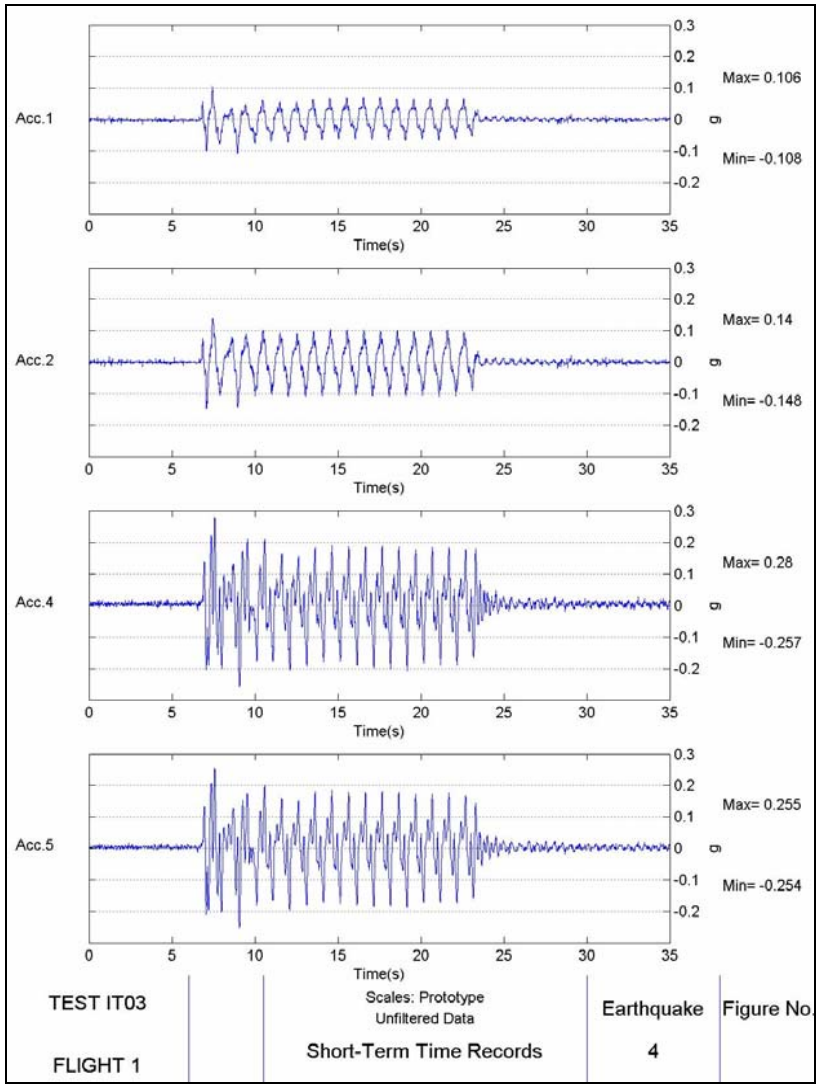

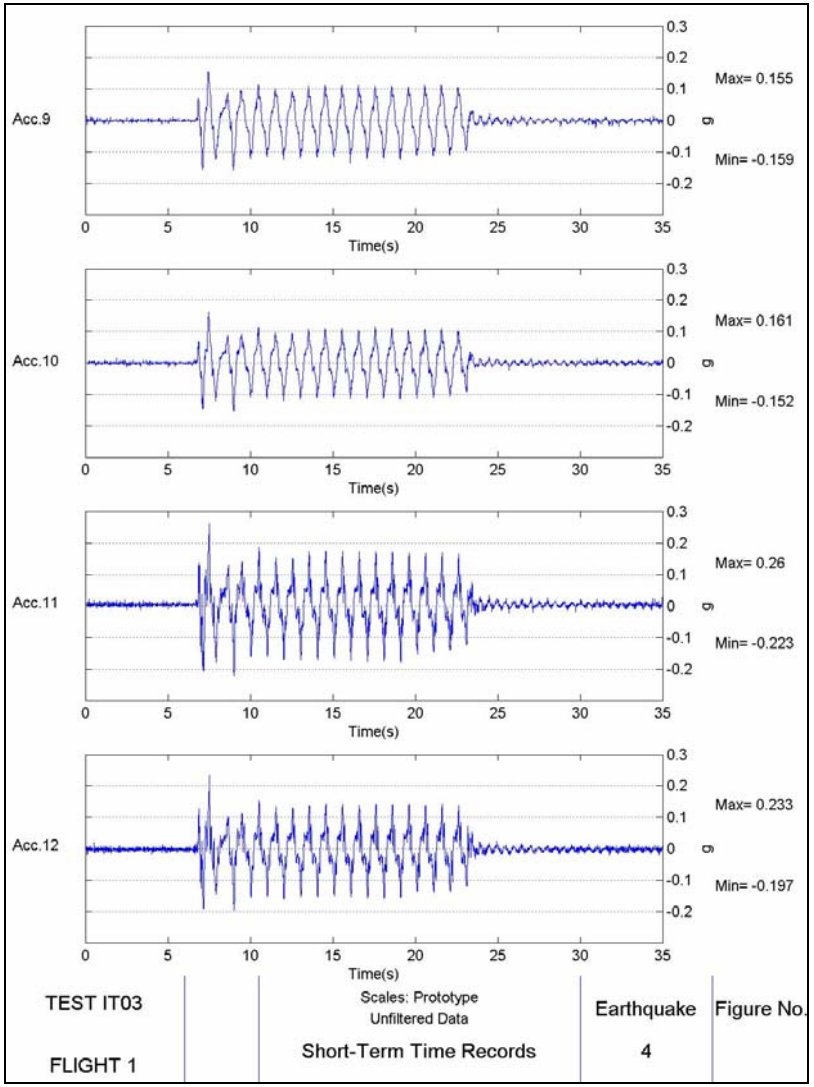

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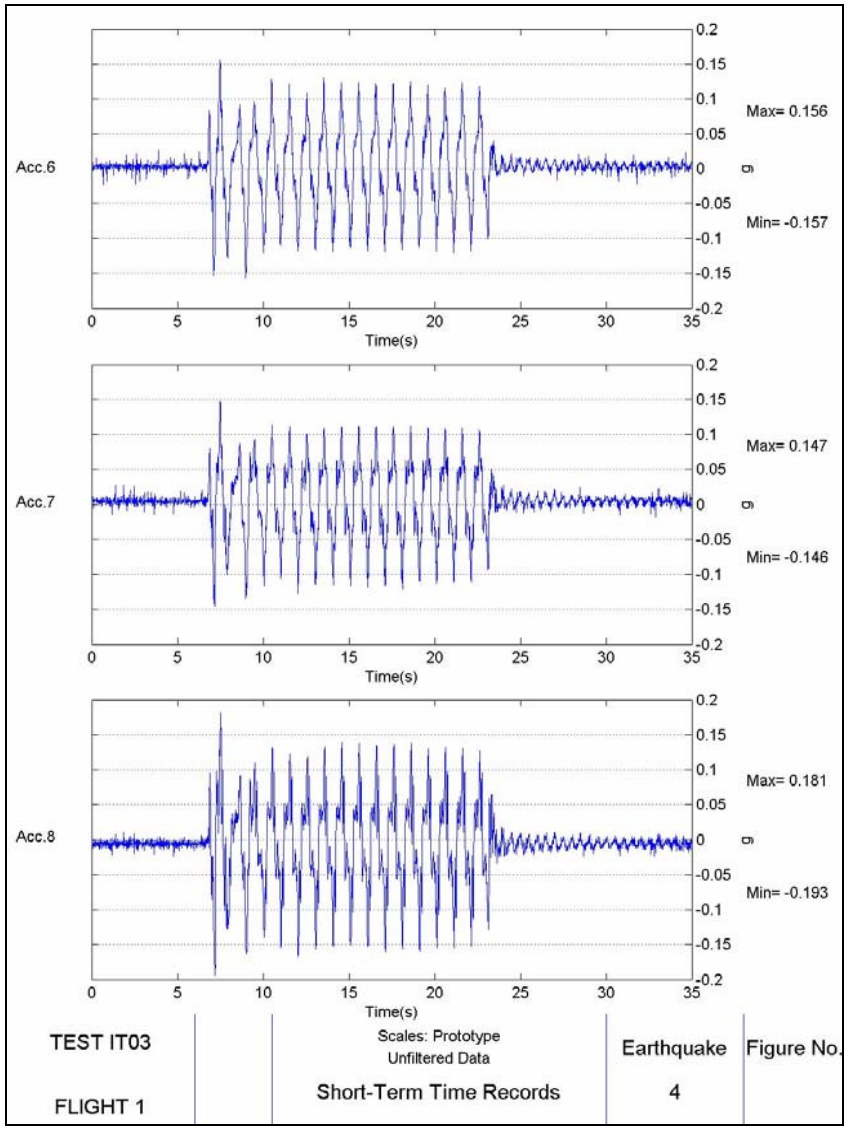

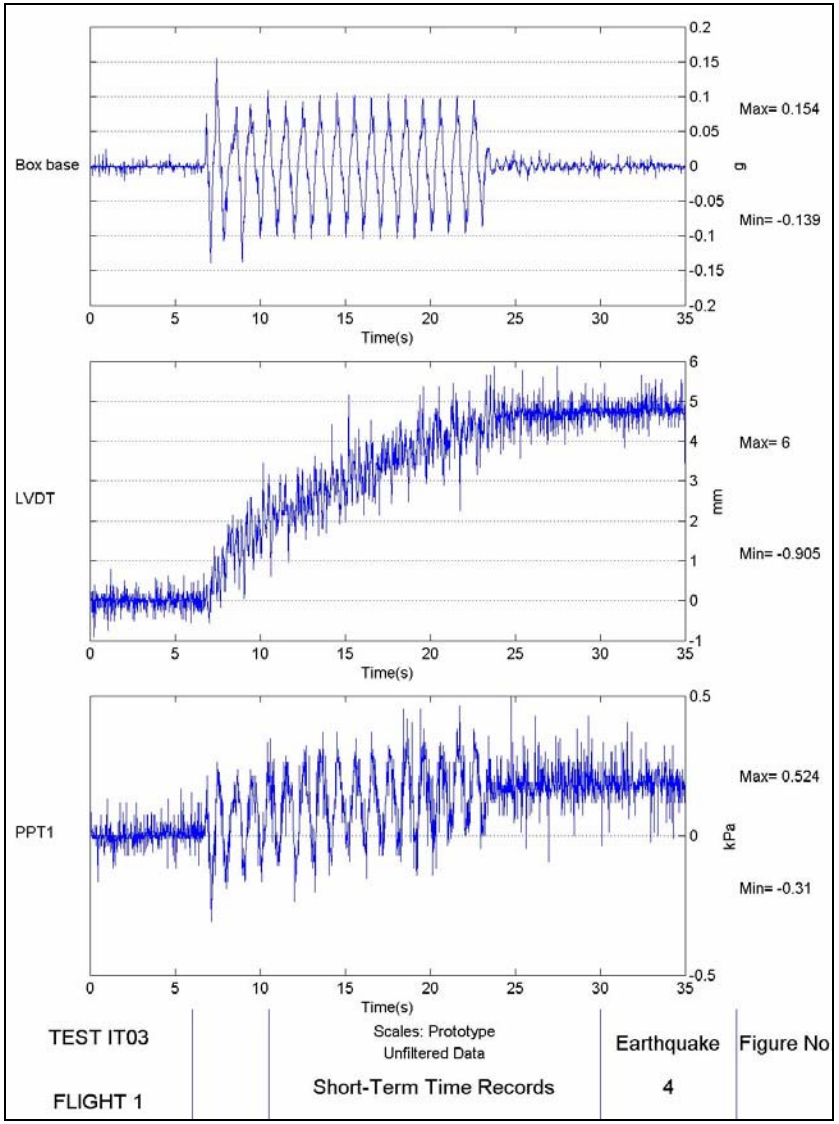

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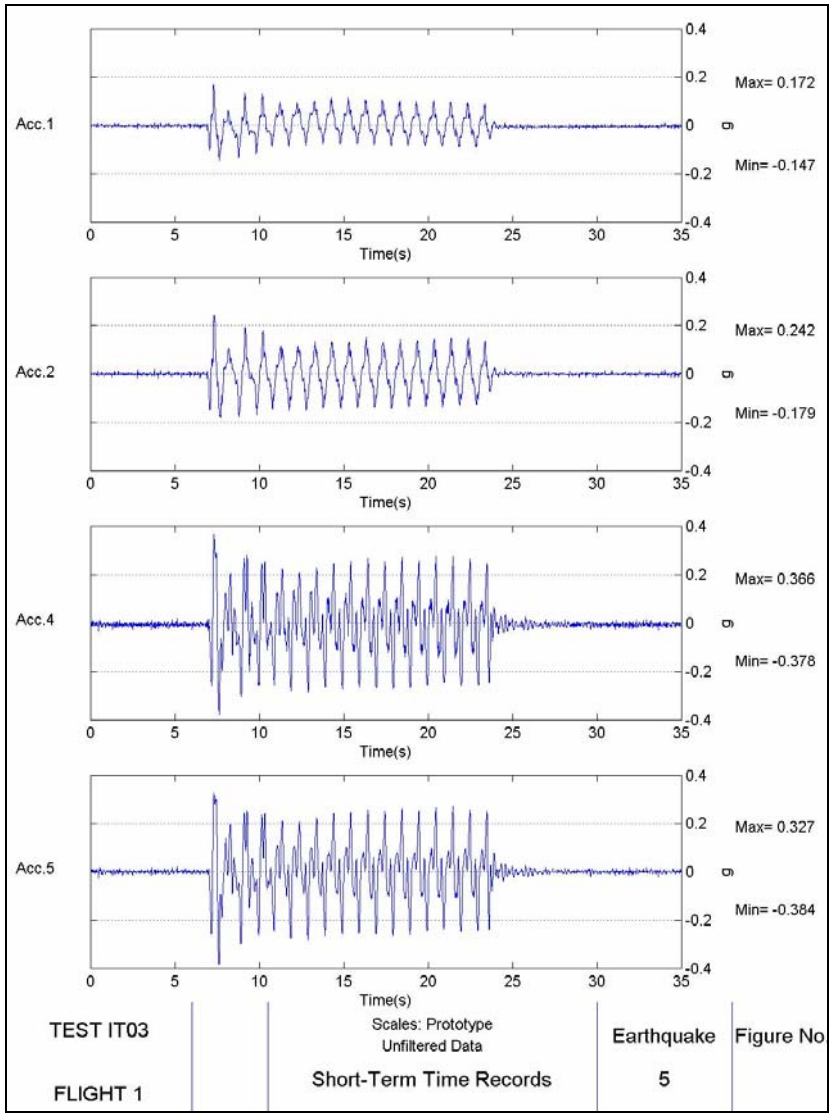

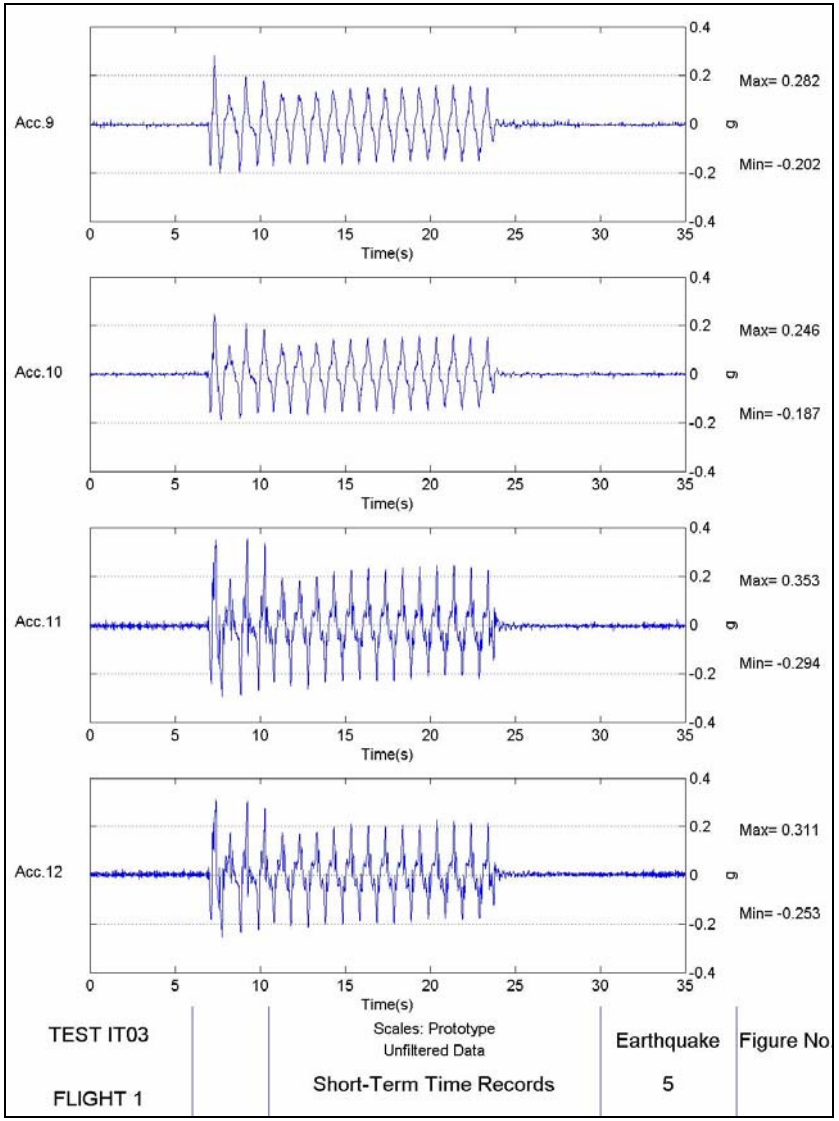

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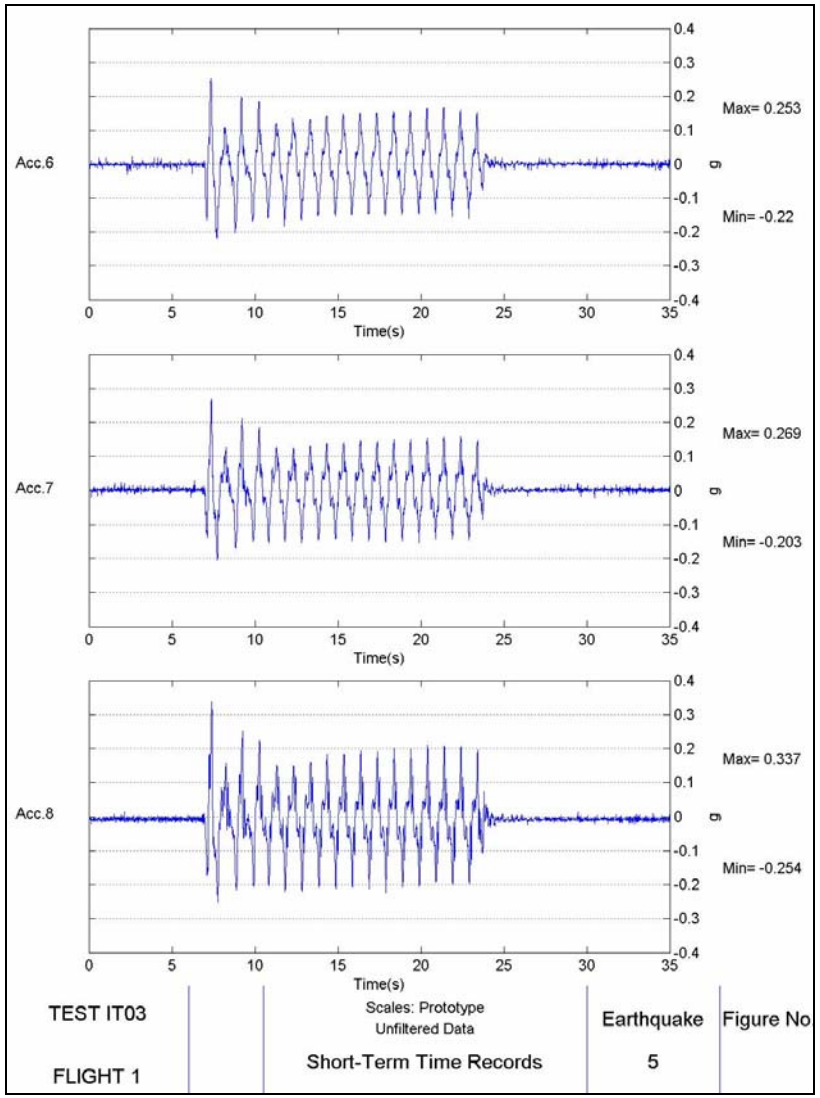

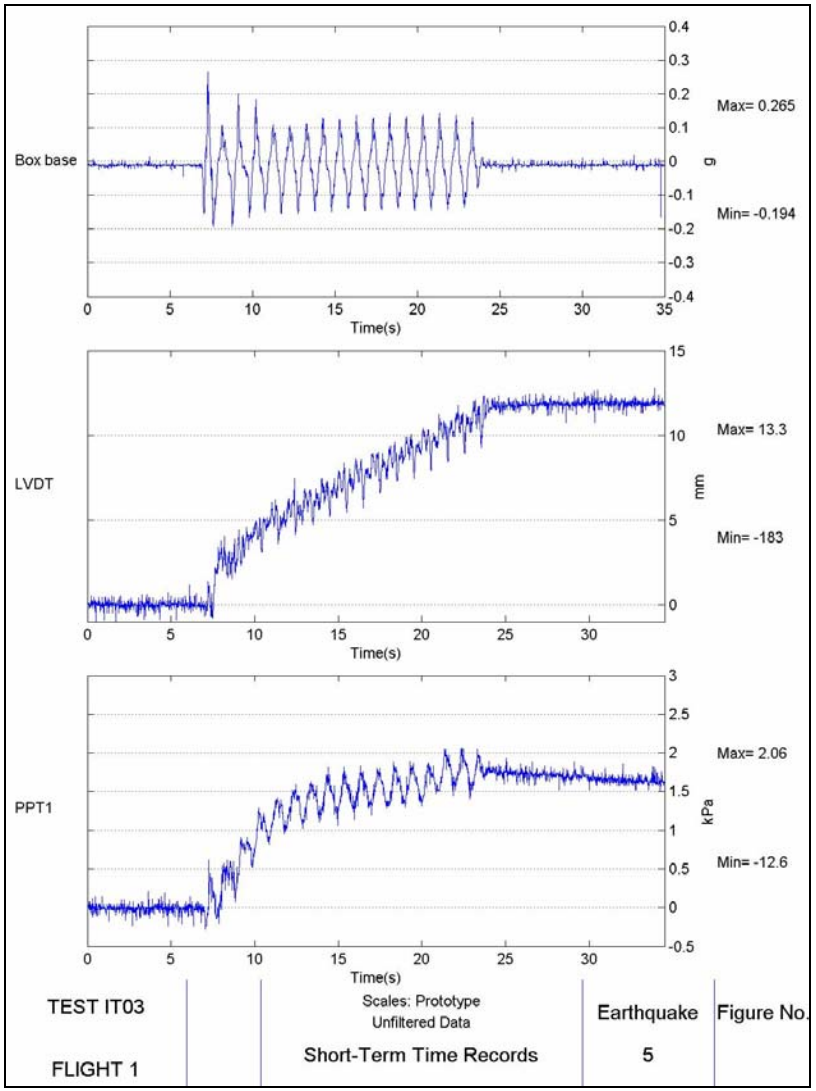

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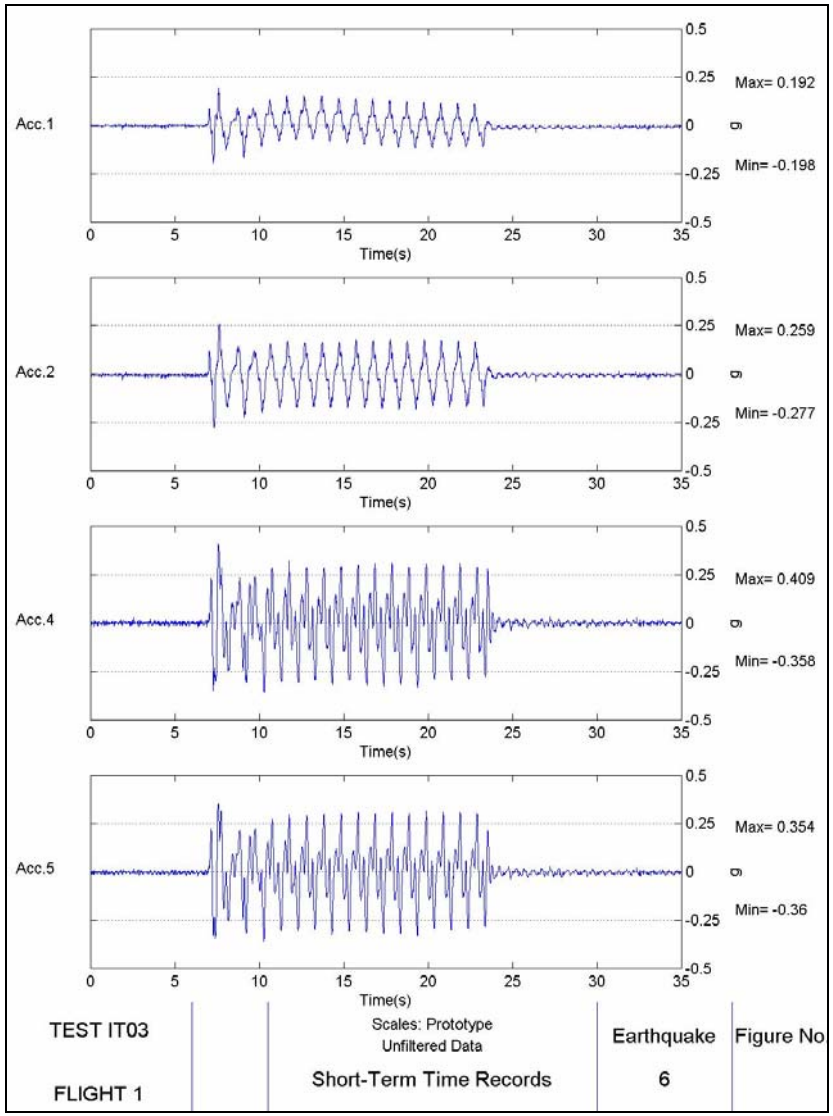

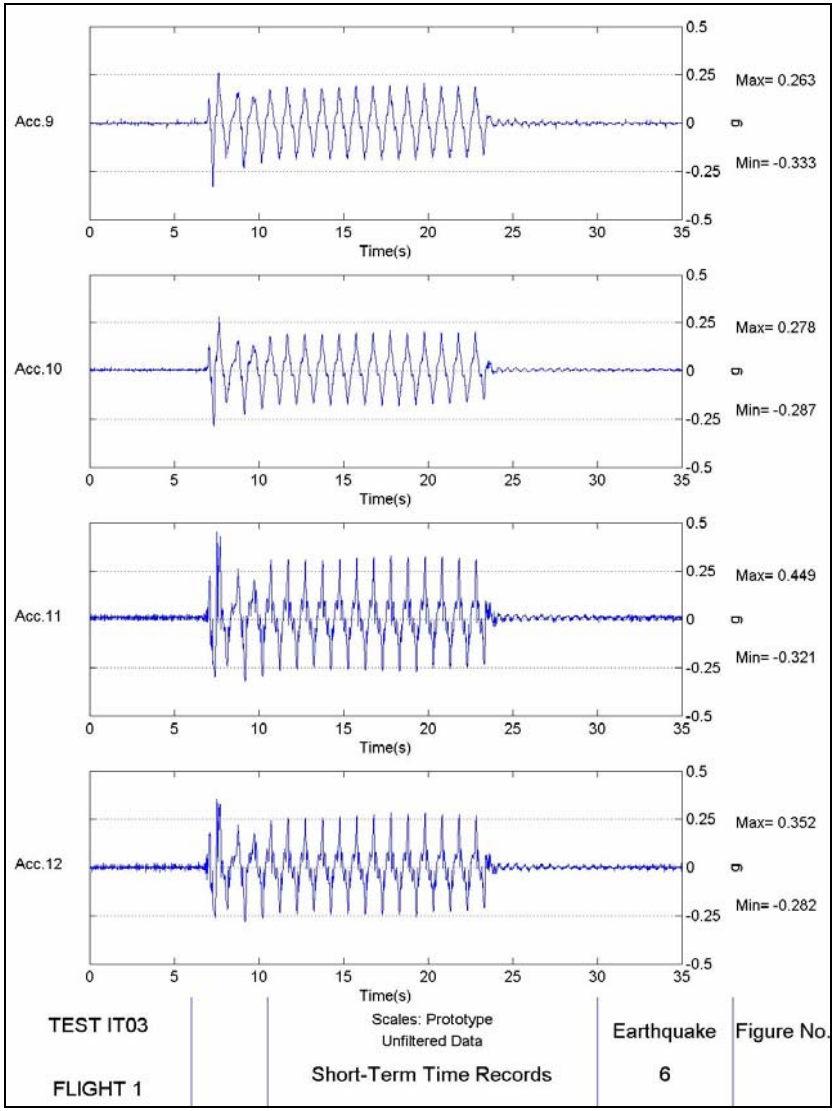

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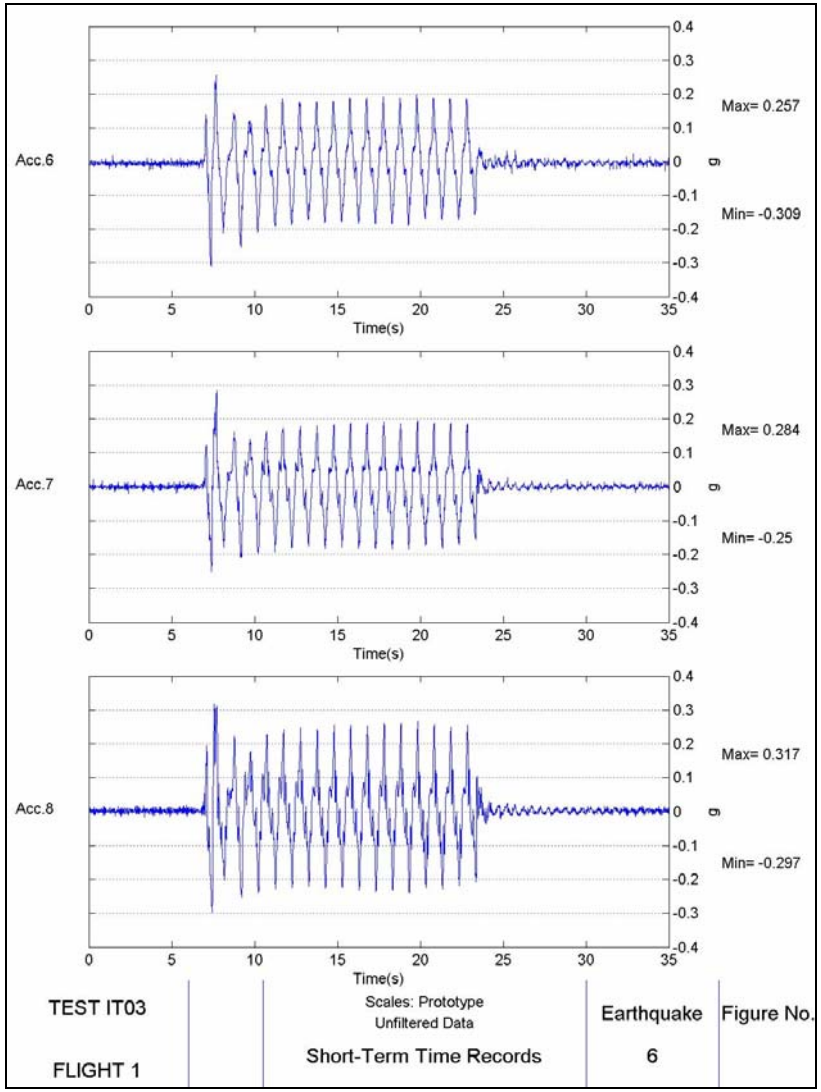
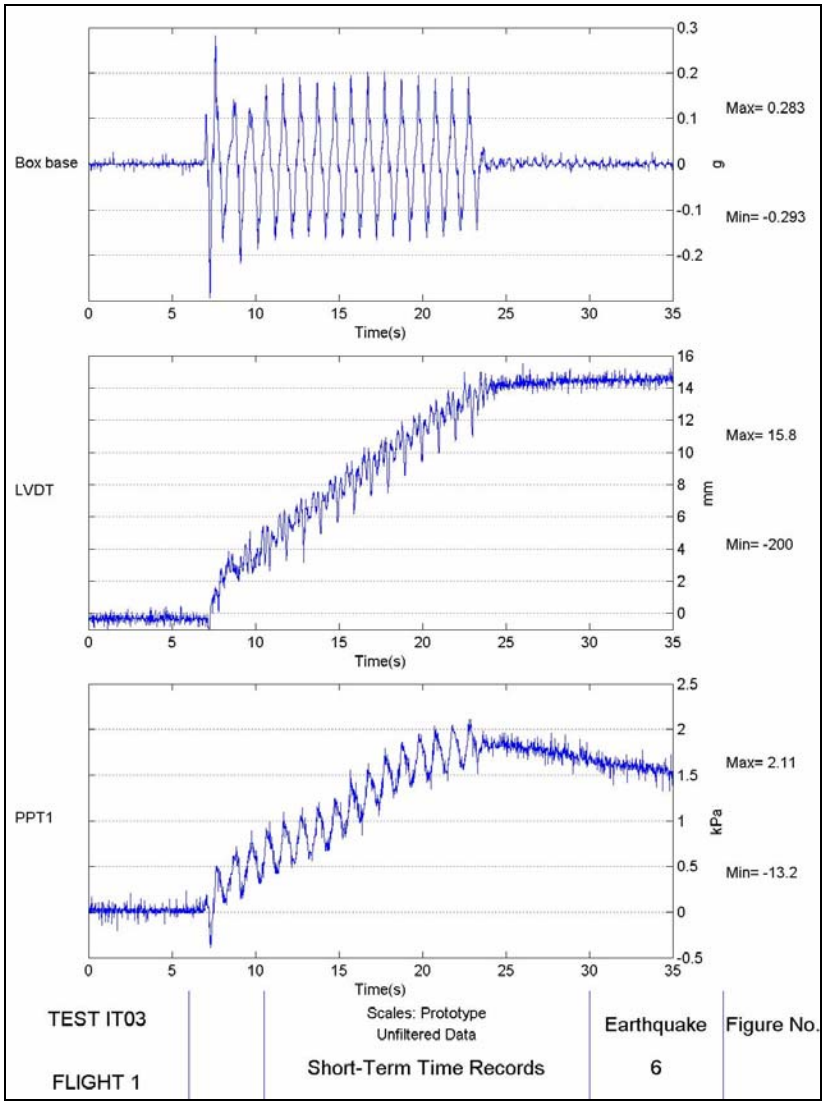
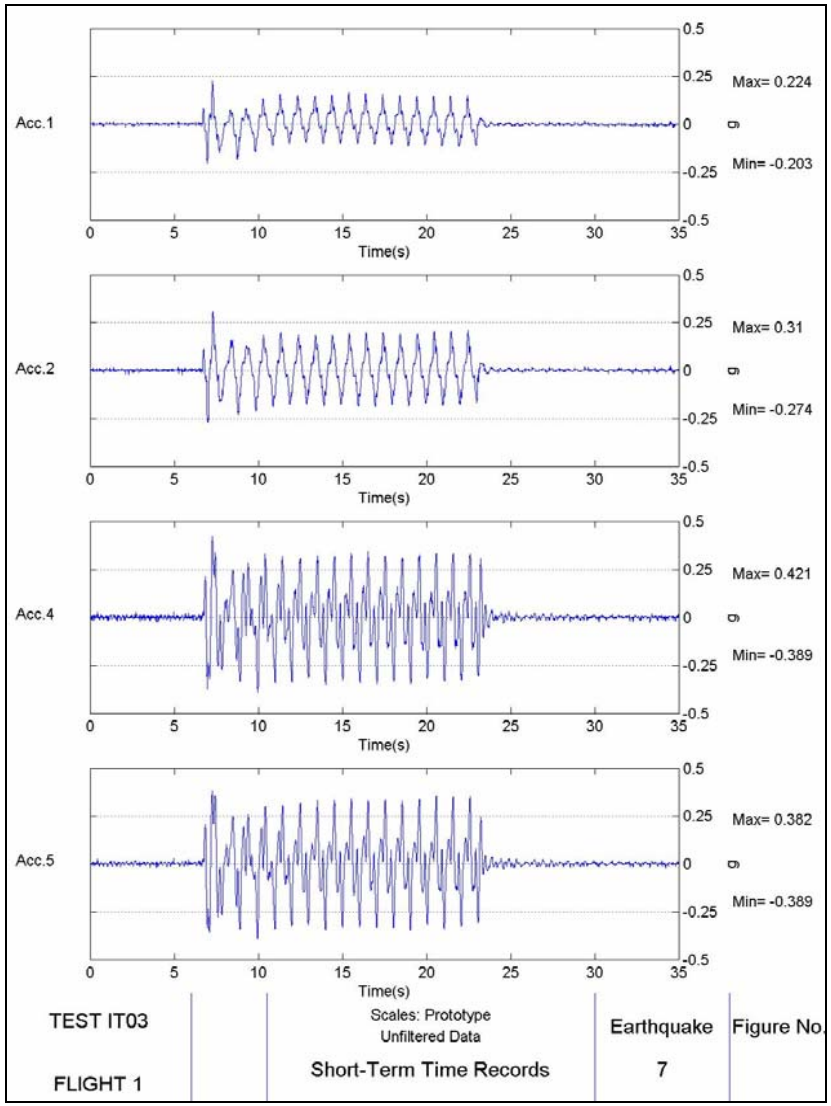
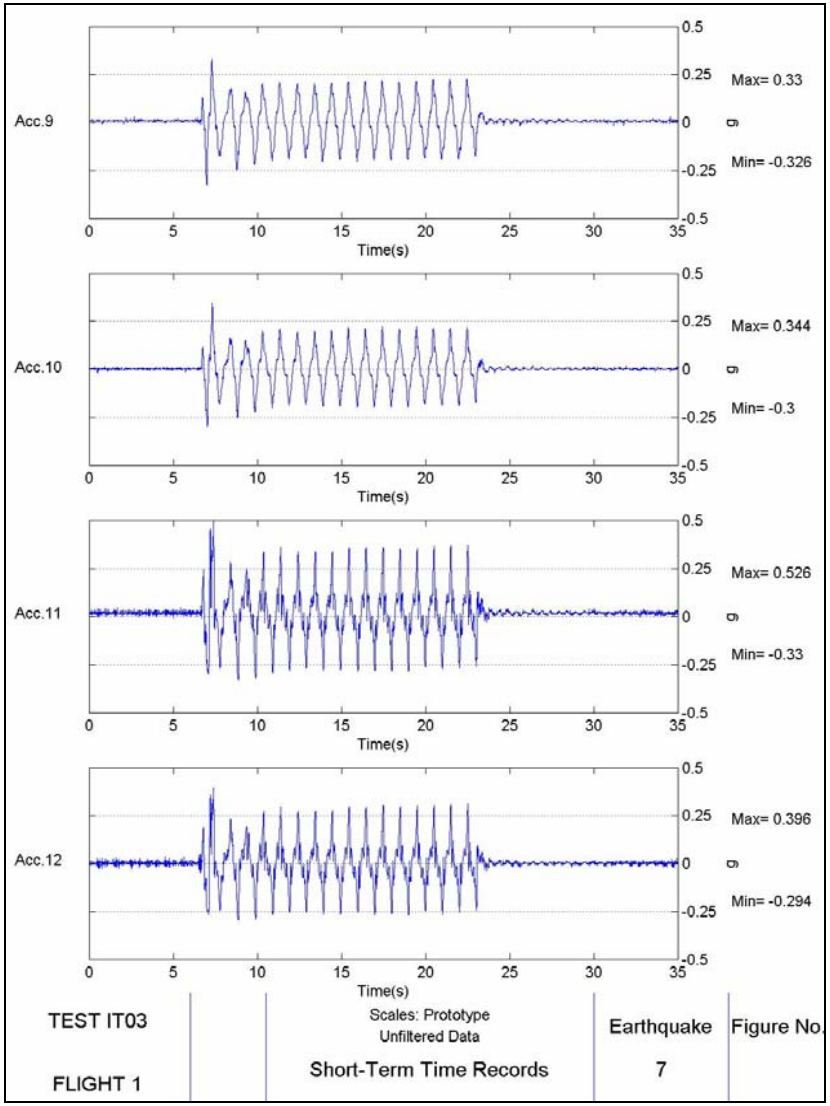


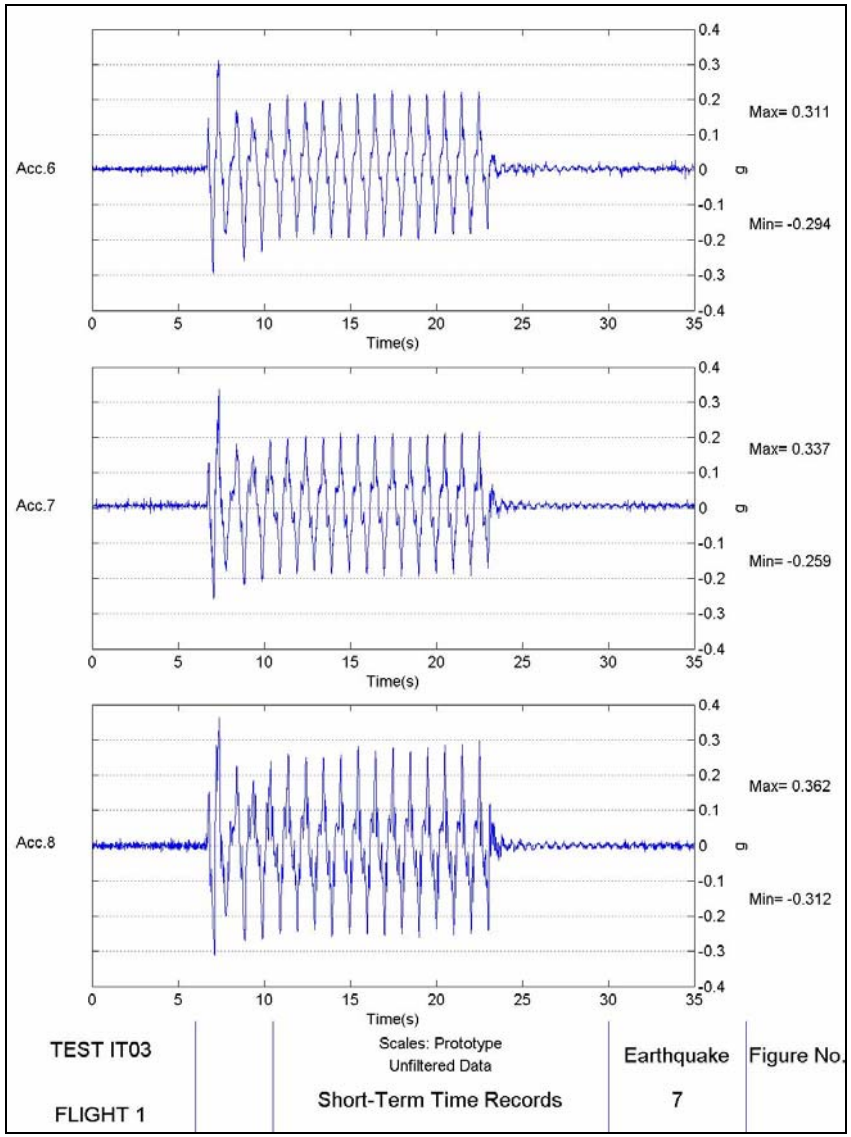


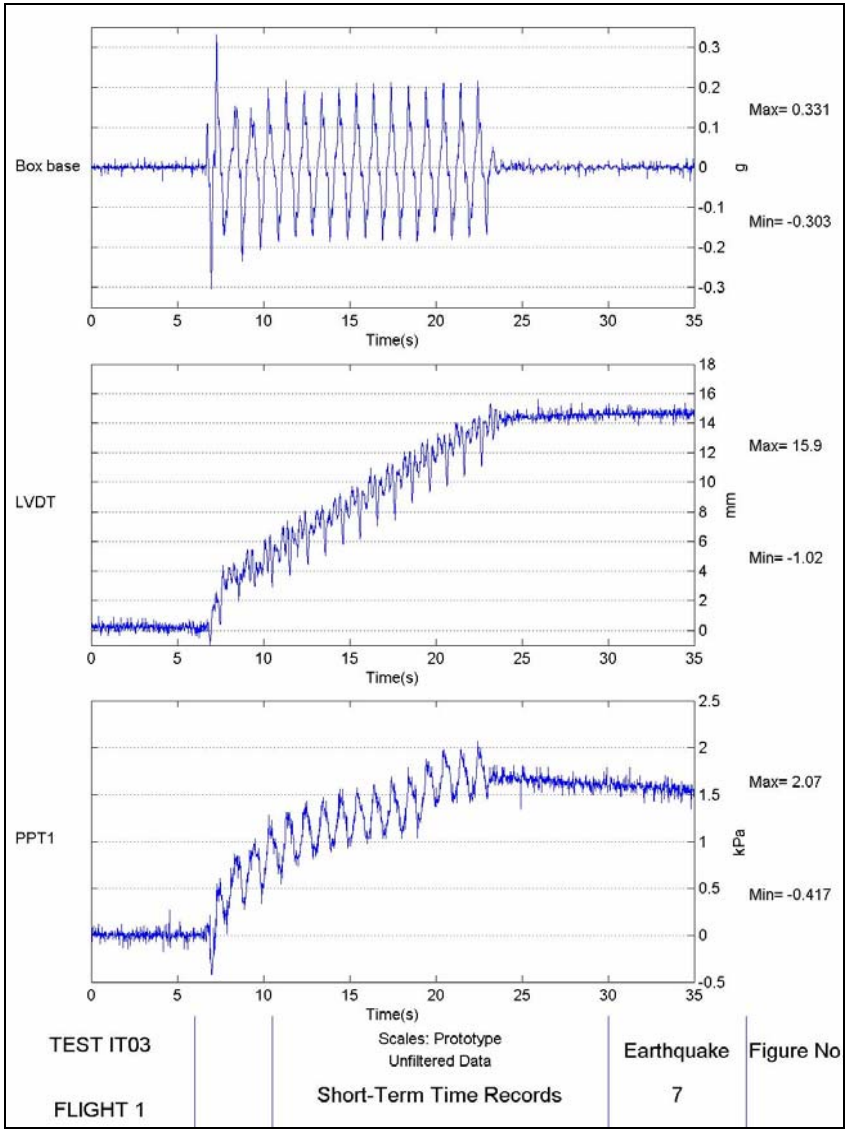
5.13 Data from IT03, Earthquake 7





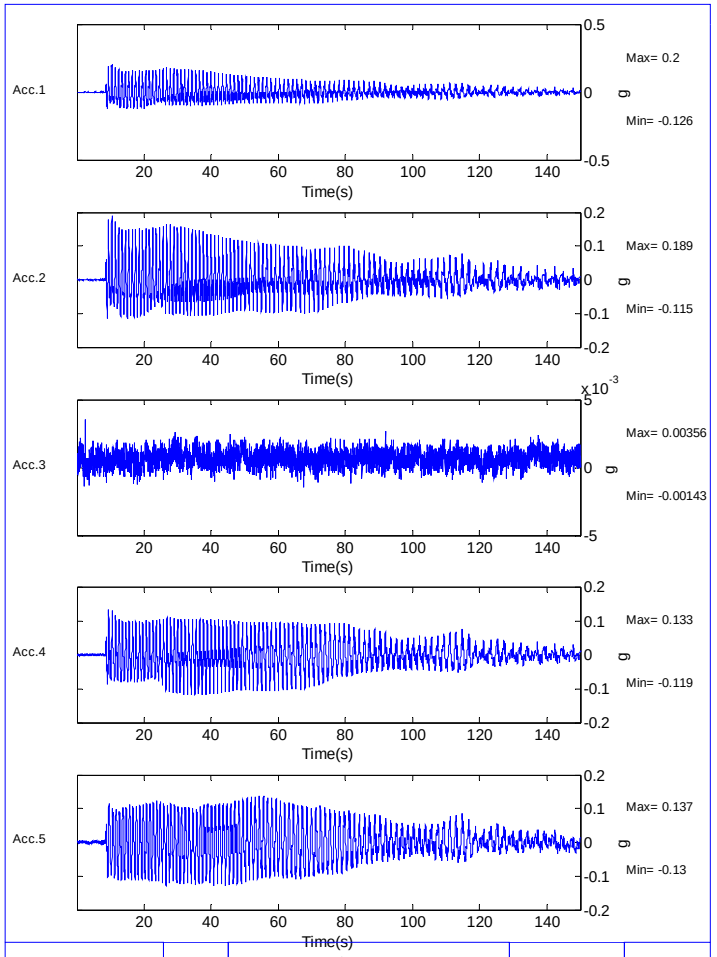
5.14 Data from IT03, Earthquake 7



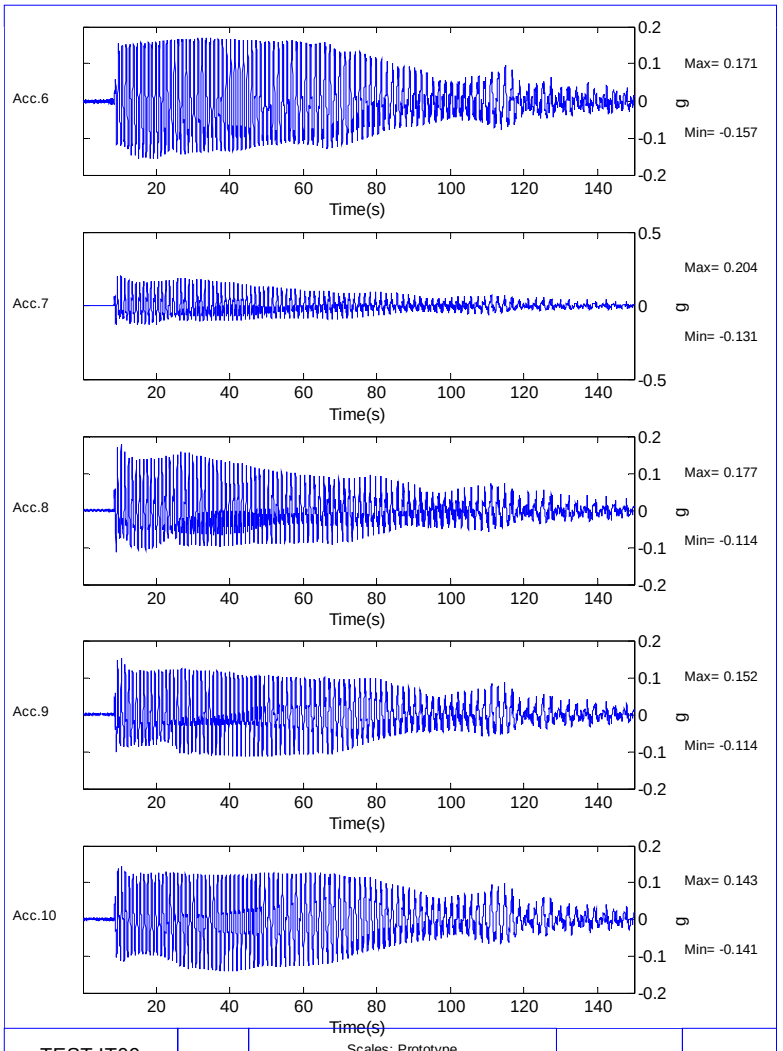


6 Data from IT09

6.1 Data from IT09, Earthquake 1 (50g)

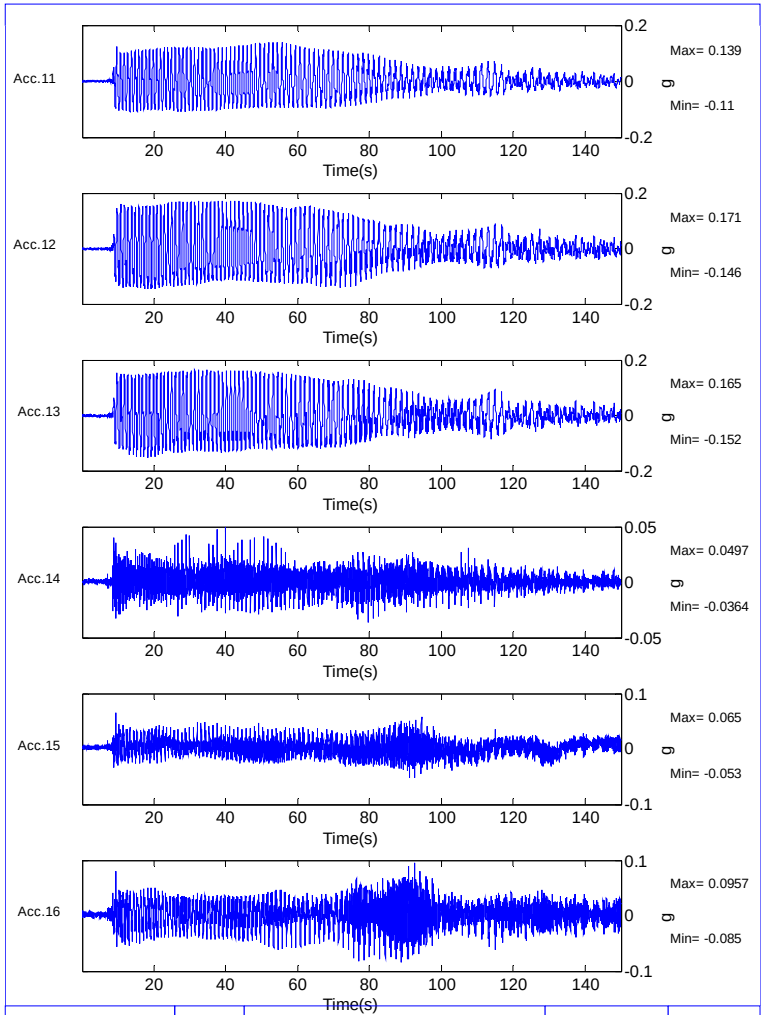


TEST IT09		Scales: Prototype Unfiltered Data	Earthquake	Figure No.
FLIGHT 1		Long-Term Time Records	1	

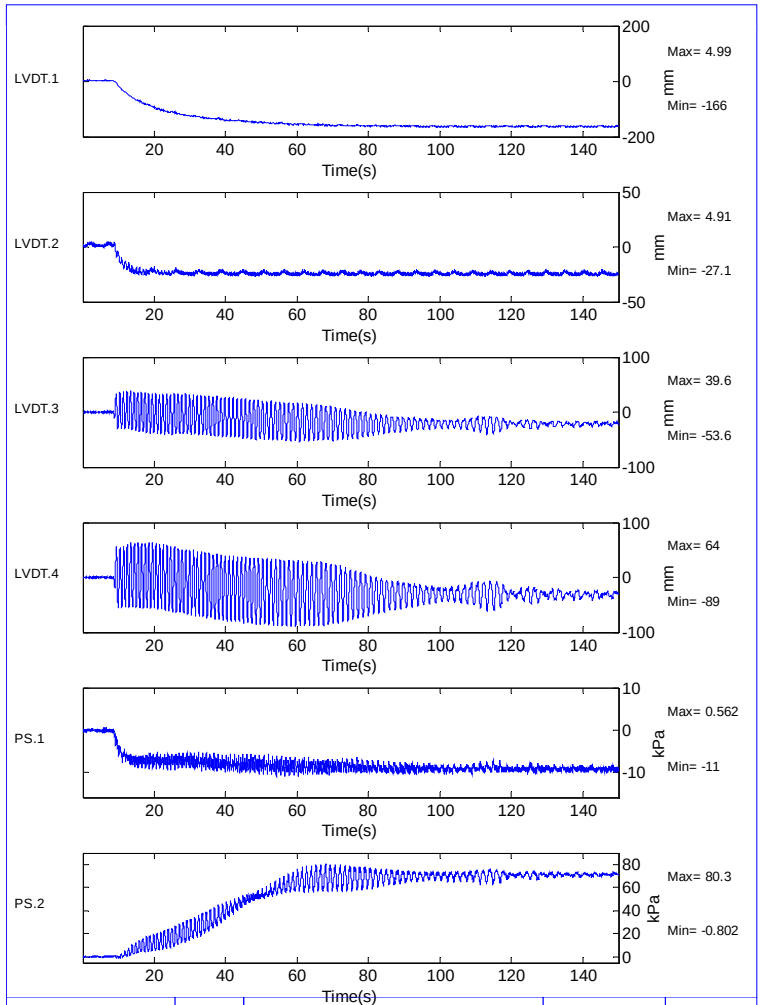


TEST IT09		Scales: Prototype Unfiltered Data	Earthquake	Figure No.
FLIGHT 1		Long-Term Time Records	1	

6.2 Data from IT09, Earthquake 1 (50g)

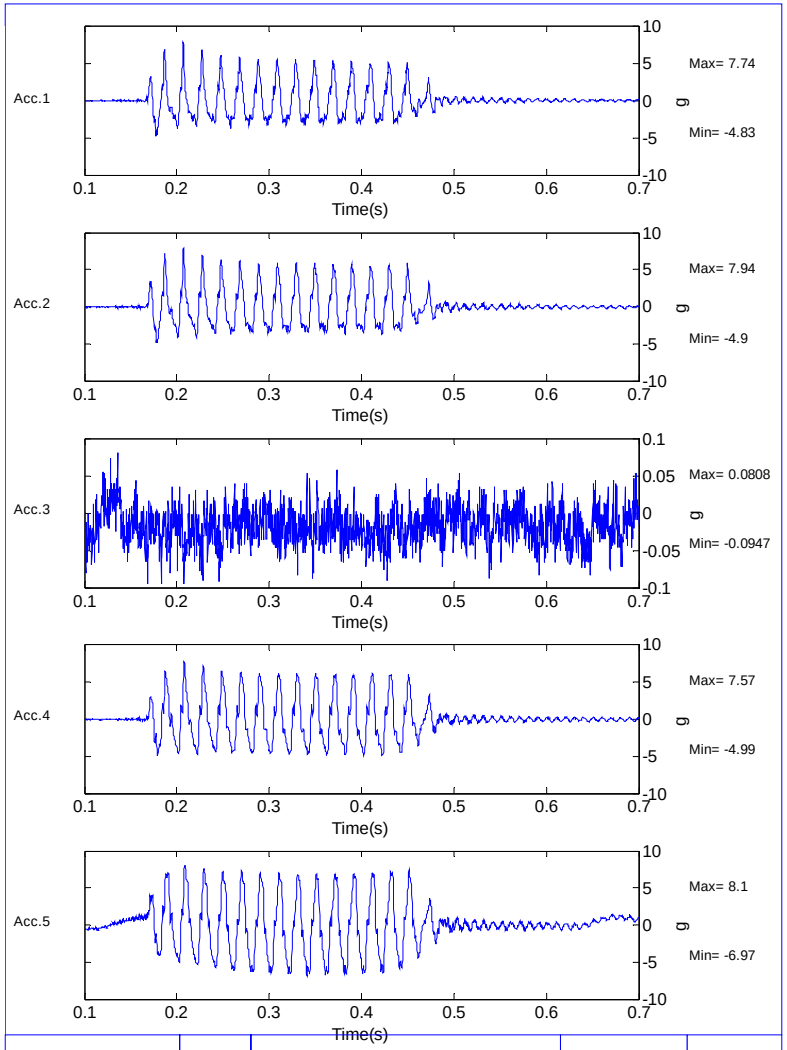


TEST IT09		Scales: Prototype Unfiltered Data	Earthquake	Figure No.
FLIGHT 1		Long-Term Time Records	1	

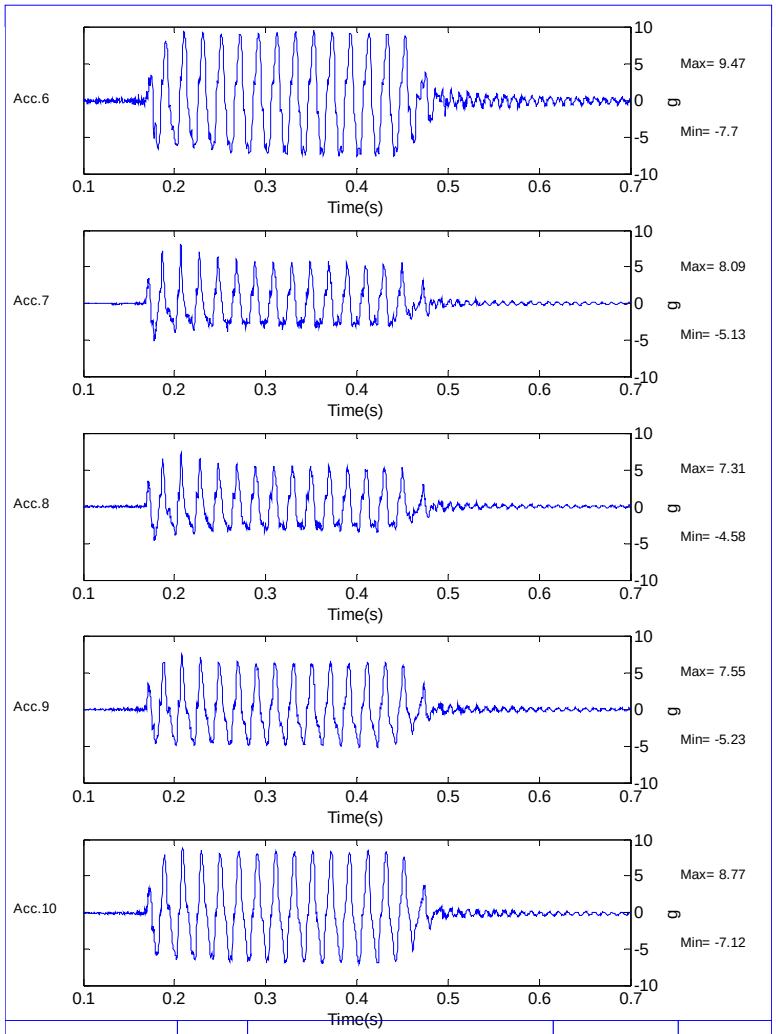


TEST IT09		Scales: Prototype Unfiltered Data	Earthquake	Figure No.
FLIGHT 1		Long-Term Time Records	1	

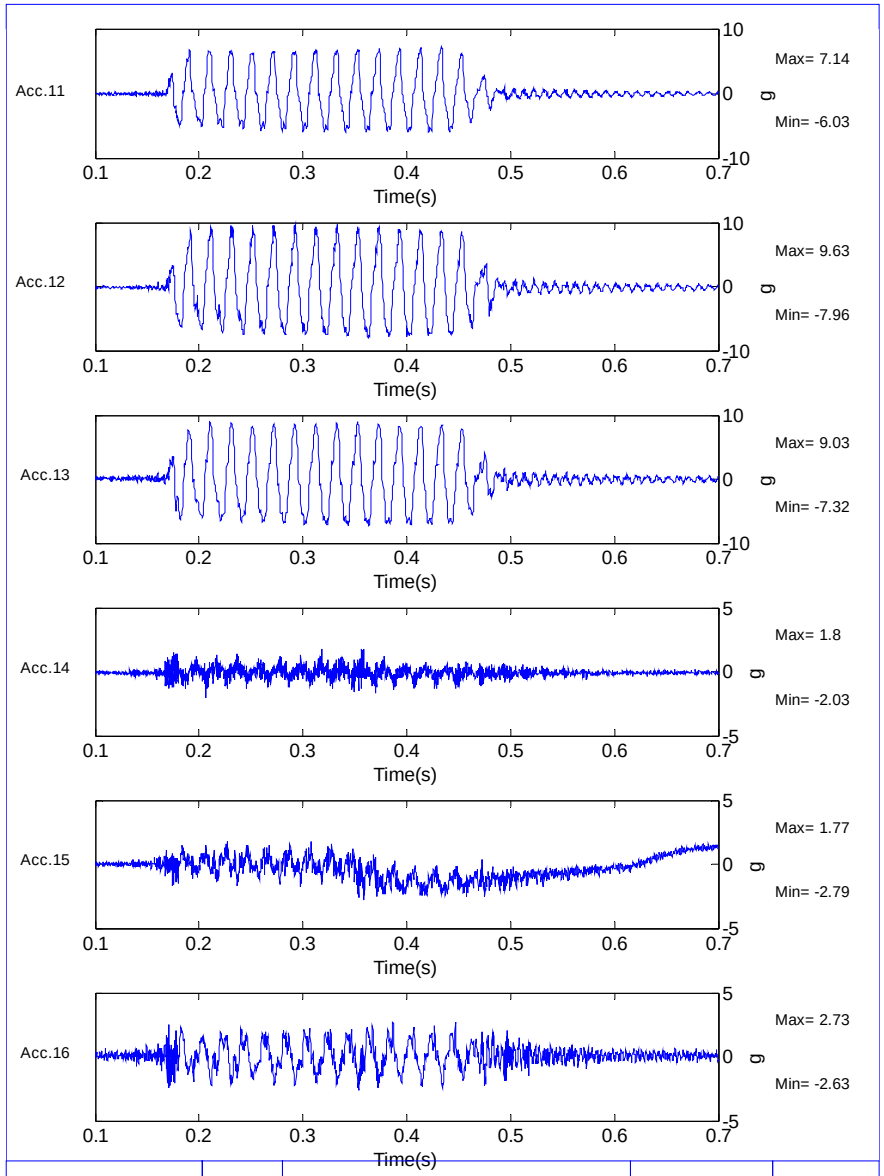
6.3 Data from IT09, Earthquake 2 (80g)



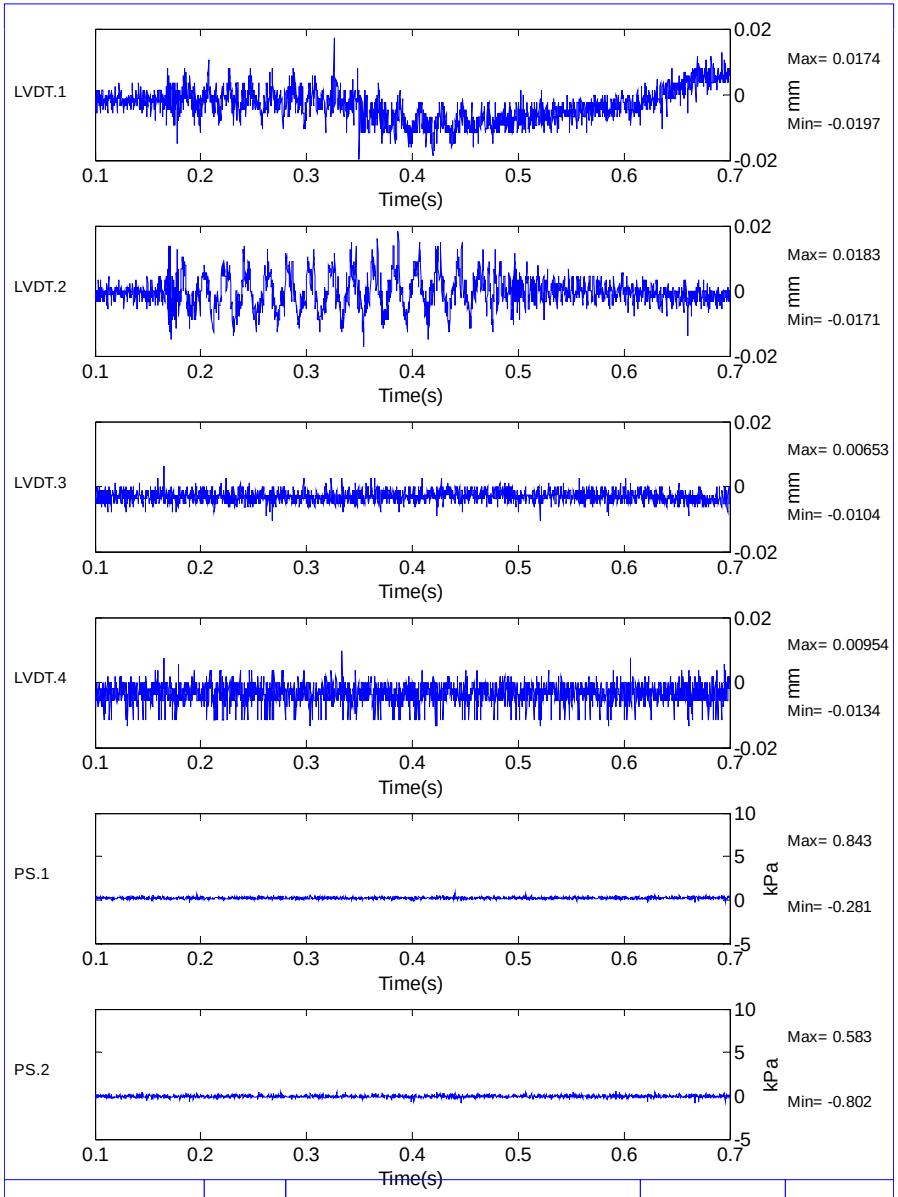
TEST IT09 FLIGHT 1		Scales: Model Unfiltered Data Short-Term Time Records	Earthquake 2	Figure No.



TEST IT09 FLIGHT 1		Scales: Model Unfiltered Data Short-Term Time Records	Earthquake 2	Figure No.

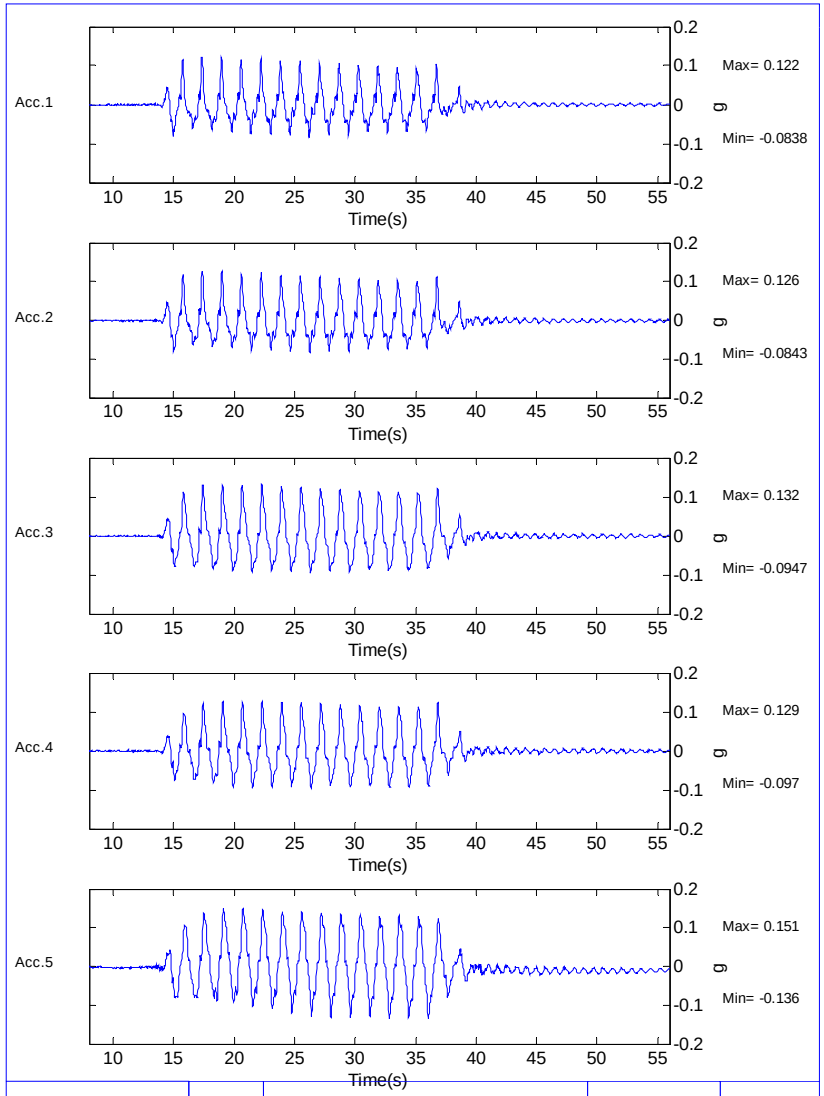


TEST IT09		Scales: Model Unfiltered Data	Earthquake	Figure No.
FLIGHT 1		Short-Term Time Records	2	

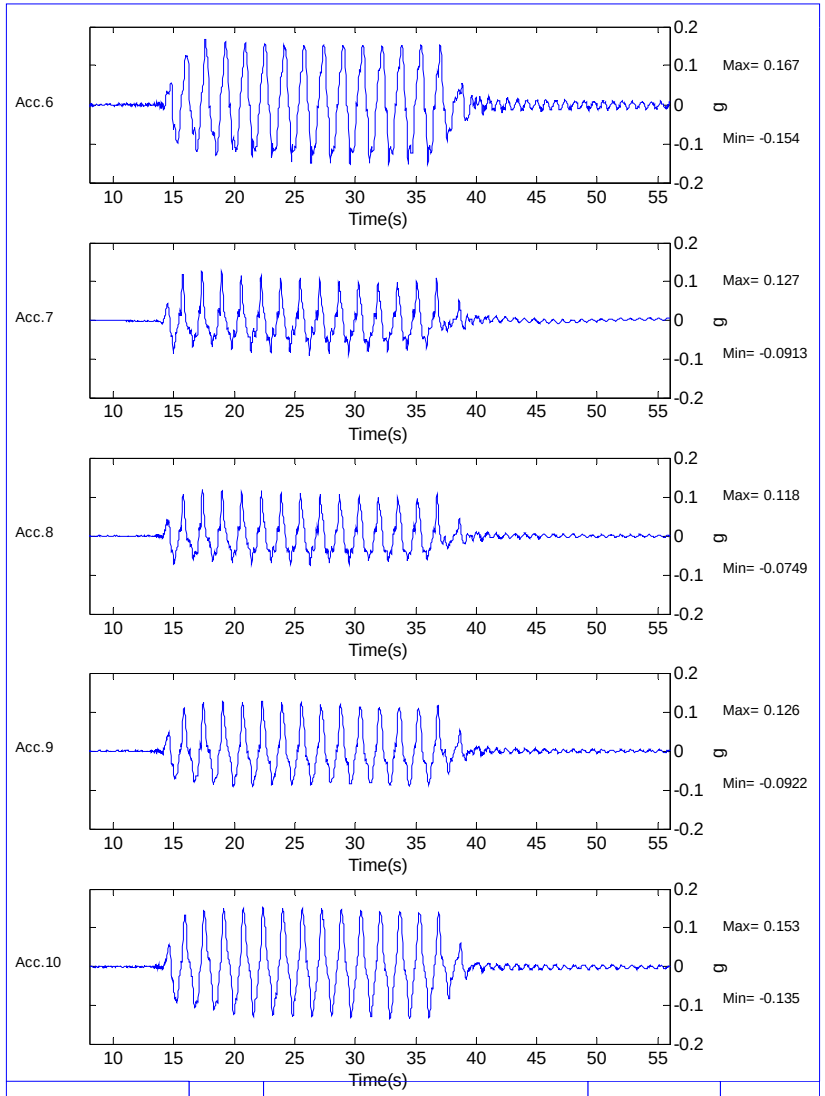


TEST IT09		Scales: Model Unfiltered Data	Earthquake	Figure No.
FLIGHT 1		Short-Term Time Records	2	

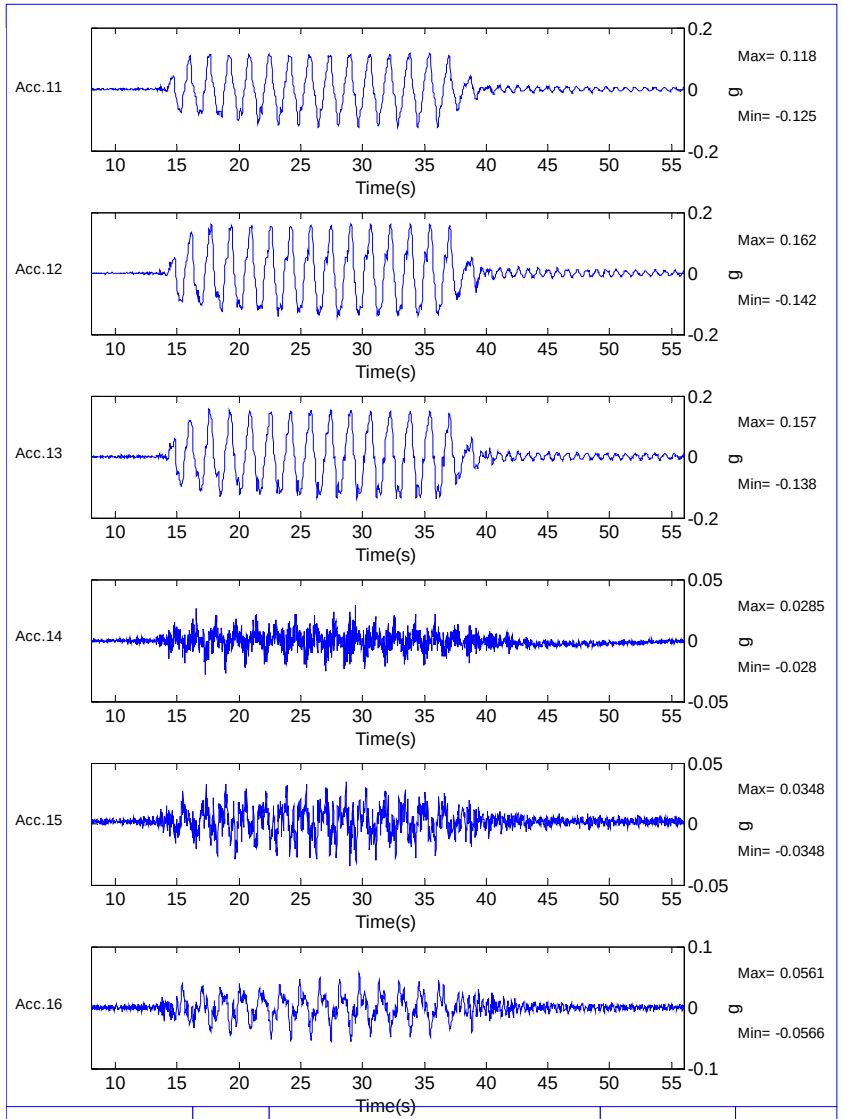
6.4 Data from IT09, Earthquake 3 (80g)



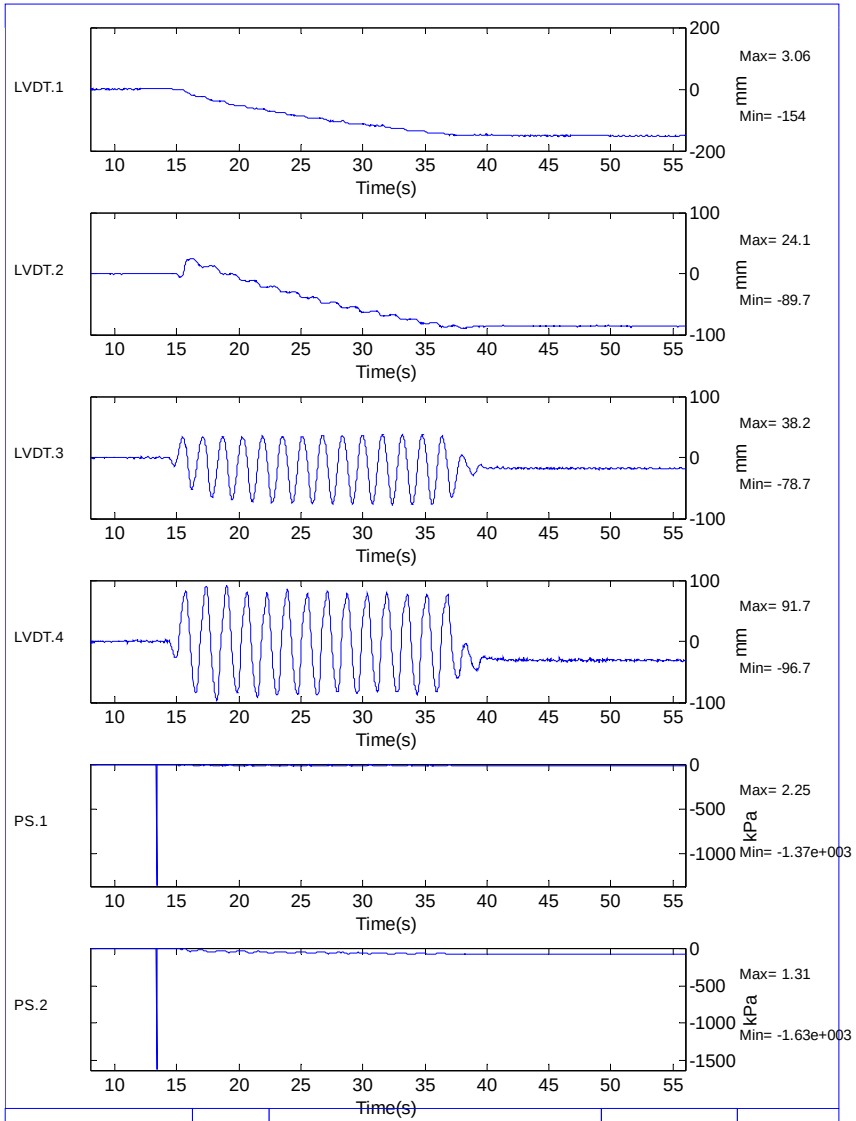
TEST It09		Scales: Prototype Unfiltered Data	Earthquake	Figure No.
FLIGHT 1		Short-Term Time Records	3	



TEST It09		Scales: Prototype Unfiltered Data	Earthquake	Figure No.
FLIGHT 1		Short-Term Time Records	3	

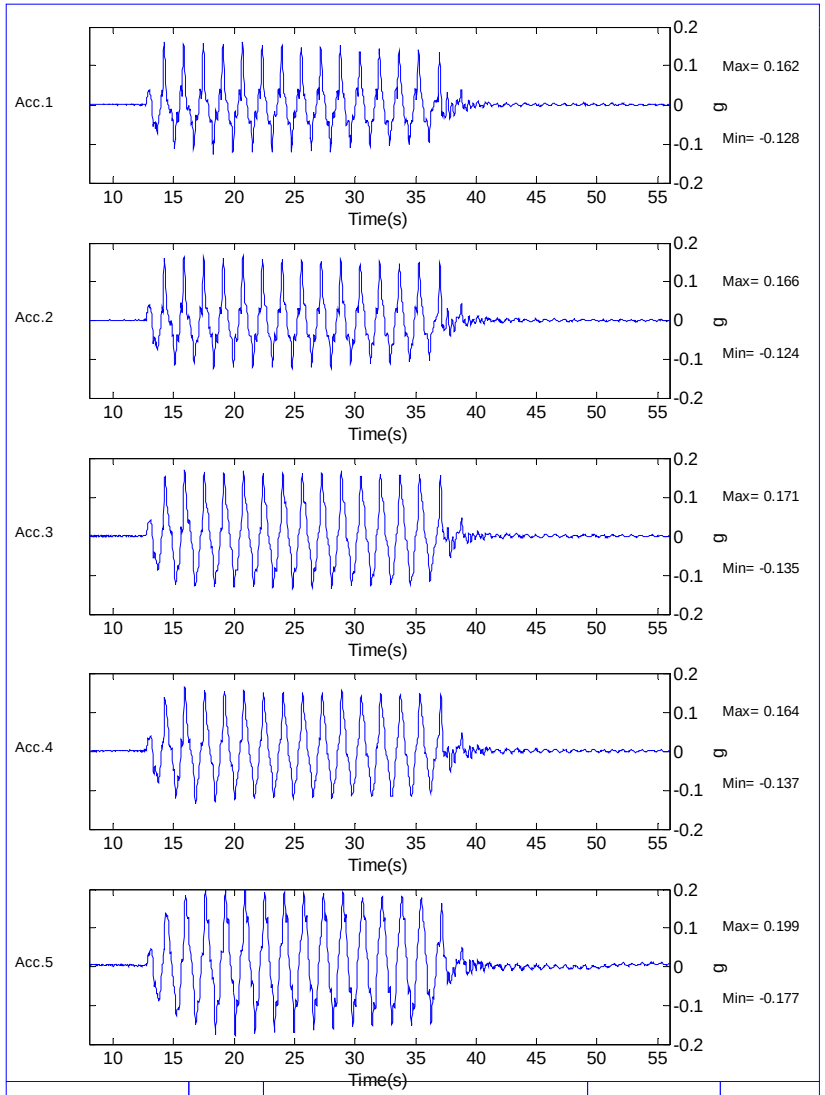


TEST It09		Scales: Prototype Unfiltered Data	Earthquake	Figure No.
FLIGHT 1		Short-Term Time Records	3	

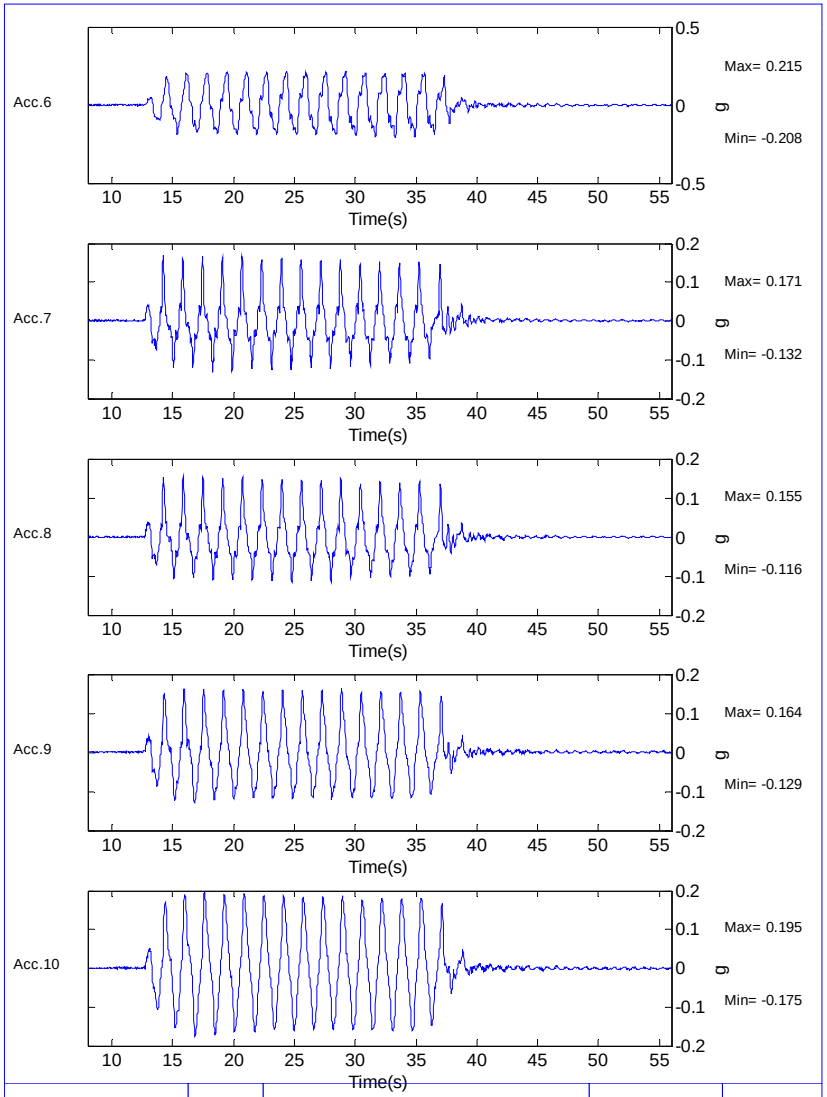


TEST It09		Scales: Prototype Unfiltered Data	Earthquake	Figure No.
FLIGHT 1		Short-Term Time Records	3	

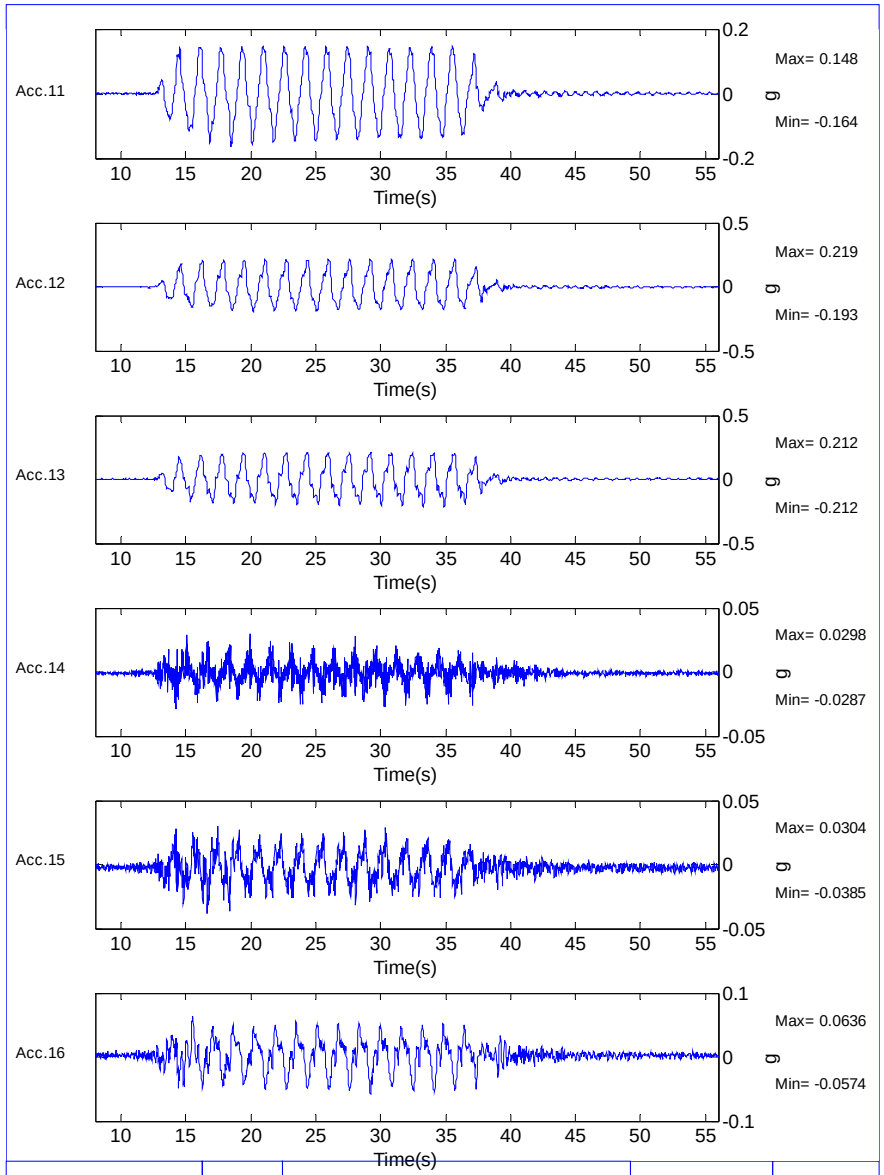
6.5 Data from IT09, Earthquake 4 (80g)



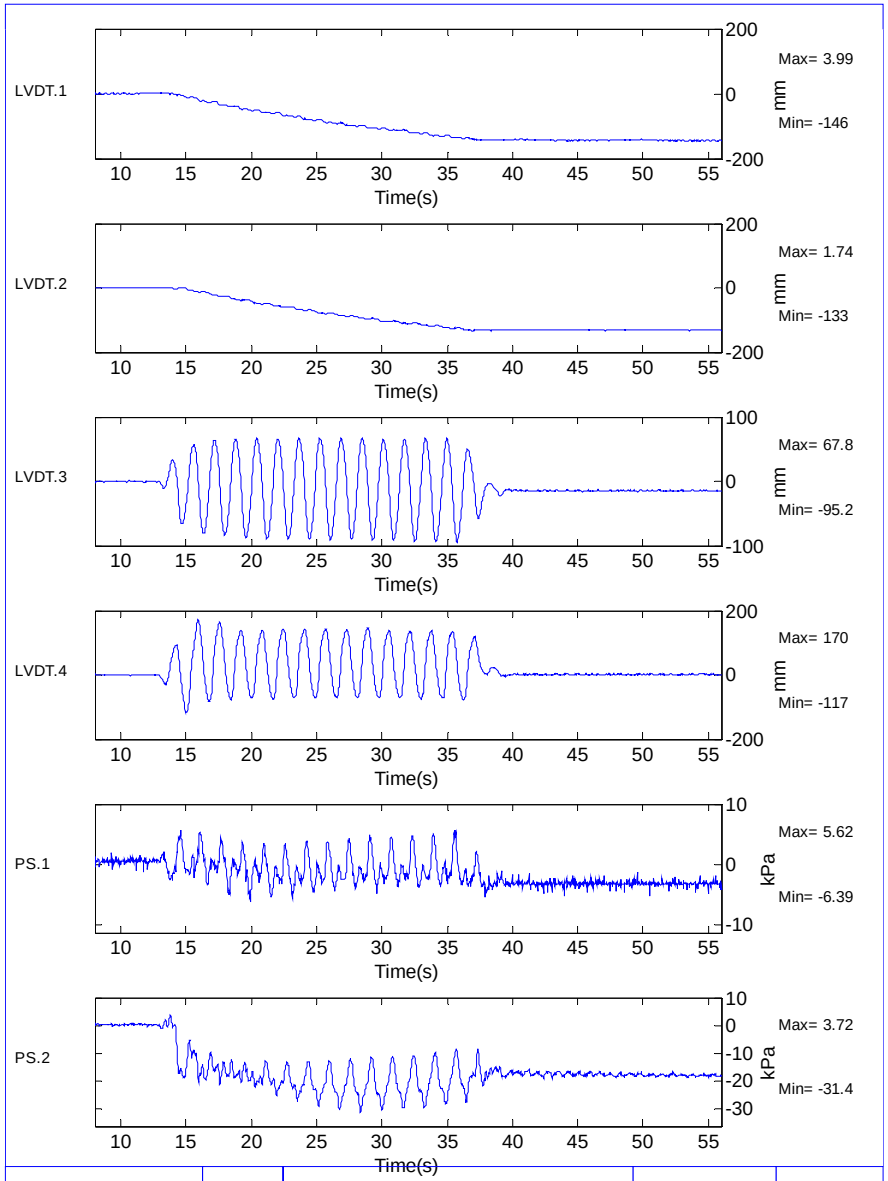
TEST It09		Scales: Prototype Unfiltered Data	Earthquake	Figure No.
FLIGHT 1		Short-Term Time Records	4	



TEST It09		Scales: Prototype Unfiltered Data	Earthquake	Figure No.
FLIGHT 1		Short-Term Time Records	4	

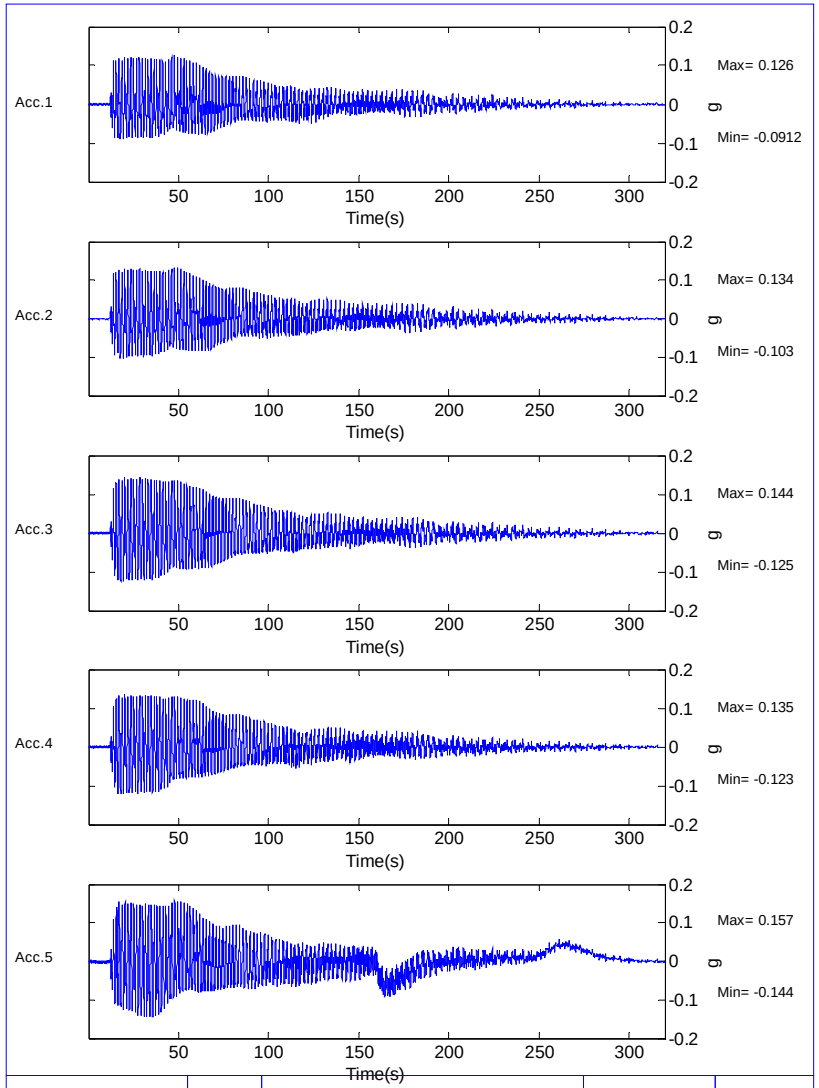


TEST It09		Scales: Prototype Unfiltered Data	Earthquake	Figure No.
FLIGHT 1		Short-Term Time Records	4	

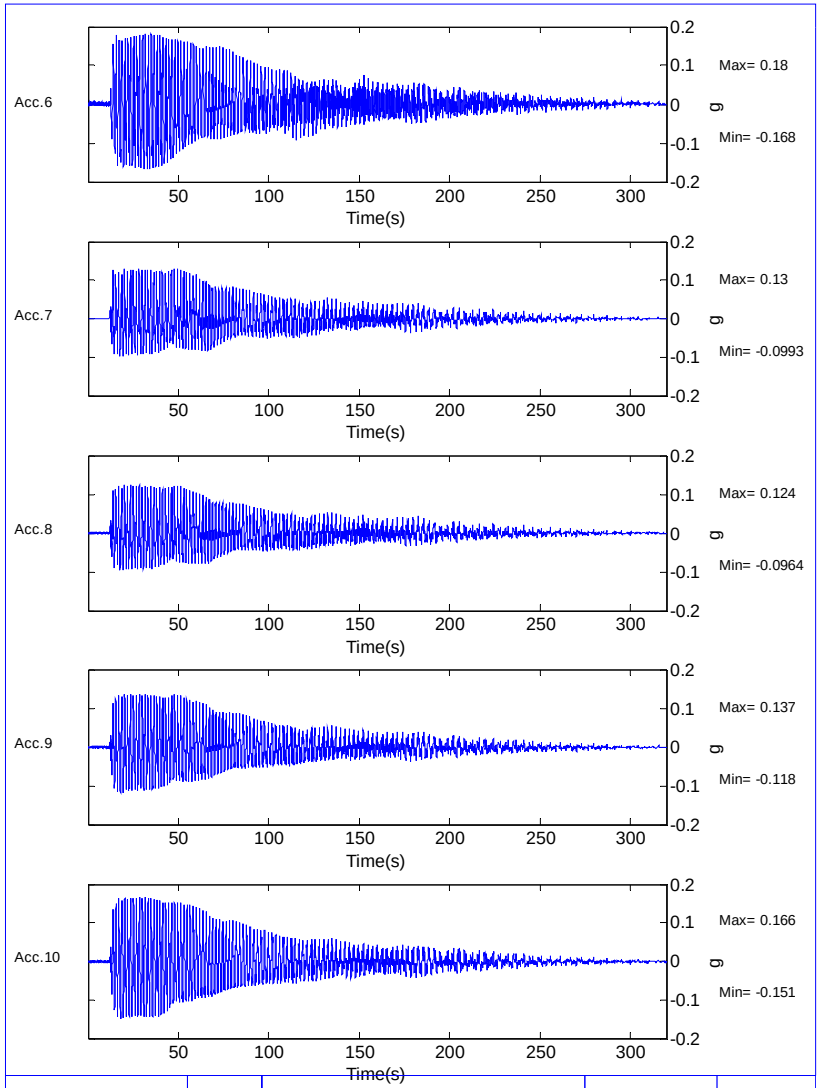


TEST It09		Scales: Prototype Unfiltered Data	Earthquake	Figure No.
FLIGHT 1		Short-Term Time Records	4	

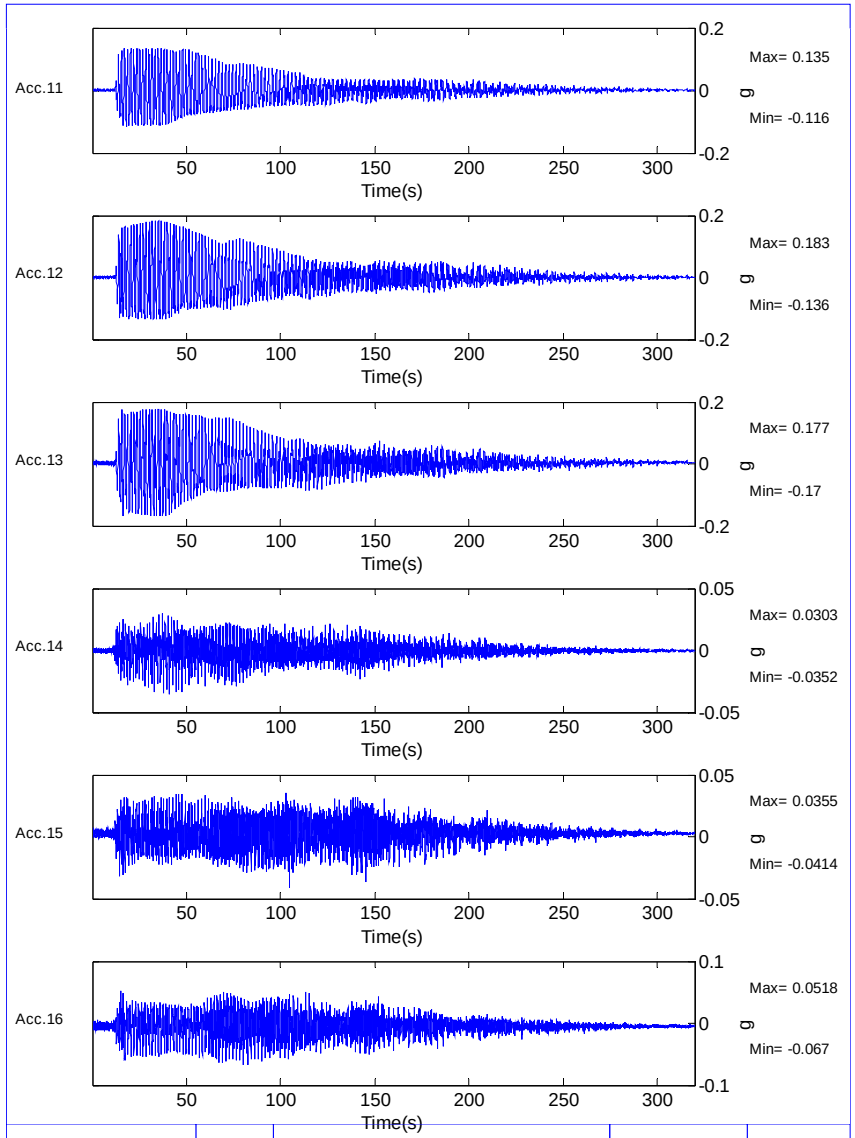
6.6 Data from IT09, Earthquake 5 (80g)



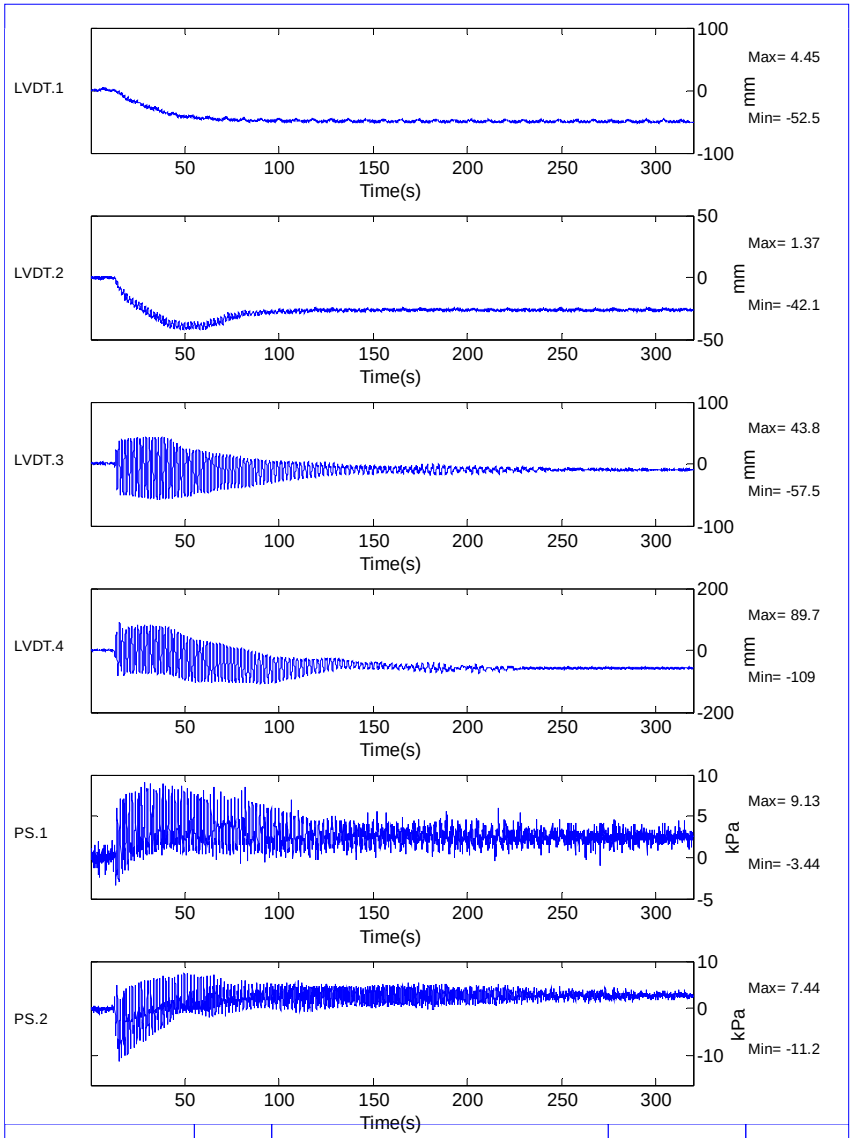
TEST It09 FLIGHT 1		Scales: Prototype Unfiltered Data Long-Term Time Records	Earthquake 5	Figure No.



TEST It09 FLIGHT 1		Scales: Prototype Unfiltered Data Long-Term Time Records	Earthquake 5	Figure No.

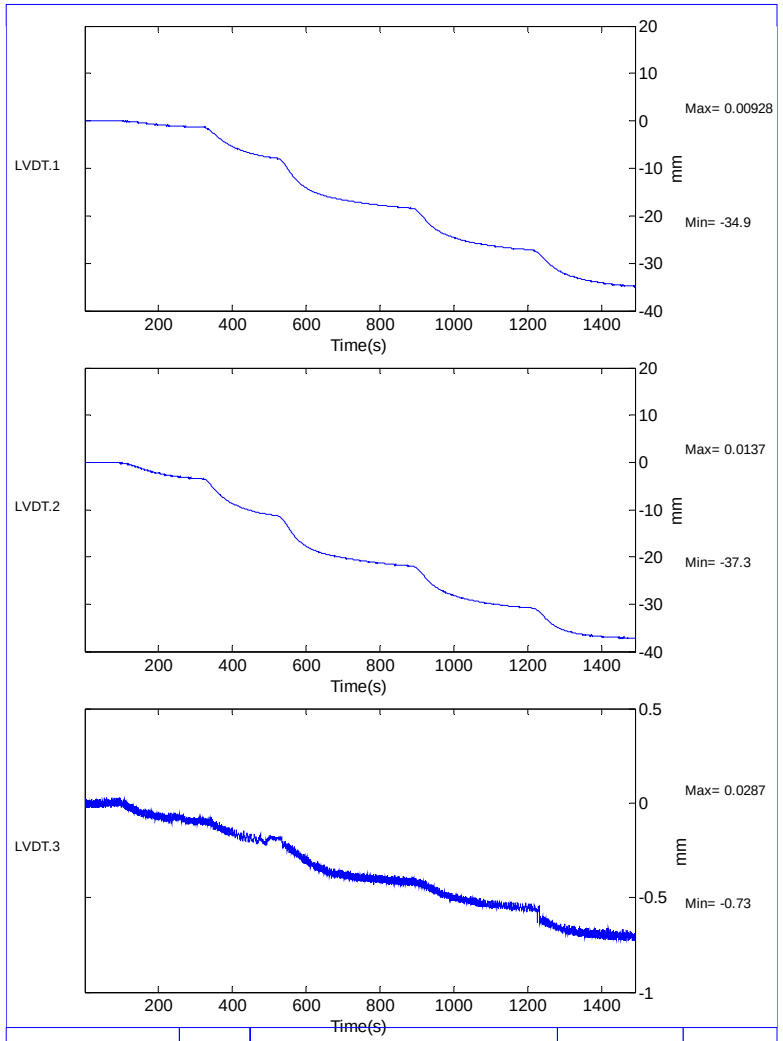


TEST It09		Scales: Prototype Unfiltered Data	Earthquake	Figure No.
FLIGHT 1		Long-Term Time Records	5	

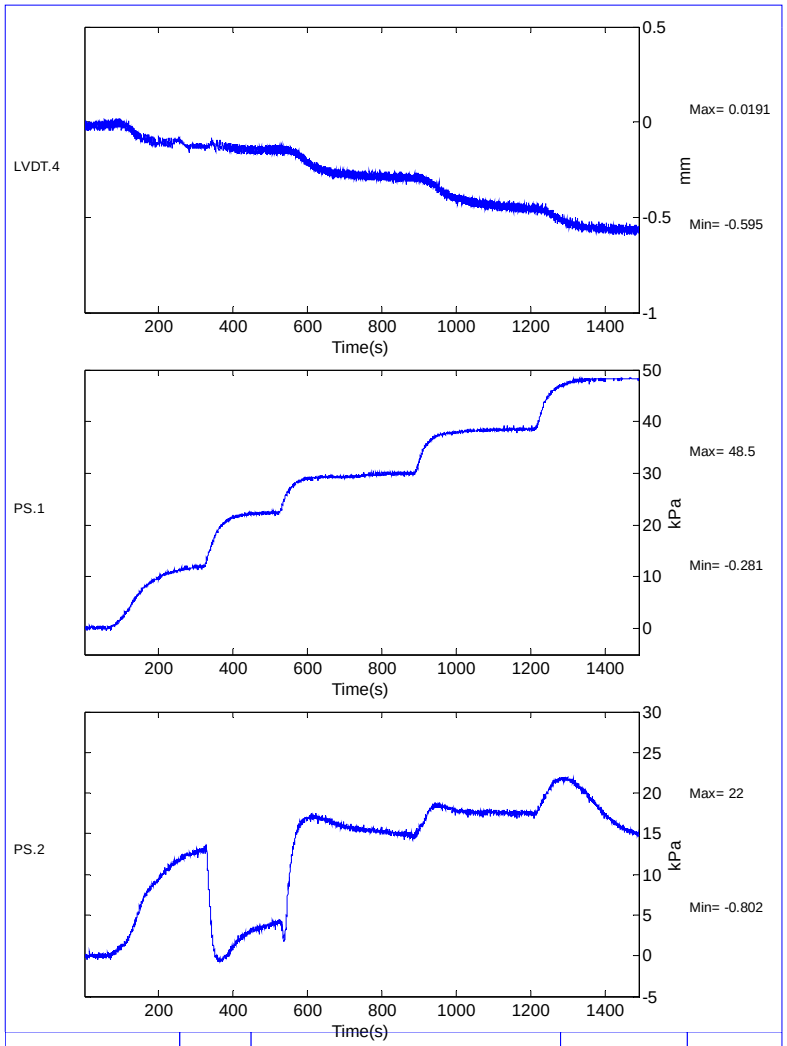


TEST It09		Scales: Prototype Unfiltered Data	Earthquake	Figure No.
FLIGHT 1		Long-Term Time Records	5	

6.7 Swing up to 50g

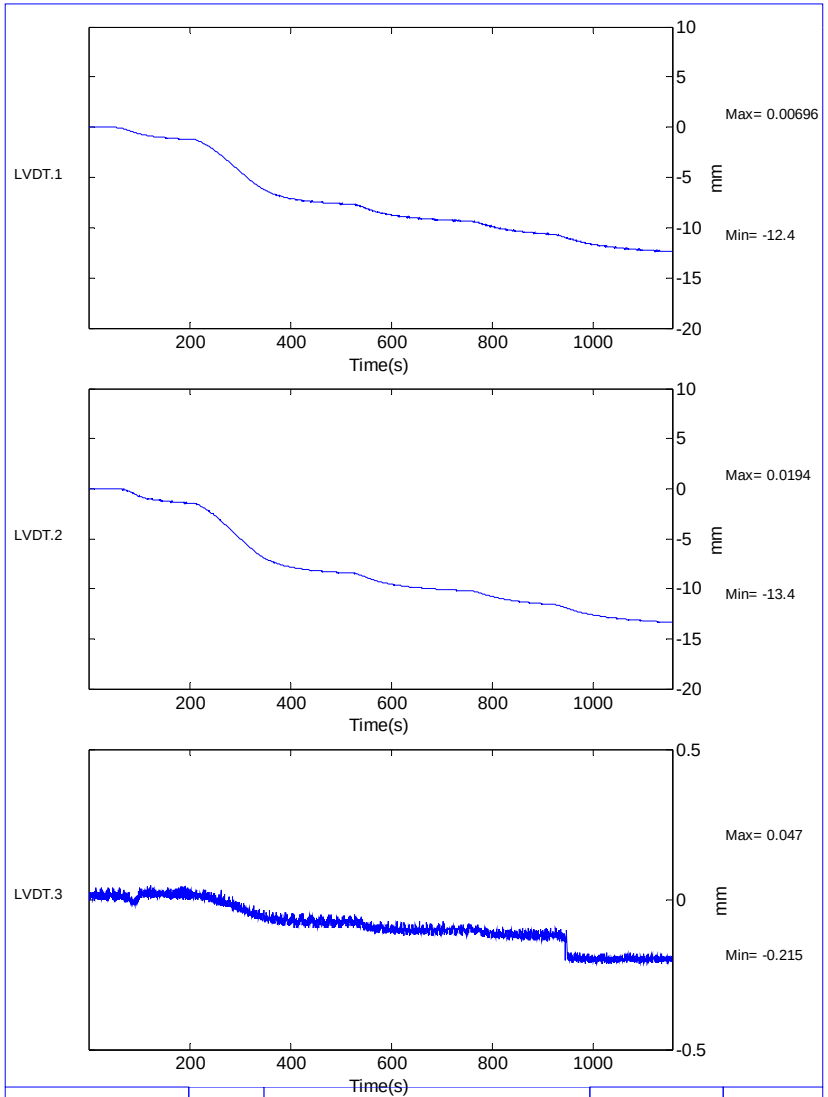


TEST IT09		Scales: Model Unfiltered Data	Earthquake	Figure No.
FLIGHT 1		Long-Term Time Records	Swing up1	

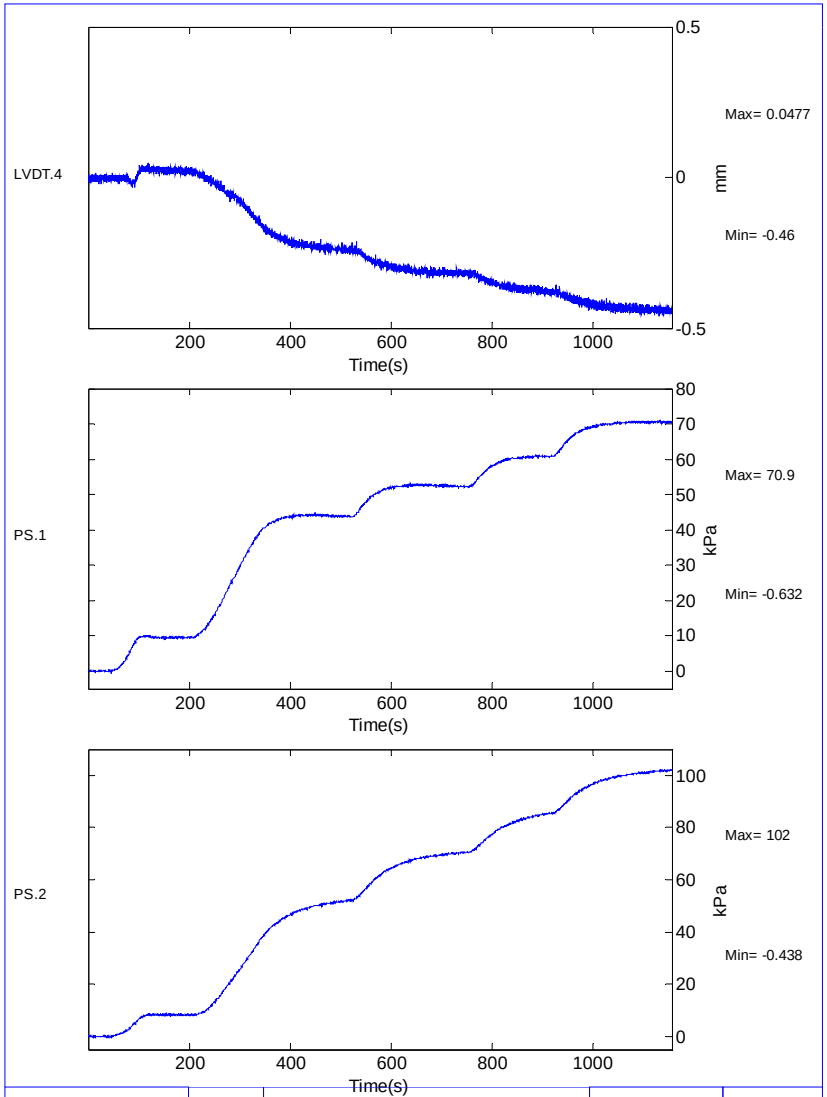


TEST IT09		Scales: Model Unfiltered Data	Earthquake	Figure No.
FLIGHT 1		Long-Term Time Records	Swing up1	

6.8 Swing up to 80g



TEST It09		Scales: Model Unfiltered Data	Earthquake	Figure No.
FLIGHT 1		Long-Term Time Records	Swing up4	



TEST It09		Scales: Model Unfiltered Data	Earthquake	Figure No.
FLIGHT 1		Long-Term Time Records	Swing up4	