Deltares

DelftCluster Railway transition zones

Factual report short term measurement 2008

A.D. Hartman

Deltares

Title
DelftCluster Railway transition zones

Project	Reference	Pages
1001069-000	1001069-000-GEO-0004-sr	41

Summary
For the Delft Cluster Railway transition zones project, extensive measurements were made. The measurements are divided into three types. The short-term measurements are the subject of this report. The long-term measurements and soil investigation are described in other reports.

The goal of the report is to make sure that all measurements are available to everyone involved and to give all data proper names. This will prevent problems with wrong or old data.

This report gives an overview of both data measured on site and data as provided to Deltares by third parties.

Some of the measured raw data is presented as graphs. Where this is the case both the raw and the graphical data are provided on CD-Rom.

Version	Date	Author	Initials	Review	Initials	Approval	Initials
01	Dec.2008	A.D. Hartman		dr.ir P. Hölscher		ing. M. Hutteman	
02	Nov. 2009	A.D. Hartman		dr.ir P. Hölscher		ing. M. Hutteman	

State
final

Contents

List of Tables

List of Figures

1 Introduction

This report gives an overview of the extensive short term measurements undertaken for the Delft Cluster project Railway transition zones. The objective of the project was to measure the response of the railway track and ground, at a transition zone' during the passage of regular service trains. Both Deltares and the University of Southampton performed measurements at the Gouda Goverwelle (GoGo) site. Both institutes have large amounts of measured data available for the project. Secondly, additional data is provided by Dutch railway operators. In order to make sure that data can be shared without problems it is essential that all data is properly documented. To ensure a problem free exchange of measurements and data, they are not only summarized in this report but they are given proper names as well. This way there will be less chance of misunderstandings between the two institutes when discussing measurement data.

2 Train data

During the short-term measurements, four train types passed the test site. This chapter gives all available data on the trains. Names are given to ensure clarity. For each train type a further clarification is provided to differentiate between carriages with and without motor and loaded or unloaded. A shorthand for the train names is given in Table 2.1 at the end of this paragraph.

2.1 Locomotive + carriages

This train type consists of a locomotive, which pulls or pushes non-driven carriages. The official name for these trains as used by the Dutch Railways (NS) are EL 1700 series for the locomotive and ICR for the carriages. In this project they will be named locomotive + carriages with the number of carriages given as a number. For example: Locomotive + 7 carriages. If there are 2 locomotives the place of the second locomotive is also given because it is much heavier than the carriages. A train with two locomotives at one end of the train will be described as: 2 Locomotives + 7 carriages. A train with locomotives at either end will be: Locomotive + 7 carriages + locomotive.

Figure 2.1 Carriage (ICR)

Figure 2.2 1700 series locomotive

The available data on the trains is given in Tables 1-9 in Appendix 1

2.2 Mat 64

Mat 64 is an abbreviation as used by the Dutch railways (NS) for Materiel (equipment) built in 1964. This train type is a self driven single deck electric train. These trains have two sub types. The Mat 64 type V which consist of 2 cars, both driven, and the Mat 64 type T which consist of four cars of which 2 are driven. The main difference, which is relevant for the research, is that the undriven carriages of the type T are lighter than the drives ones.

Figure 2.3 Mat 64 type V

Figure 2.4 Mat 64 type T

2.3 ICM

The ICM is an electric self driven train consisting of 3 or 4 cars. There are four types of this train. The ICM 1 and ICM 2 consist of 3 cars and have four driven axles on 2 bogies. The lager ICM 3 and ICM 4 consist of 4 cars and have 6 driven axles on 3 bogies. As with the Mat 64, the driven cars are heavier.

Figure 2.5 ICM type 1 or 2

Figure 2.6 ICM type 3 or 4

2.4 Double decker

The most modern trains used by NS are double decked self driven electric trains. The name, which the NS uses, is DD-VIRM or simply VIRM. To prevent confusion between ICR (2.1), ICM (2.3) and VIRM this train will simply be called a double decker. There are two types of this train. The VIRM-IV consists of four cars of which the first and last are driven and one car is equipped with brake energy recovery system. The VIRM-VI consists of six cars and has one extra driven car in the center of the train.

Figure 2.7 Double decker type-IV

Figure 2.8 Double decker type-VI

2.5 Other train types

During the 6th of may measurements two other train types passed the test site. However, since the raw measurement data for these trains were not selected for processing, no additional train data is provided. These train types were freight trains of varying composition and Sprinter, a light rail vehicle for transport of people over short distances. There is one more common NS train type. This type is double decker push-pull trains. However these trains did not pas the test site during measuring at all.

2.6 Structure of train data tables

The train data tables in Appendix A give separate mass for the car, the bogie and the wheel set. The axle load and the net weight of the complete train can be calculated from these masses as follows:

- Axle load = ¼ m_{car} + ½ m_{bogie} + $m_{wheelset}$
- Net weight = m_{car} + 2*m_{bogie} + 4*$m_{wheelset}$

Name	Shorthand	Data on appendix page
Locomotive + 7 carriages	L+7C	2
Locomotive + 7 carriages + locomotive	L+7C+L	2
Mat 64 type T or V	mat V or Mat T	3-4
ICM type 1/2 or 3/4	ICM 1/2 or ICM 3/4	5
Double decker type IV or VI	DD 4 or DD 6	6-7
Freight train	freight train	No data
Sprinter	sprinter	No data
Double decker push-pull	DD pp	No data

Table 2.1 Train shorthand naming

3 Measurements

On the 6th may 2008, both Deltares and Southampton were on site to perform measurements. Both institutes performed several types of measurements. This chapter gives an overview of all measurement performed, and the available data of the Deltares measurements. A comparison is made between the data obtained using the different techniques adopted by Deltares and Southampton.

3.1 General description of measurements

Deltares used accelerometers, which were placed at depth beneath the track or on the approach slab. Some points have been measured in multiple directions. Southampton used geophones installed at surface level on the sleepers as well as at defined depths beneath the track. These instruments measure velocities whereas the Deltares instruments measure accelerations. Sleeper displacements were also measured by Southampton using high speed digital photography which recorded the movement of targets attached to the sleeper ends.

The locations of the instruments are shown in the drawing in Appendix D and 5. A complete overview of the instruments used and the orientation in which these instruments were used is given in Appendix C.

3.2 Available measurements

Not all trains, which passed the test site, were measured by both Deltares and Southampton. Furthermore, some measurements cannot be used because the train was on the wrong track. All measurements and files are named after the time at which the train passed. The names of the raw data files are kept as they were made at the 6th of may. The processed data files are named systematically.

Appendix B gives an overview of all useable measurements. It shows the names of all files corresponding with a train passage. It also gives the time frame in which the train passed. This window is given in seconds from the start of the measurement.

3.3 Data processing

The Deltares measurements are integrated twice. The first time to get velocities, the second time to give displacements. Southampton measured velocities, therefore their measurements needed to be integrated only once. Before integration both a high pass and a low pass filter were applied to both the Deltares and the Southampton data.

The Southampton and Deltares measurements were obtained at a sampling rate of 500Hz and 1000Hz respectively. The measurements were synchronized through a digital trigger.

The processed measurement data obtained by both Southampton and Deltares have been compared for locations where instruments were installed by both institutes. The calculated displacements are plotted in a single graph to show the difference between the two measurement techniques.

3.3.1 Deltares processing

The raw data is elaborated into the processed data with the use of MatLab. The measured accelerations are filtered by a zero-phase digital bandpass filter from the MatLab signal processing toolbox. This filter is constructed from a high pass filter and a low pass filter. At the low frequency side, the cut off frequency is 1 Hz. The attenuation at 0.75 Hz is a factor 100 (-40 dB). At the high frequency side, the cut off frequency is 30 Hz. The filter decrease smoothly over the range from 30-55 Hz to an attenuation factor of about 1000 (-60 dB). The filter characteristics are shown in Appendix F.

The columns in the MatLab matrices correspond with the instruments as given in Appendix C. The length of the processed measurements is approximately 10 seconds, and starts after the trigger, which is imbedded in the raw measurement. This trigger has also been used to synchronize the measurements obtained by Southampton and Deltares.

One MatLab file exists for each train passage. The MatLab file stores the time (G_{time}), the measured acceleration (G_{raw}), the the filtered acceleration (G_{filt}), the velocity (G_{int}) and displacements (G_{int2}).

Information on the used accelerometers and geophones is shown in Appendix G.

3.3.2 Southampton processing

Southampton measurements were obtained using low frequency geophones (LF-24, Sensor Nederlands, Appendix G).). The Lf-24 geophone has a natural frequency of 1Hz with a linear output sensitivity of 15V/m/s above an excitation frequency of 10Hz; response curves for the LF-24 geophone are shown in Appendix G.

To calculate geophone velocity and displacement data the raw data is processed using Matlab. The first data processing step is to convert the raw data into apparent velocity, which is obtained by dividing the geophone voltage output by the geophone sensitivity. This apparent velocity is corrected to account for the true response of the geophone at low frequencies. This is obtained by applying a deconvolution algorithm in the frequency domain. Therefore a FFT is applied to the dataset, which once corrected is converted into the time domain by applying an inverse FFT. The resulting corrected velocities are filtered using a zero-phase passband digital filter similar to that used for the Deltares measurements, highlighted above.

Displacements are calculated from the velocity data by using the cumulative summation function in Matlab.

4 Structure of the database

4.1 Arrangement of database

The database on the CD-Rom is structured in 4 folders containing:

- Raw measurement data.
- Processed data with graphs in .EPS format.
- Pictures and movies made during the measurements.
- Information on the instruments.

The measurements are named after the time at which the train passed. Although the raw data filename has not been changed it does have the time of the train passage in it. The elaborated names are either a ‘D’ for Deltares or an ‘S’ for Southampton, followed by the time of the train passage. The instruments are named the same throughout all of the folders. These names are shown in Appendix C of this report, as well as in the data overview file in the raw data folder of the database.

4.2 Raw data

The raw data folder contains all information as measured on site by both Deltares and Southampton. This information has not been processed at all.

The raw Deltares measurements are stored as a matrix as a .GEF file. (Geotechnical Exchange Format). An overview of all available measurements is stored in the raw data folder (appendix Band appendix c). Information on the data in the file and the units of the data are stored in the header of the GEF file. Software for viewing and manipulating of GEF files is available at http://www.geffiles.org/weggeven/software.html free of charge (text in English). Alternatively, the files can be opened with the use of Excel.

The raw Southampton geophone data is stored as ASCII files named according to the given protocol followed by “Vel” to indicate velocities. The first column is time [ms], the following columns indicate velocities[mm/s]. See table 12, appendix C for the location of the geophones.

The raw camera data is stored in a separate folder under Southampton raw data. The results are presented as ASCII files containing 3 vectors; time [ms], horizontal motion [mm], and vertical motion [mm].

4.2.1 Processed data

The accelerations measured by Deltares have been converted into displacements and velocities with the use of MatLab. The MatLab files are stored in the folder of each train passage. The graphs of the displacements and velocities are stored in the same folders. The format of the pictures is .EPS, a vector based format. Software for viewing .EPS files can be downloaded from http://pages.cs.wisc.edu/~ghost/gsview/index.htm free of charge (text in English). Information on the file content is in the file “contents of subfolder.txt”.

The files showing the comparison between Southampton and Deltares are located in the folders of train passages D16_18 to D17_23, which are found in the Deltares processed data folder. The name of this file is comp_south.EPS.

The velocities measured by Southampton with the use of geophones have been converted into displacements. The results are stored in ASCII-files. The time-base is 0.002 s per step unit of displacements is mm. The definition of the columns is shown in appendix 12, Table 3.

The displacements observed by the camera are stored in the Deltares processed data folder. The position of the targets filmed is shown is appendix B; table10; columns 9 and 10. The data, processed by Technical University Delft, is presented as .EPS files.

4.2.2 Information on instruments

This folder contains drawings that show the location of all of the instruments. Specifications of the measurement instruments (accelerometers and geophones) are also included in this folder.

4.2.3 Pictures and movies

Pictured and movies that where made during the measuring on the sixth of May and during installation of the instruments are stored in this folder.

4.3 Structure of data files

Table 4.1 gives an overview of al different file types found in the database.

File extension	Type of content	Corresponding programme
GEF	Data (matrix)	GEF plot tool
EPS	Image	Ghostview
MAT	Data (matrix)	MatLab
XLS	Data (table)	MS Excel
JPG	Picture	MS picture viewer
MPG	Movie clip	MS media player
DOC	Text	MS Word
PDF	Image / text	Adobe Reader
DWG	Drawing	Autodesk Autocad
TXT	Text / Data	MS Wordpad

Table 4.1 Overview of file types

A Train data

The units of the data in the train data tables are as shown in the following Table:

Bak (car)	Length of car from bumper to bumper	[m]
	Mass of car	[kg]
	Moment of inertia of car	[kgm^2]
	Damping between car and bogie	[Ns/m]
	Spring stiffness between car and bogie	[N/m]
	Distance between center of car and centre of bogie	[m]
Draaistel (bogie)	Mass bogie	[kg]
	Moment of inertia of bogie	[kgm^2]
	Damping between bogie and wheel	[Ns/m]
	Spring stiffnes between bogie and wheel	[N/m]
	Distance between center of bogie and wheel axle	[m]
	Number of wheel axles on bogie	[-]
Wielstel (wheelset)	Mass of wheelset	[kg]
	Radius of wheelset	[m]
	Conicity	[-]
	Number of harmonics describing non-roundness	[-]
	Non-roundness per harmonic	[m]

Table A.1 Structure of train data

Figure A.1 1700-series locomotive with carriages on the test site (Mat 64 on rear track)

	Traintype:	**Locomotive 1700 series**	**ICR_carriage_empty**	**ICR_carriage_loaded**
Car (bak)	Length of car from bumper to bumper	17,9	25	25
	mass of car	40300	54000	66000
	Moment of inertia of car	157797,3971	812250	992750
	Damping between car and bogie	139000	35400	35400
	spring stiffness between car and bogie	24000000	800000	800000
	Distance between center of car and centre of bogie	4,847	9,5	9,5
Bogie (draaistel)	Mass bogie	16796	3400	3400
	Moment of inertia of bogie	10973,38667	1856,853333	1856,853333
	Damping between bogie and wheel	45700	10000	10000
	Spring stiffnes between bogie and wheel	2232000	1800000	1800000
	Distance between center of bogie and wheel axle	1,4	1,28	1,28
	Number of wheel axles on bogie	2	2	2
Wheelset (wielstel)	Mass of wheelset	3032,5	750	750
	Radius of wheelset	0,5	0,48	0,48
	Conicity	0,05	0,05	0,05
	Number of harmonics describing non-roundness	1	1	1
	Non-roundness per harmonic	0,0001	0,0001	0,0001
Calculated by Victor Hopman Deltares				
	Location of bumper (m)	0	0	0
	First wheel	2,703	1,72	1,72
	Second	5,503	4,28	4,28
	Third	12,397	20,72	20,72
	Fourth	15,197	23,28	23,28

Table A.2 Locomotive + carriages data

Figure A.2 *Mat 64 type V on the test site*

	Traintype:	mat64_undriven_empty	mat64_undriven_loaded
Car (bak)	Length of car from bumper to bumper	24,93	24,93
	mass of car	28800	38000
	Moment of inertia of car	247107	326043,9583
	Damping between car and bogie	23200	35900
	Spring stiffness between car and bogie	1000000	1500000
	distance between center of car and centre of bogie	7,175	7,175
Bogie (draaistel)	Mass bogie	3000	3000
	Moment of inertia of bogie	1890,625	1890,625
	Damping between bogie and wheel	4330,127019	4330,127019
	Spring stiffnes between bogie and wheel	2500000	2500000
	Distance between center of bogie and wheel axle	1,375	1,375
	Number of wheel axles on bogie	2	2
wheelset (wielstel)	Mass of wheelset	825	825
	Radius of wheelset	0,46	0,46
	Conicity	0,05	0,05
	Number of harmonics describing non-roundness	1	1
	Non-roundness per harmonic	0,0001	0,0001
Calculated by Victor Hopman Deltares			
	Location of bumper (m)	0	0
	First wheel	3,915	3,915
	Second	6,665	6,665
	Third	18,265	18,265
	Fourth	21,015	21,015

Table A.3 Mat 64 undriven cars data

	Traintype:	mat64_driven_empty	mat64_driven_loaded
Car (bak)	Length of car from bumper to bumper	26,07	26,07
	Mass of car	28200	37400
	Moment of inertia of car	241958,9375	320895,8958
	Damping between car and bogie	23200	35900
	Spring stiffness between car and bogie	1000000	1500000
	Distance between center of car and centre of bogie	7,175	7,175
Bogie (draaistel)	Mass bogie	6400	6400
	Moment of inertia of bogie	4033,333333	4033,333333
	Damping between bogie and wheel	7483,314774	7483,314774
	Spring stiffnes between bogie and wheel	3500000	3500000
	Distance between center of bogie and wheel axle	1,375	1,375
	Number of wheel axles on bogie	2	2
wheelset (wielstel)	Mass of wheelset	1000	1000
	Radius of wheelset	0,46	0,46
	conicity	0,05	0,05
	Number of harmonics describing non-roundness	1	1
	Non-roundness per harmonic	0,0001	0,0001
Calculated by Victor Hopman Deltares			
	Location of bumper (m)	0	0
	First wheel	4,485	4,485
	Second	7,235	7,235
	Third	18,835	18,835
	Fourth	21,585	21,585

Table A.4 Mat 64 driven cars data

Figure A.3 *ICM type 1 or 2 on the test site*

	Traintype:	ICM_undriven_empty	ICM_undriven_loaded
Car (bak)	Length of car from bumper to bumper	27,05	27,05
	Mass of car	30200	42200
	Moment of inertia of car	454258,3333	634758,3333
	Damping between car and bogie	28500	35800
	Spring stiffness between car and bogie	1353000	1593000
	Distance between center of car and centre of bogie	9,5	9,5
Bogie (draaistel)	Mass bogie	2600	2600
	Moment of inertia of bogie	1354,166667	1354,166667
	Damping between bogie and wheel	3866,522986	1250
	Spring stiffnes between bogie and wheel	2300000	2800000
	Distance between center of bogie and wheel axle	1,25	1,25
	Number of wheel axles on bogie	2	2
wheelset (wielstel)	Mass of wheelset	875	875
	radius of wheelset	0,46	0,46
	conicity	0,05	0,05
	Number of harmonics describing non-roundness	1	1
	Non-roundness per harmonic	0,0001	0,0001
Calculated by Victor Hopman Deltares			
	Location of bumper (m)	0	0
	First wheel	2,775	2,775
	Second	5,275	5,275
	Third	21,775	21,775
	Fourth	24,275	24,275

Table A.5 ICM undriven cars data

	Traintype:	ICM_driven_empty	ICM_driven_loaded
Car (bak)	Length of car from bumper to bumper	26,05	26,05
	Mass of car	28800	39000
	Moment of inertia of car	433200	586625
	Damping between car and bogie	32400	39700
	Spring stiffness between car and bogie	1481000	1719000
	Distance between center of car and centre of bogie	9,5	9,5
Bogie (draaistel)	Mass bogie	6100	6100
	Moment of inertia of bogie	3177,083333	3177,083333
	Damping between bogie and wheel	5000	5000
	Spring stiffnes between bogie and wheel	2300000	2800000
	Distance between center of bogie and wheel axle	1,25	1,25
	Number of wheel axles on bogie	2	2
wheelset (wielstel)	Mass of wheelset	1500	1500
	Radius of wheelset	0,46	0,46
	Conicity	0,05	0,05
	Number of harmonics Describing non-roundness	1	1
	Non-roundness per harmonic	0,0001	0,0001
Calculated by Victor Hopman Deltares			
	Location of bumper (m)	25	0
	First wheel	2,275	2,275
	Second	4,775	4,775
	Third	21,275	21,275
	Fourth	23,775	23,775

Table A.6 ICM driven cars data

Figure A.4 Double decker type-VI on test site

	Traintype:	DD_undriven_empty	DD_undriven_loaded
Car (bak)	Length of car from bumper to bumper	28,2	28,2
	Mass of car	37732	49140
	Moment of inertia of car	628866,6667	819000
	Damping between car and bogie	32000	39400
	Spring stiffness between car and bogie	1354000	1582000
	Distance between center of car and centre of bogie	10	10
Bogie (draaistel)	Mass bogie	3006	3006
	Moment of inertia of bogie	1565,625	1565,625
	Damping between bogie and wheel	1250	1250
	Spring stiffnes between bogie and wheel	2400000	2569000
	Distance between center of bogie and wheel axle	1,25	1,25
	Number of wheel axles on bogie	2	2
wheelset (wielstel)	Mass of wheelset	1737,5	1737,5
	Radius of wheelset	0,46	0,46
	Conicity	0,05	0,05
	Number of harmonics describing non-roundness	1	1
	Non-roundness per harmonic	0,0001	0,0001
Calculated by Victor Hopman Deltares	Location of bumper (m)	0	0
	First wheel	2,85	2,85
	Second	5,35	5,35
	Third	22,85	22,85
	Fourth	25,35	25,35

Table A.7 Double decker driven car data

	Traintype:	DD_driven front_empty	DD_driven front_loaded
Car (bak)	Length of car from bumper to bumper	28,2	28,2
	Mass of car	45318	56378
	Moment of inertia of car	755300	939633,3333
	Damping between car and bogie	42200	50100
	Spring stiffness between car and bogie	1968000	2227000
	Distance between center of car and centre of bogie	10	10
Bogie (draaistel)	Mass bogie	3772	3772
	Moment of inertia of bogie	1964,583333	1964,583333
	Damping between bogie and wheel	2000	2000
	Spring stiffnes between bogie and wheel	2445000	2445000
	Distance between center of bogie and wheel axle	1,25	1,25
	Number of wheel axles on bogie	2	2
wheelset (wielstel)	Mass of wheelset	1819	1819
	Radius of wheelset	0,46	0,46
	Conicity	0,05	0,05
	Number of harmonics describing non-roundness	1	1
	Non-roundness per harmonic	0,0001	0,0001
Calculated by Victor Hopman Deltares	Location of bumper (m)	0	30
	First wheel	2,85	2,85
	Second	5,35	5,35
	Third	22,85	22,85
	Fourth	25,35	25,35

Table A.8 Double decker driven front car data

	Traintype:	DD_driven middle _empty	DD_driven middle_ loaded
Car (bak)	Length of car from bumper to bumper	28,2	28,2
	Mass of car	45318	56378
	Moment of inertia of car	755300	939633,3333
	Damping between car and bogie	42200	50100
	Spring stiffness between car and bogie	1968000	2227000
	Distance between center of car and centre of bogie	10	10
Bogie (draaistel)	Mass bogie	5602	5602
	Moment of inertia of bogie	3530,427083	3530,427083
	Damping between bogie and wheel	5000	5000
	Spring stiffnes between bogie and wheel	3652000	3652000
	Distance between center of bogie and wheel axle	1,375	1,375
	Number of wheel axles on bogie	2	2
wheelset (wielstel)	Mass of wheelset	2404	2404
	Radius of wheelset	0,46	0,46
	Conicity	0,05	0,05
	Number of harmonics describing non-roundness	1	1
	Non-roundness per harmonic	0,0001	0,0001
Calculated by Victor Hopman Deltares	Location of bumper (m)	0	0
	First wheel	2,725	2,725
	Second	5,475	5,475
	Third	22,725	22,725
	Fourth	25,475	25,475

Table A.9 Double decker driven middle car data

B Available measurements

Train		Deltares				Southampton			
time	**type**	**window**	**raw data**	**Elaborated data**	**Comparison**	**raw data**	**elaborated data**	**Filmed point**	**File name**
15:14	Double decker	[0-13]	15_14_05.gef	D 15_14	No	-	-	Geophone 1	15_14
15:27	Mat 64 type V	[0-22]	15_27_37.gef	D 15_27	No	-	-	-	
15:48	loc +10	[4-16]	15_48_40.gef	D 15_48	No	-	-	Geophone 2	15_48
15:50	ICM	[4-12]	15_50_37.gef	D 15_50	No	-	-	Geophone 2	15_50
15:59	Mat 64 type V	[6-18.5]	15_59_52.gef	D 15_59	No	-	-	Geophone 2	15_59
16:14	Double decker	[0-3]	16_14_12.gef	D 16_14	No	data1	S 16_14	-	
16:18	ICM	[2-12]	16_18_08.gef	D 16_18	Yes	data2	S 16_18	-	
16:29	Mat 64 type V	[4-15.5]	16_29_47.gef	D 16_29	Yes	data3	S 16_30	Geophone 5	16_29
16:47	loc +9+loc	[4-14]	16_47_22.gef	D 16_47	Yes	data4	S 16_47	Geophone 6	16_47
16:50	ICM	[4.5-16.5]	16_50_07.gef	D 16_50	Yes	data5	S 16_50	Geophone 6	16_50
16:59	Mat 64 type V	[5-13]	16_59_06.gef	D 16_59	Yes	data6	S 16_59	-	
17:20	ICM	[3.5-15.5]	17_20_48.gef	D 17_20	Yes	data7	S 17_20	Geophone 7	17_20
17:23	Double decker	[4-13.5]	17_23_08.gef	D 17_23	Yes	data8	S 17_23	Geophone 7	17_23
17:31	Mat 64 type V	[9-29]	17_31_04.gef	D 17_31	No	-	-	-	

Table B.1 Overview available measurements and file names

C Sensor processing

Deltares						
MatLab column	column in GEF	sensor name	direction	location	comments	Depth [m]
1	8	T5 v	V	2		1
2	9	T5 hl	Hl	2		1
3	10	T5 he	H//	2		1
4	11	T1 v	V	2		3
5	12	T1 hl	Hl	2		3
6	13	T1 he	H//	2		3
7	14	T4 v	V	5		3
8	15	T4 hl	Hl	5		3
9	16	T4 he	H//	5		3
10	17	opn 5	H//	6	approach slab	0,45
11	18	opn 6	H//	5		1
12	19	opn 7	V	5		1
13	20	opn 8	V	6	approach slab	0,45
14	21	opn 9	Hl	1		1,1
15	22	opn 10	V	4	approach slab	0,9
16	23	opn 11	V	3	approach slab	1,45

Table C.1 Deltares processing overview

// = Parallel to track

/ = Perpendicular to track

Southampton					
Excel file column	Sensor name	Direction	Location	comments	depth
1	S1	V	Culvert	Position of S1, centre of culvert. Geo installed on sleeper end by cess rail	Sleeper
2	S2	V	Transition zone	2.38m from S1	Sleeper
3	S3	V	Transition zone	3.56m from S1	Sleeper
4	S4	V	Transition zone	4.97m from S1. Positioned on far rail end of sleeper	Sleeper
5	S5	V	Transition zone	5.43m from S1	sleeper
6	S6	V	Embankment?	6.63m from S1	sleeper
7	S7	V	Embankment	8.45m from S1	sleeper
8	S8	V	In borehole, 1.45 below ballast top	3.88m from S1. Borehole in centre of track	Borehole (centre)
9	S9	H	In borehole, 1.45m below ballast top	3.88m from S1. Borehole in centre of track (Deltares D16)	Borehole (centre)
10	S10	V	In borehole, 1.45m below ballast top	5.43m from S1. Borehole at end of sleeper (Deltares D14)	Borehole (sleeper end)
11	S11	V	In borehole, 1.45m below ballast top	5.78m from S1. Borehole in centre of track (Deltares D1-2-3)	Borehole (centre)

Table C.2 Southampton processing overview

D Location of Southampton instruments

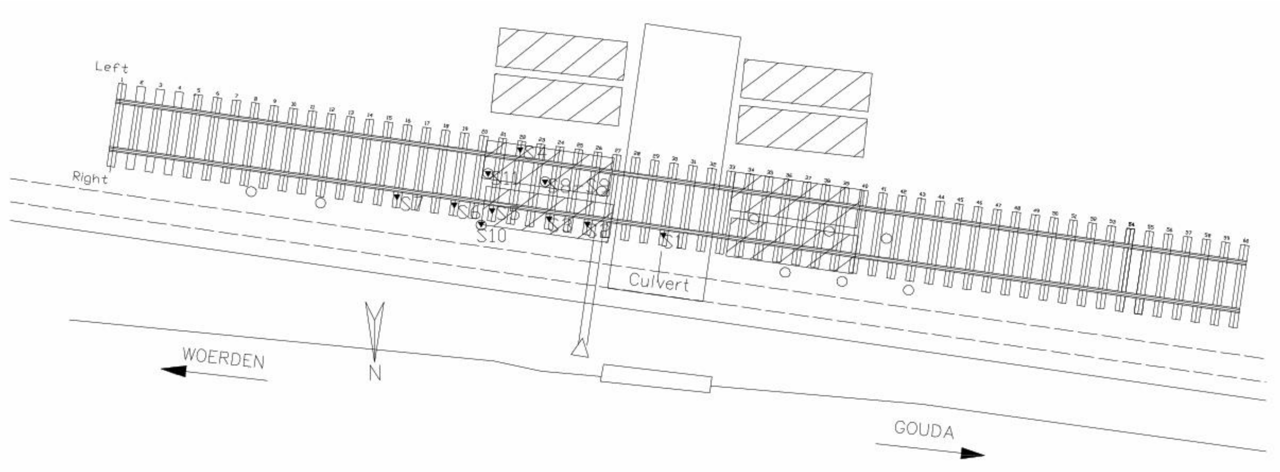


Figure D.1 Location of Southampton instruments top view

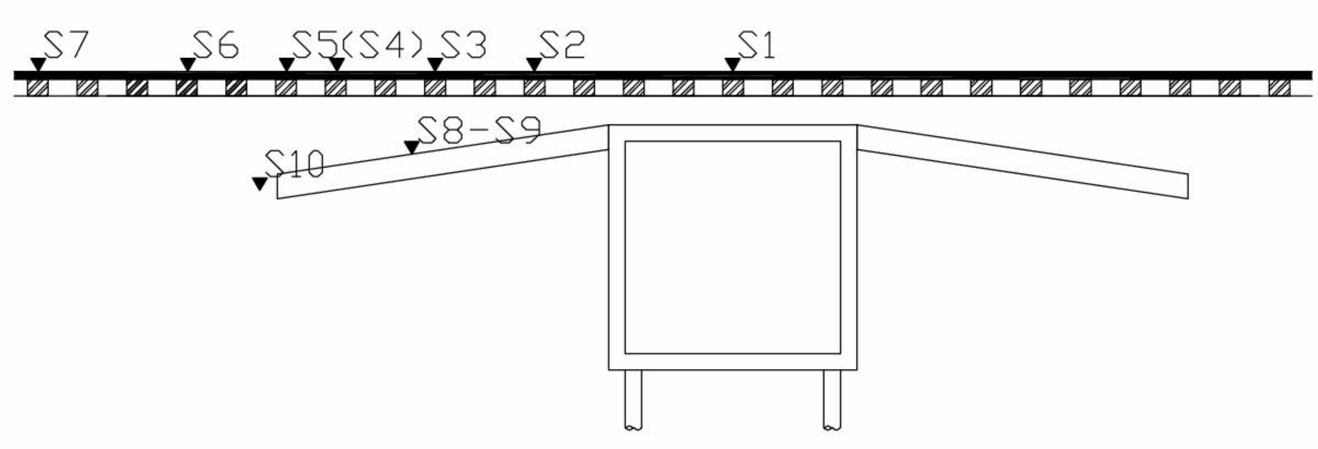


Figure D.2 *Location of Southampton instruments side view*

Location of Deltares Instruments

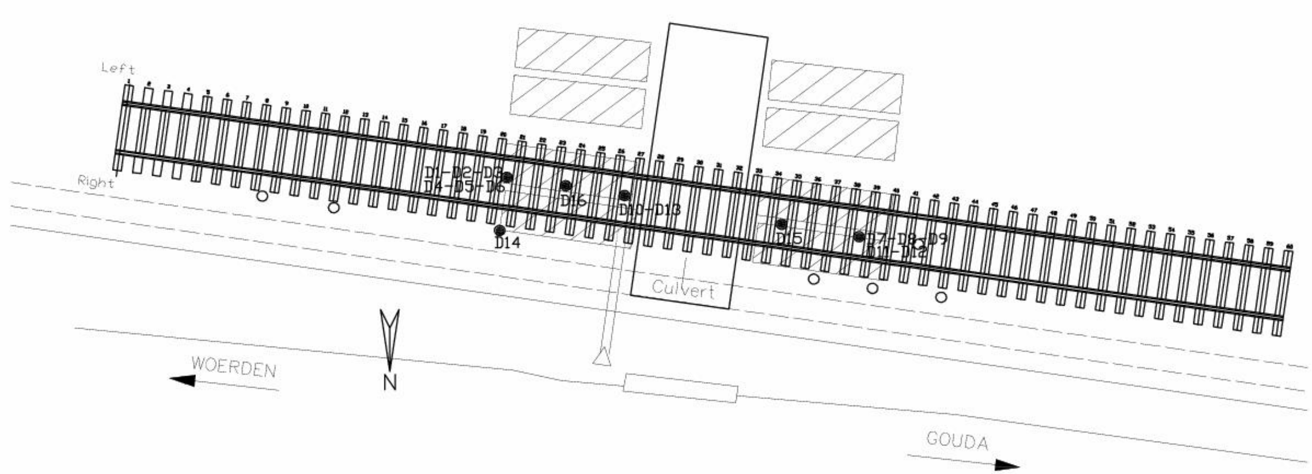


Figure D.3 Location of Deltares instruments top view

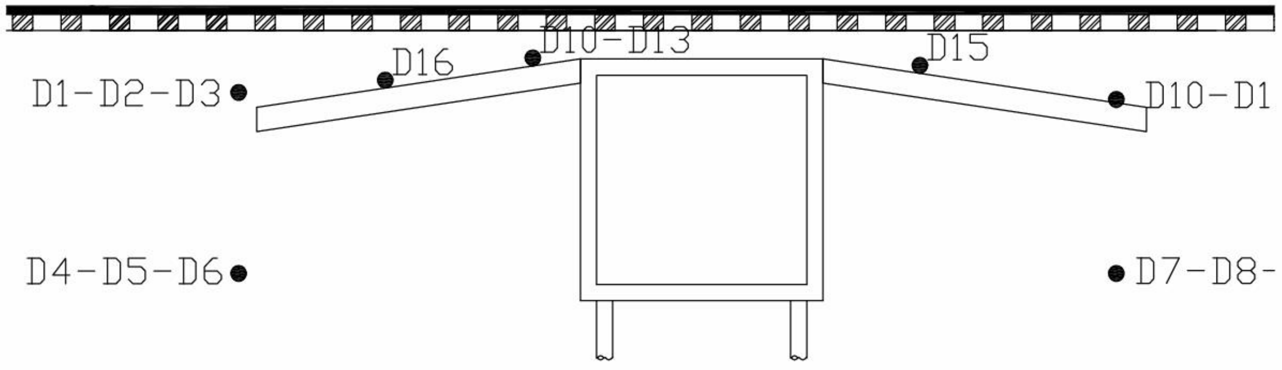


Figure D.4 Location of Deltares instruments side view

Note1: Drawing is not scaled
Note2: Instruments numbered 10-13 on left approach slab are incorrect. This should be 11-12.
Note3: Vertical positioning of instruments is not correct. Correct depths are in Appendix C

E Deltares filter graphs

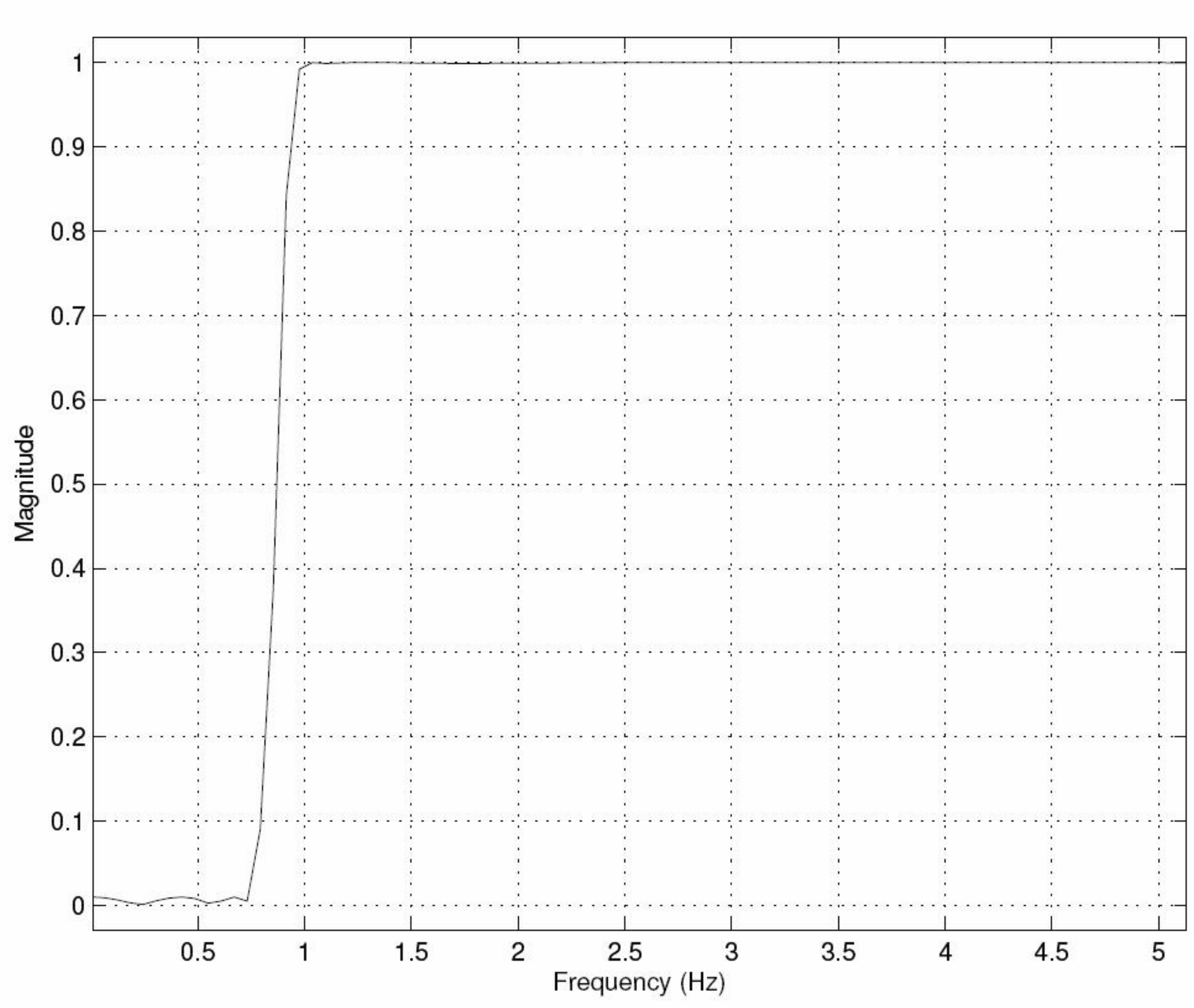


Figure E.1 Deltares High pass filter

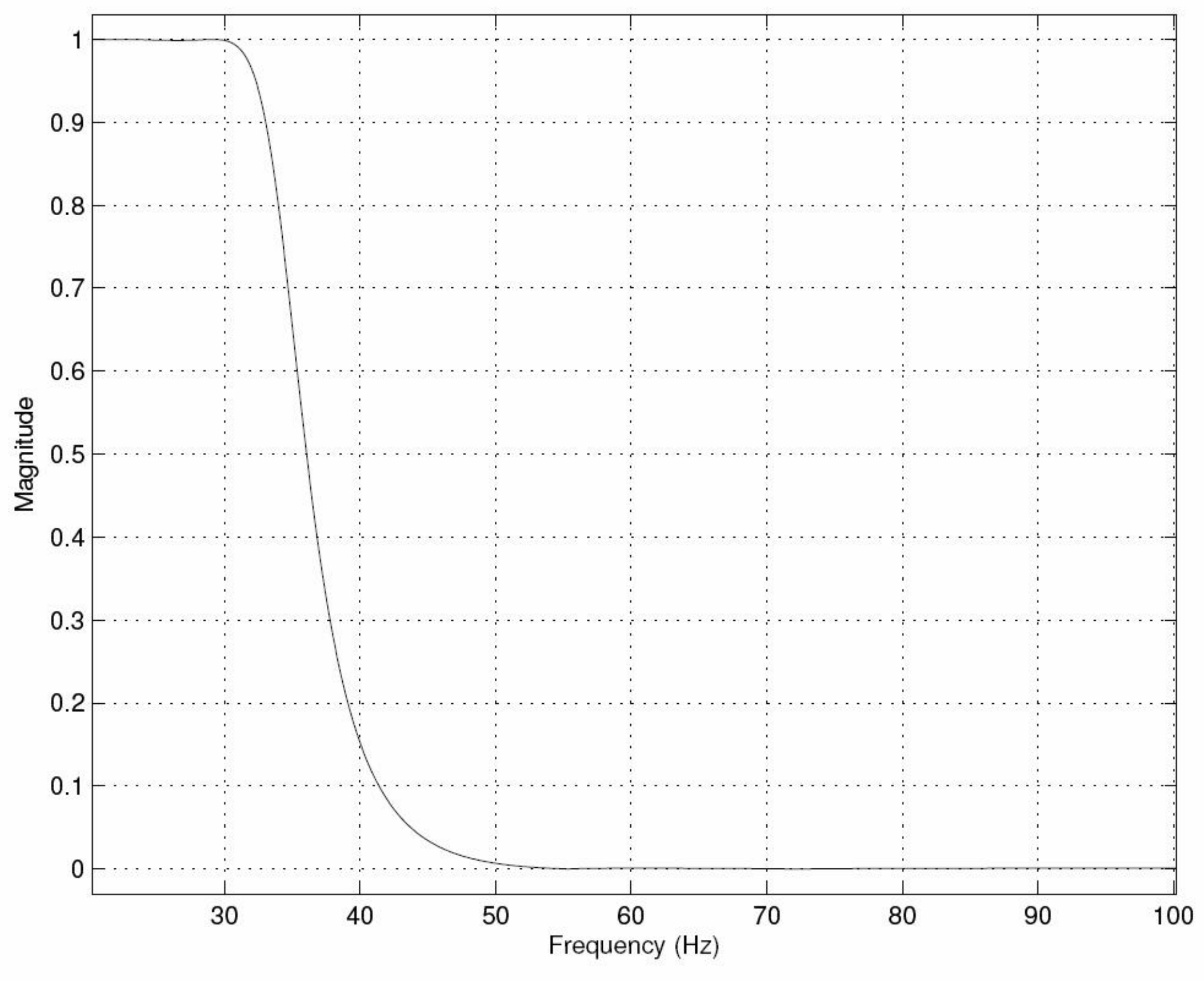


Figure E.2 Deltares Low pass filter

F Accelerometer and geophone specifications

Honeywell

Honeywell
Q-Flex® QA700 Accelerometer
Economical temperature-compensated sensor

For Q-Flex technology in an economical temperature-compensated package, Honeywell produces the QA700 for a broad array of moderate performance applications, including: flight and flight simulator control systems, radar platform leveling, rocket booster control systems, tactical missile control systems, and seismic sensing.

As with the entire Q-Flex family of accelerometers, the QA700 features a patented Q-Flex etched-quartz-flexure seismic system. An amorphous quartz proof-mass structure provides excellent bias, scale factor, and axis alignment stability.

The integral electronics develops an acceleration-proportional output current providing both static and dynamic acceleration measurements. By use of a customer supplied output load resistor, appropriately scaled for the acceleration range of the application, the output current can be converted into a voltage.

As an option, the QA700 can be provided with a temperature-compensating algorithm where bias, scale factor, and axis misalignment performance are dramatically improved.

Robust design and quality assurance provides superior reliability.

Features

- Tactical navigation grade performance
- High value
- Environmentally rugged
- Analog output
- Compact design
- Field-adjustable range
- Dual built-in test
- Optional thermal compensation

Applications

- Flight and flight simulator control systems
- Radar platform leveling
- Rocket booster control systems
- Tactical missile control systems
- Seismic sensing

Accelerometers exported from the United States must be done in accordance with the Export Administration Regulations (EAR) and/or the International Traffic in Arms Regulations (ITAR) as applicable. EXP025 March 2004

Configuration Drawings

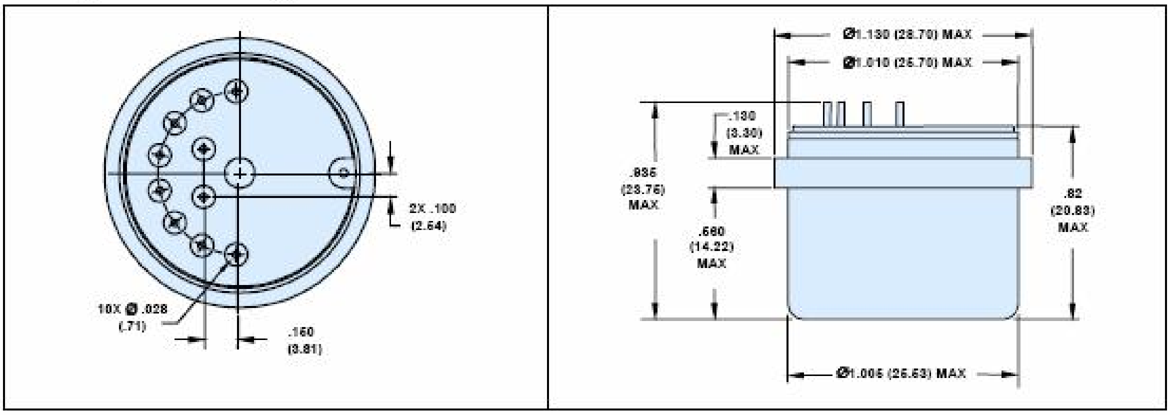


Figure F.1 Honeywell Accelerometer

Performance Characteristics

Additional product specifications, outline drawings and block diagrams, and test data are available on request.

Performance	
Input Range [g]	±30
Bias [mg]	<8
One-year Composite Repeatability [µg]	<1200
Temperature Sensitivity [µg/ºC]	<70
Scale Factor [mA/g]	1.23 to 1.43
One-year Composite Repeatability [ppm]	<1200
Temperature Sensitivity [ppm/ºC]	<200
Axis Misalignment [µrad]	<2000
Vibration Rectification [µg/g^{2}rms]	<50 (50-200 Hz) <100 (200-750 Hz) <150 (750-2000 Hz)
Intrinsic Noise [µg-rms]	<7 (0-10 Hz) <70 (10-500 Hz) <1500 (500-10,000 Hz)
Environment	
Operating Temperature Range [ºC]	-55 to +95
Shock [g]	250
Vibration Peak Sine [g]	25 @ 20-2000 Hz
Resolution/Threshold [µg]	<1
Bandwidth [Hz]	>300
Thermal Modeling	
	-010 NO -020 YES
Electrical	
Quiescent Current per Supply [mA]	<16
Quiescent Power [mW] @ ±15 VDC	<480
Electrical Interface	Temp Sensor
	Voltage Self Test
	Current Self Test
	Power / Signal Ground
	-10 VDC Output +10 VDC Output
Input Voltage	±13 to±18
Physical	
Weight [grams]	46 Nominal, 50 Max.
Diameter below mounting surface [inches]	Ø1.07 ±0.01
Height - bottom to mounting surface [inches]	.600 Max
Case Material	300 Series Stainless Steel

ISO-9001 Certification Since 1995

For more information, please visit www.inertialsensor.com

Figure F.2 Performance characteristics

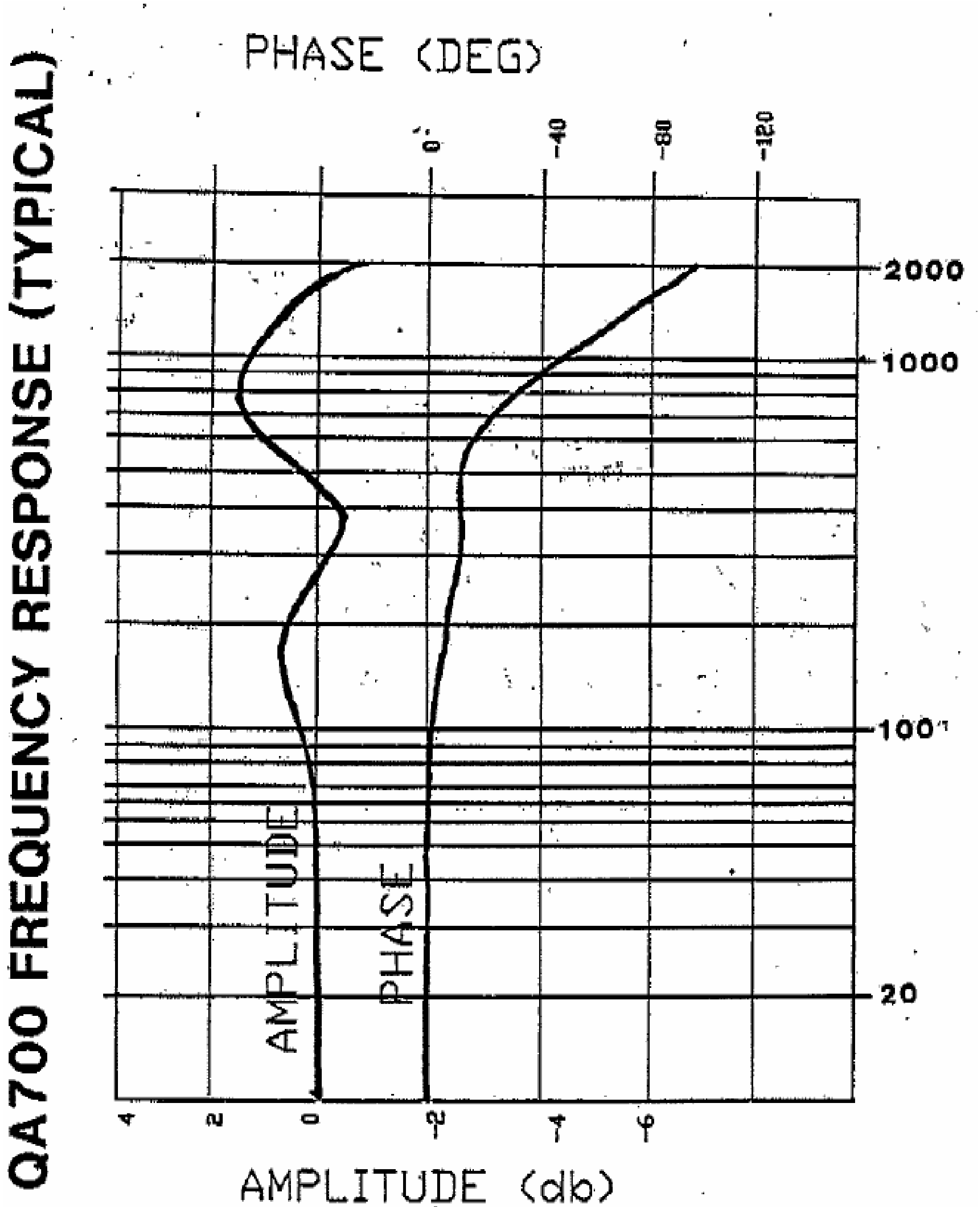


Figure F.3 *QA700 frequency response (typical)*

LF-24 Low Frequency Geophone

When Performance Counts

Features

- Economic low frequency geophone designed for vibration– monitoring
- Small dimensions compared to conventional 1Hz geophones
- Vertical and horizontal versions available
- Low power electronic circuit, providing reverse-filter function below geophone's natural frequency
- Extended bandwidth down to 1 Hz @ 100% damping
- Rugged design allowing high shock peaks
- Electronics fully-potted in epoxy resin
- 5-pin, watertight connector C091-M (IP-65)
- Low output impedance
- Electrical load does not affect damping characteristics
- Customized designs possible

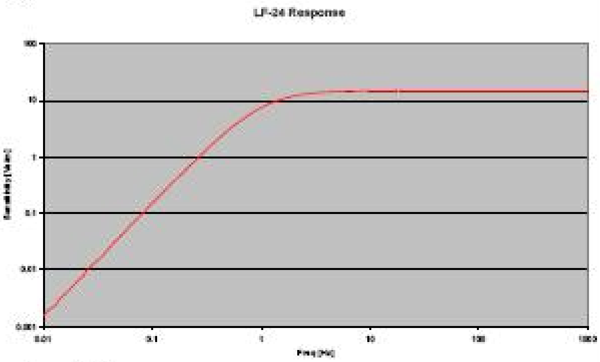
The LF-24 Low Frequency Geophone is optimized for size and performance where weight and cost are important factors in vibration-monitoring and low-frequency seismic measurement. The device uses a low power electronic circuit to provide a reverse-filter function below the geophone natural frequency, extending the recording bandwidth downwards to 1Hz. The compensation circuit permits the use of a higher-natural-frequency geophone, allowing for high-shock peaks that could seriously damage conventional low frequency geophones. The electronics are fully potted in epoxy resin for reliability. The 5-pin connector is provided for signal output and power supply. The low-impedance output matches many recording devices and electrical load will not affect the damping characteristics.

SENSOR Nederland b.v.

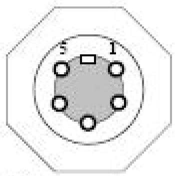
Figure F.4 LF-24 low frequency Geophone

Specifications: LF – 24 Low Frequency Geophone

Frequency		
Natural frequency	1 Hz	
Tolerance	± 15%	
Maximium tilt angle for specified Fn	Vertical	10°
	Horizontal	5°
Distortion		
Distortion with 0.7 in/s p.p. coil to case velocity	<0.15%	
Distortion measurement frequency	12 Hz	
Damping		
Open circuit (typical)	100 %	
Sensitivity		
Sensitivity	15 V/m/s	
Tolerance	± 10%	
Spurious frequency	240 Hz	
Equivalent input noise	300nm/s. sqrt(Hz)	above 10Hz
Power supply voltage	±5 to ±15V DC	Symmetrical
Supply current	±1mA	at rest
Physical Characteristics		
Diameter	34 mm	
Height	65 mm	
Weight	170 g	
Mounting thread	M8	
Operating temperature range	-20°C to 60°C	
Storage temperature range	-40°C to 70°C	
Connector		
Type	Amphenol series *C091-M* 5-pin (IP-65)	
Warranty period	180 days	



Connector Pinning



Pin		Wire colour
1	Signal +	Yellow
2	Power -	Grey
3	Power Gnd	Green
4	Power +	Pink
5	Signal Gnd	White

Ordering Information

LF-24 Vertical	P/N 1100241
LF-24 Horizontal	P/N 1100242

Europe
Sensor Nederland bv
Fax +31 71 561 7145
Phone +31 71 560 1234

United States - Stafford, TX
Input/Output Inc.
Fax +1 281 879 3626
Phone +1 281 933 3339

England
Input/Output Inc.
Fax +44 1603 415143
Phone +44 1603 481020

Web Site
www.geophone.com
www.i-o.com

SENSOR Nederland b.v.
An I/O subsidiary

Figure F.5 Specifications LF-24 low frequency Geophone