NGI

The Ryggfonn Project

Avalanche Data from the Winters 1994/95 and 1995/96

581200-32 20 desember 1997

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Summary

This report presents data collected from the full-scale Ryggfonn project during the winters 1994/95 and 1995/95. Only four avalanches were observed in the course of these two winters, three of which were naturally released and one artificially released. The present report describes briefly the weather characteristics of each winter season. The measurements obtained from the avalanche path include moment and shear strains caused by the avalanches on a steel tower, as well as the pressure on three load cells fixed to a concrete structure. In addition, the shear strain was measured on a steel mast erected on top of a 15 high dam.

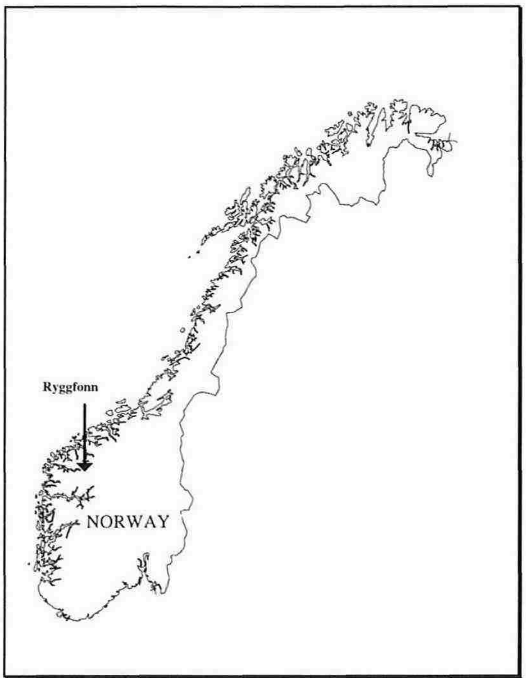
When possible, the avalanches have been classified according to the ICSI 1981 avalanche code and the deposit boundaries have been mapped.

Contents

Review and reference document

1 INTRODUCTION

This report covers two winters, 1994/95 and 1995/96, and summarises the data obtained from the measurements in the Ryggfonn avalanche path.



Ryggfonn is situated in Western Norway

The Ryggfonn project is a full scale experiment carried out to investigate forces of avalanches of different types and magnitudes on fixed structures, and the effects of a retaining dam in the avalanche path. The experiment site is the Ryggfonn avalanche path close to NGI's research station Fonnbu, Grasdalen, Western Norway.

The Ryggfonn avalanche usually starts from a north-facing cirque at around 1530 m a.s.l. and runs down a slightly channelled path into the valley floor below. The vertical drop from the starting zone to the runout area is around 900 m.

The installations in the lower part of the avalanche path have varied from time to time, but for most of the experiments they have consisted of the following (see also Figure 1 in the appendix):

- A 15 m high and 75 m wide retaining dam in the avalanche runout zone. On top of the dam is a 6.5 m high steel mast that is instrumented with strain gauges and sometimes an anemometer.
- A 4.5 m high concrete structure fitted with three load cells, each with an area of 0.72 m², situated 230 m up-slope from the dam.
- A 10 m (from 1994: 8.5 m) high tubular steel tower situated 320 m up-slope from the dam. The tower consists of four sections, each having a diameter of 1335 mm and plate thickness 15 mm.

  The tower is instrumented with strain gauges for measuring shear and moment strains at three sections, mechanical pressure indicators for every 0.5 m and a geophone for detecting the avalanches and triggering the recording system. Since there are some doubts about the accuracy of the calibration factors of the steel tower at this time, the load data in this report are given as a measure of deformation of the steel in microstrain (μS).
- Geophones placed on the ground or snow surface 50 and 100 m up-slope from the dam for the purpose of detecting the vibrations from passing avalanches.

- An instrument shelter near the runout area with recording equipment. The equipment converts the analogue signals to digital signals and records them on a digital tape recorder.
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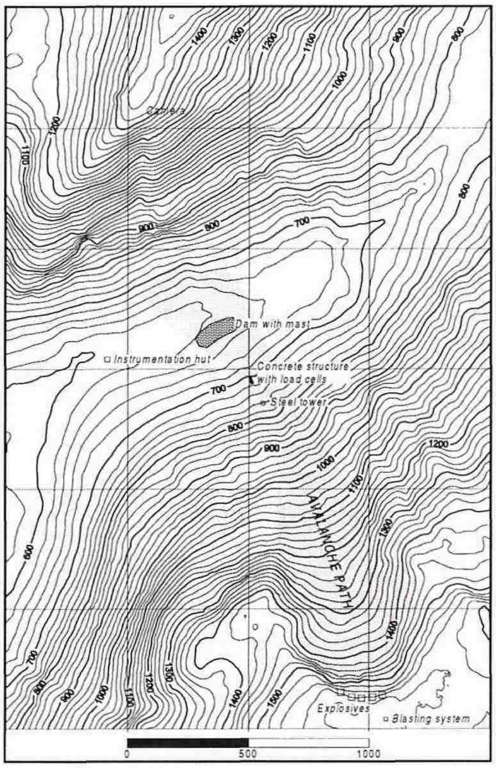
The avalanches studied are both natural and artificially released. In the case of natural avalanches, the recording system is started when the signal from a geophone on the uppermost construction (the steel tower) exceeds a pre-set triggering level.



Map of the Ryggfonn avalanche path

Artificial avalanches are released by detonating up till five preplaced charges in the starting zone by means of a radio controlled detonating system. Typically, each charge consists of 75 to 100 kg of dynamite. Artificial avalanches are usually videotaped and photographed with at time-lapse camera. In some cases, filming is done from the opposite mountain ridge.

If possible, all avalanches are mapped and sometimes surveyed for area and volume calculations. The avalanches are classified according to the avalanche classification system given in the Avalanche Atlas of UNESCO/ International Commission on Snow and Ice of the International Association of Hydrological Sciences, 1981.

2 THE WINTER 1994/95

2.1 General conditions

The winter 1994/95 was characterised by about average winter precipitation and snow accumulation. The avalanche activity this winter was moderate with only two natural and one artificial avalanche recorded.

Only section C of the steel tower was instrumented this winter, giving a somewhat incomplete picture of the loads that were applied on this construction (Figure 2).

2.2 Avalanches

The following avalanches were observed the Ryggfonn avalanche path this winter:

- February 4. 1995 at 3:21 h: Medium sized natural, dry snow avalanche. Avalanche code (ICSI 1981): A3, B2, C1, D2, E1, F4, G1, H1, J1.
- February 4. 1995 at 5:41 h: Small natural, mixed snow avalanche. Avalanche code (ICSI 1981): A3, B2, C1, D2, E7, F1, G2, H1, J1.
- March 3. 1995, at 13:27 h: Medium sized dry, artificially released avalanche. Avalanche code (ICSI 1981): A3, B2, C1, D2, E1, F4, G1, H1, J4.

2.3 The February-4 avalanches

The first avalanche to reach the constructions and trigger the recording system occurred naturally on February 4 at 3:21 h, and a second natural avalanche ran shortly afterwards at 5:41 h the same morning.

Weather conditions and snow properties

The avalanches released after a period of considerable new snow accumulation. The total amount of precipitation the five preceding days before the avalanches was 170 mm. During the night of February 4, the wind from south-west picked up and caused strong snow drift in the newly deposited snow (Figure 3). The air temperature at 930 m a.s.l. was below freezing during the whole period, although during the last avalanche the temperature in the runout area at 630 m a.s.l. had risen above 0 C°.

Avalanche characteristics

Little is known about the extent of these avalanches since they occurred during severe weather conditions. Recordings from the sensors at the dam show that the dam was overrun by the first avalanche at 3:21. This would indicate that the avalanche was a comparatively fast moving dry snow avalanche. The deposits could not be surveyed because of the weather conditions and subsequent avalanching. The second avalanche, at 5:41 h was probably smaller since it did not hit the mast on the dam.

The observations made of the debris (see map on figure 5) indicates that the deposit from the first avalanche (and from neighbouring avalanches) was thinly spread over a comparatively large area. The second avalanche was deposited in more distinct ridges, probably because the snow was wetter in the runout area at this time.

Avalanche velocity

The fronts of the avalanches seem to have either missed the steel tower or the initial impact forces may have been rather low, something that have caused a belated triggering of the recording system. It is therefore not possible to assess correctly the speeds of the two avalanches between the steel tower and the load cells.

The speeds between the load cells and the dam are also not known. Because of a belated triggering of the recording system the data from the first avalanche does not show the time of impact at the loads cells. The avalanche at 5:41 h stopped before it reached the dam (Figures 10 and 14). It can be inferred from the measurements however that the first avalanche was moving at a considerable higher speed than the second one.

The tubular steel tower

There are hardly any distinguishable signals at all from the strain gauges at the steel tower during the first avalanche (Figure 7). Only very small loads were also measured during the second avalanche (Figure 11).

The concrete structure

The highest loads were measured during the first avalanche, where a peak value of nearly 100 kN was recorded on the middle load cell. The recorded loads were much lower during the second avalanche. In this case the middle load cell received a maximum load of 25 kN (Figures 8 and 12).

2.4 The March 3-avalanche

Weather conditions and snow properties

The weather during the week before the avalanche release was characterised of a period of new snow accumulation, followed by cold and fair weather (Figure 3). The snow in the avalanche path consisted mainly of dry, newly fallen snow.

Avalanche characteristics

The avalanche was released by detonating 100 kg of dynamite buried under the massive cornice overhanging the starting zone. The detonation resulted in a

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powder avalanche with a dust cloud that travelled across the valley to the opposite slope (map of the deposit on figure 15).

Because of the snow conditions, the avalanche debris was comparatively thinly spread out over the runout area. The depth of the debris was mostly in the range of 0.5 to 1 m.

In general terms the avalanche can be described as a dry, small to medium sized, powder avalanche.
Avalanche code (ICSI 1981): A3, B2, C1, D2, E1, F4, G1, H1, J4.

Avalanche velocity

The avalanche speed in the runout zone is estimated from the times of impact on the constructions (Figure 19). However, the impact time at the steel tower is difficult to determine and it is possible that the head of the avalanche has missed the tower. An indication that this may be the case is that the average speed inferred from the impact times at different locations is higher at the lower stretch between the load cells and the dam (28 m/s), than between the steel mast and the load cells (24 m/s).

The tubular steel tower

A very short peak value of the deformation caused by shear stress was measured at section C to about 45 µS. The maximum deformation caused by moment at the same section was about 20 µS (Figure 16).

The concrete structure

The highest loads were on the upper load cell with peak loads in the 120 to 150 kPa range, 9 to 12 seconds after impact. The lower load cell was covered by snow from earlier avalanches (Figure 17).

Recordings from the dam

The mast on the dam was hit by the dust cloud of the avalanche and initial impact caused oscillations resulting in deformations up to 15 µS (Figure 18).

Braking effect of the dam

For the main part of the avalanche it is difficult to see any large effect of the dam in reducing the amount avalanche debris on the downslope side, even as the dam had nearly full capacity with regards to catchment volume. Considering the type of avalanche, this is perhaps not unexpected. However, the runout length may have been somewhat reduced because of the energy loss caused by the change of the vertical direction of the avalanche flow. Apparently, the flowing part of the avalanche was shooting into the air when the avalanche hit the dam. This was evident from an abrupt rise of the dust cloud at the dam and also the deposit distribution behind the dam.

3 THE WINTER 1995/96

3.1 General conditions

The result of a winter with very little snow, the avalanche activity in the Ryggfonn avalanche was at a minimum. Data from only one avalanche was obtained this season. Several blasting attempts in the late winter did not produce any avalanches that reached the instrumented runout area.

3.2 Avalanches

The following avalanche was observed the Ryggfonn avalanche path this winter:

- February 28, 19:48: Medium sized natural, dry snow avalanche. Avalanche code (ICSI 1981): A3, B2, C1, D2, E7, F7, G1, H4, J1.
-

3.3 The February 28 avalanche

Weather conditions and snow properties

The avalanche occurred during a storm period of strong winds and high precipitation (Figure 20).

Avalanche characteristics

The avalanche occurred at 19:48 hours the 28. February. Mapping of the avalanche during the storm period proved impossible, so the magnitude of the avalanche can only be inferred from the automatic recordings.

In general terms the avalanche can be described as a dry, fast moving medium sized, powder avalanche.

Avalanche velocity

The avalanche speed in the runout zone is estimated from the times of impact on the constructions (Figure 27). However, the resulting speeds, 34 m/s at the upper stretch between the steel mast and the load cells, and 46 m/s at the lower stretch between the load cells and the dam, seem unrealistic. A possible explanation can be that the head of the avalanche has either missed the steel tower or that the sensitivity of the triggering system is too low, thus causing a belated start of the recording system. During winters with exceptionally shallow snowpacks, the head of an avalanche will not always hit the load cells, since the concrete structure with the load cells is placed 4-5 m to the side of, and about 2 m higher than the deepest part of the avalanche channel.

Recordings from the steel tower

The maximum deformation caused by shear stress was measured at the lower section B (around 100 μS maximum). The maximum deformation caused by moment was also measured at the same section (around 100 μS maximum) (Figure 21). At the time of the avalanche there was only little snow around the steel tower.

Recordings from the load cells at the concrete structure

Only the two uppermost load cells were functioning during the avalanche. The middle load cell received fairly high peak value s of around 200 kPa (Figure 24).

Recordings from the dam

The mast on the dam was also hit by the avalanche and the resulting oscillations caused deformations of more than 600 μS (Figure 26).

4 APPENDIX

Related NGI-reports:

58120-03, 1983. Kvisterøy, T. Description of instrumentation and data registration system

58120-05, 1985. Norem, H., Kvisterøy, T., Evensen, B.D. Measurements of avalanche speeds and forces. Instrumentation and preliminary results of the Ryggfonn project (also published in the Annals of Glaciology, Vol. 6, 1985)

58120-06, 1985. Norem, H. and Kristensen, K.:The Ryggfonn project. Avalanche data from the winter 1982/83.

84510-01, 1985. Tronstad K.:Instrumented tubular Y-tower at Ryggfonn. Description of the instrumentation.

58120-07, 1986. Norem, H. and Kristensen K.: The Ryggfonn project. Avalanche data from the winter 1983/84

58120-08, 1986. Norem H., Kristensen, K. and Tronstad K.: The Ryggfonn project. Avalanche data from the winter 1984/85.

58120-10, 1987. Norem, H., Kristensen, K. and Tronstad, K.: The Ryggfonn project. Avalanche data from the winter 1985/86

581200-11, 1988. Norem, H., Kristensen, K. and Tronstad, K.: The Ryggfonn project. Avalanche data from the winter 1986/87

581200-13 1988. Norem, H., Kristensen, K. and Tronstad, K.: The Ryggfonn project. Avalanche data from the winter 1987/88

581200-15 1989. Norem, H., Kristensen, K. and Tronstad, K.: The Ryggfonn project. Avalanche data from the 1988/89 winter

581200-21 1991. Norem, H., Kristensen, K. and Tronstad, K.:The Ryggfonn project. Avalanche data from the 1989/90 winter

581200-23 1991. Norem, H., Nishimura, K., Bakkehøi, S.: Activities of the Japanese-Norwegian collaboration on snow avalanche research, March 1991

581200-31 1996. Kristensen, K.:The Ryggfonn project. Avalanche Data from the Winters 1991/92, 1992/93 and 1993/94. June 1996

Other:

Kristensen, K., Larsen, J.O. (1996). The Ryggfonn Avalanche Dynamics Project. Proceedings of the International Snow Science Project ISSW '96, Banff, Canada

UNESCO/International Commission on Snow and Ice of the International Association of Hydrological Sciences, 1981. *Avalanche Atlas*

5 LIST OF FIGURES

General part

Winter 1994-1995

Winter 1995-1996

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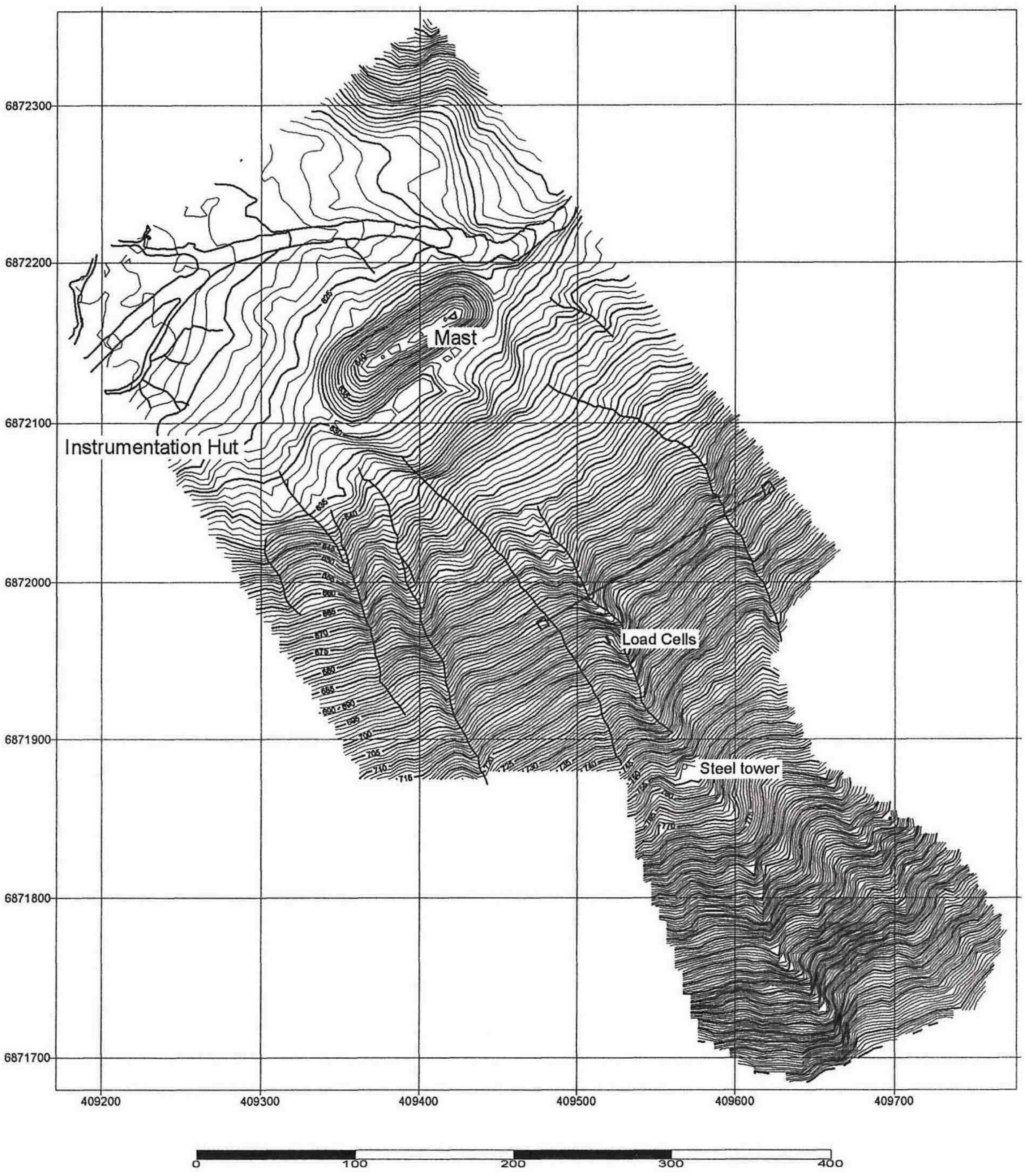
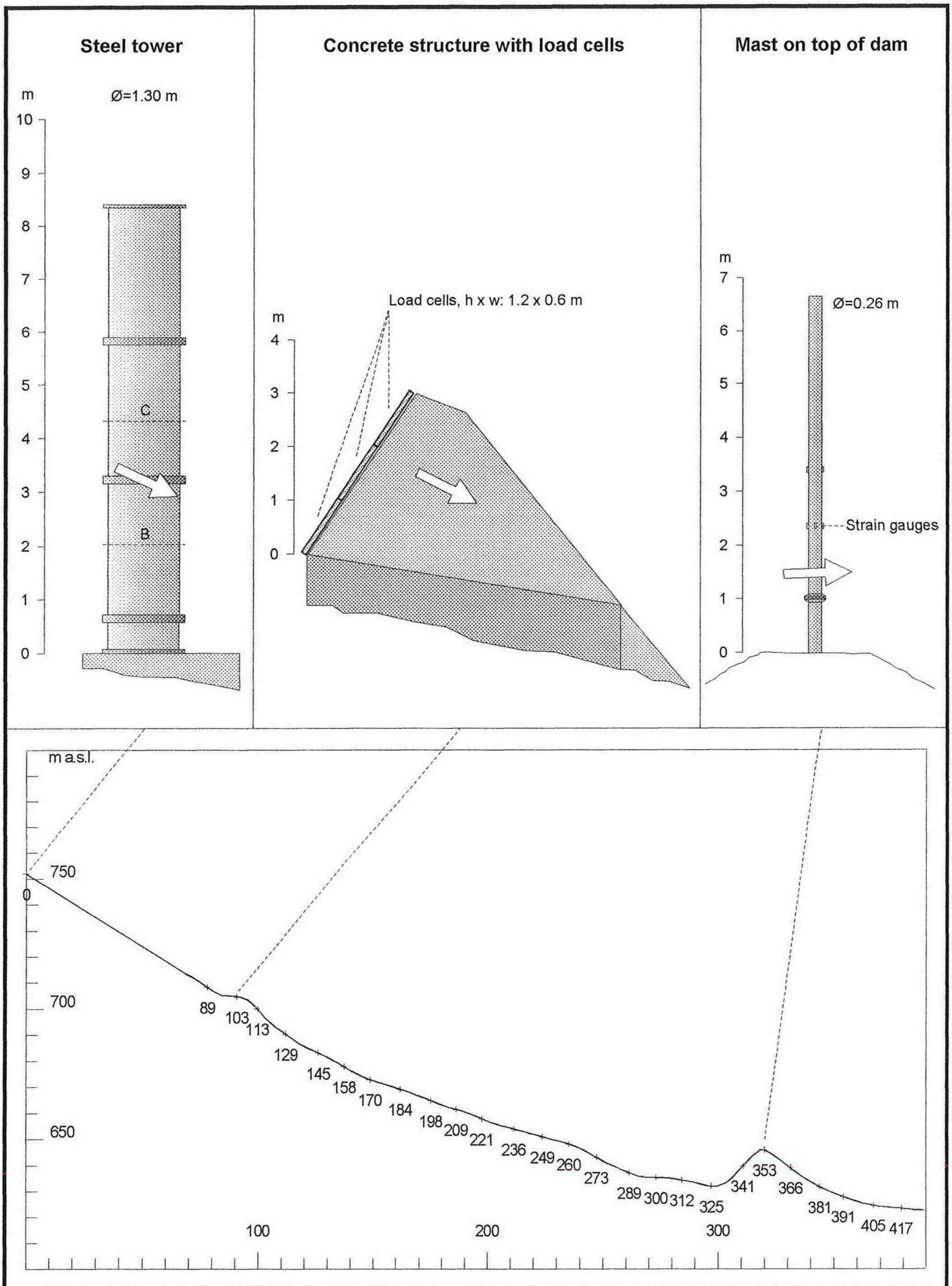


581200 - RYGGFONN	Rapport nr. 581200-32	Figur nr. 1
Map of the avalanche runout area	Tegner KK	Dato
	Kontrollert TS	
Scale 1:4000	Godkjent	NGI



581200 - RYGGFONN

Constructions in the avalanche path the winters
1994 - 1995 and 1995-1996

Report No.	Figure No.
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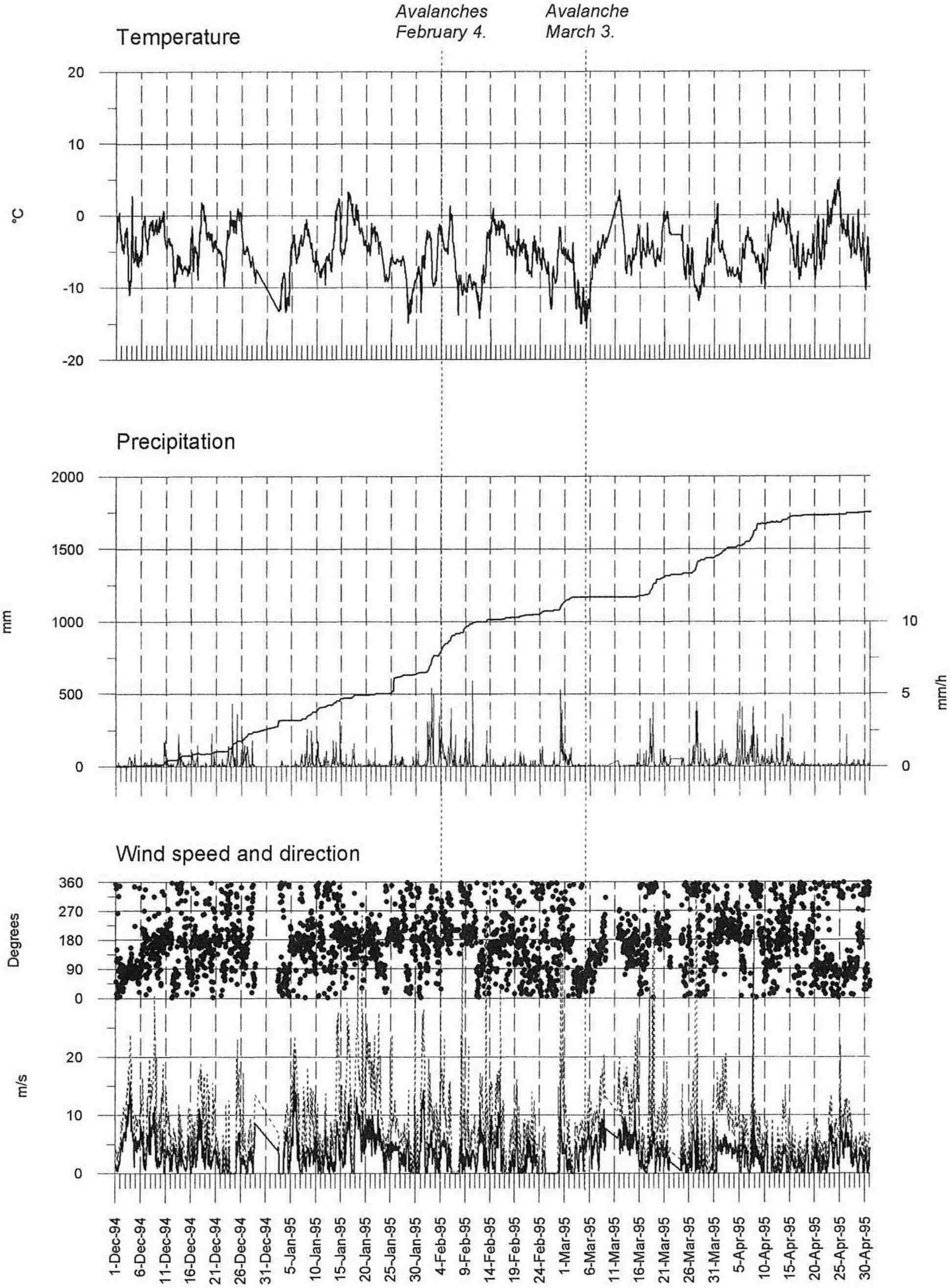

581200 - RYGGFONN	Report No. 581200-32	Figure No. **3**
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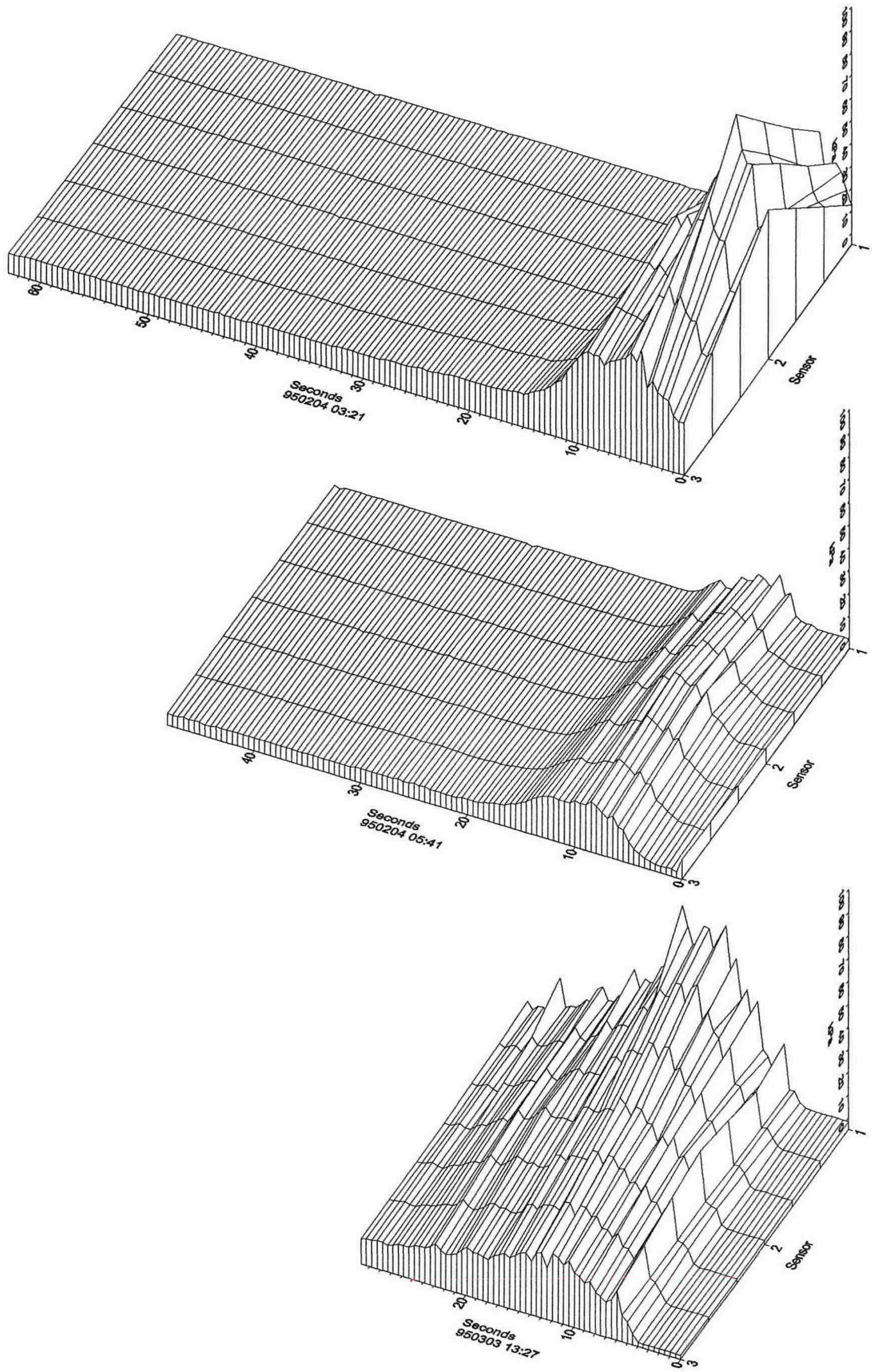

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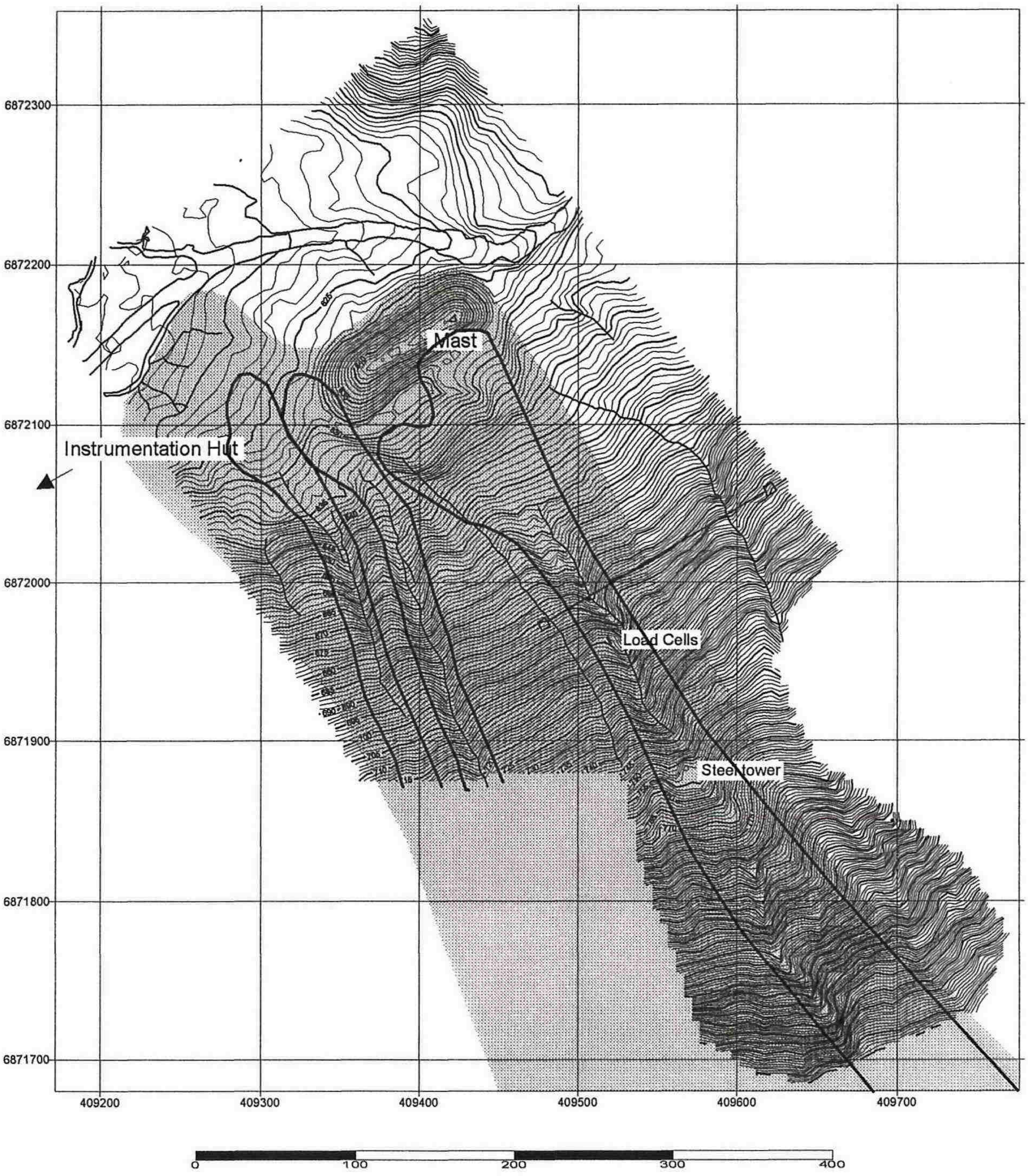
Avalanches 1994-95 Pressure distribution on the load cells from the avalanches recorded	Drawn by Checked Approved	Date NGI



581200 - RYGGFONN

Rapport nr. 581200-32

Figur nr. 5

Map of the avalanche runout area
Deposit boundaries of the 95.02.04 avalanches
probable traces of the avalanche at 3:21 h
avalanches at 5:41h
Scale 1:4000

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Godkjent

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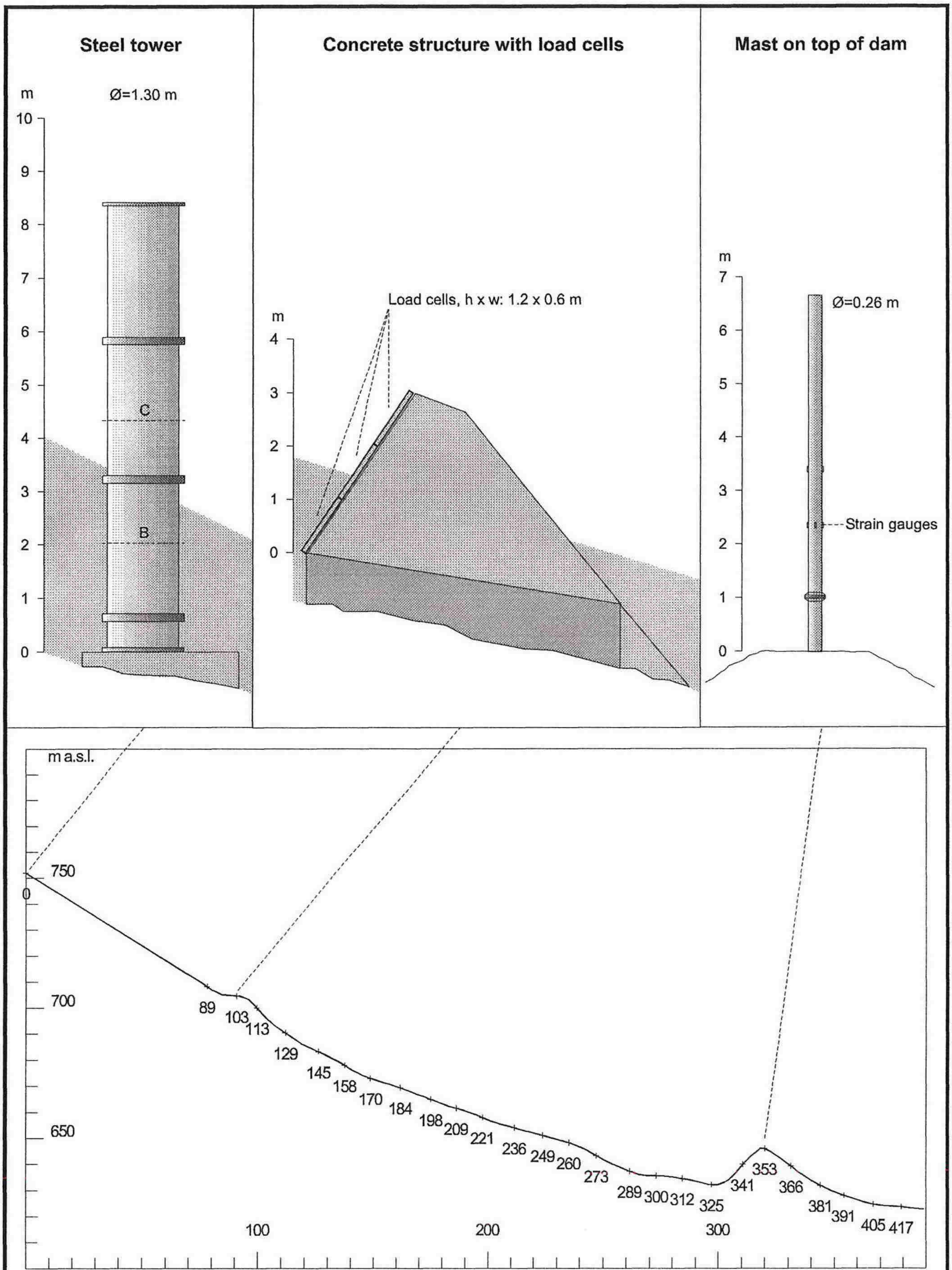

581200 - RYGGFONN	Report No. 581200-32	Figure No. 6
Avalanche debris around the constructions after the 95.02.04 avalanches	Drawn by	Date
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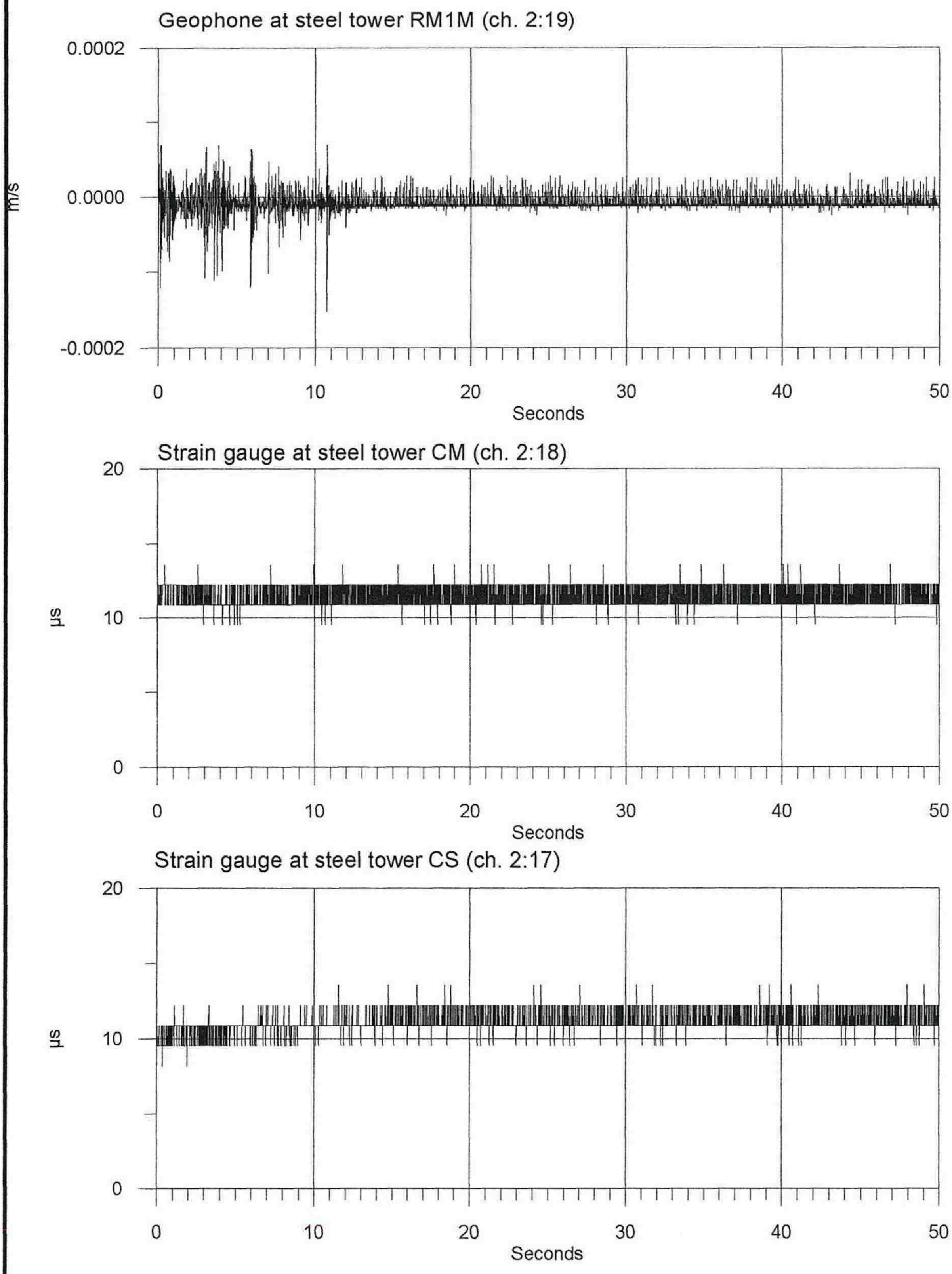

581200 - RYGGFONN	Report No 581200-32	Figure No. 7
Avalanche 95.02.04, 03:21, naturally released Recordings from sensors at steel tower	Drawn by KK Checked Approved	Date

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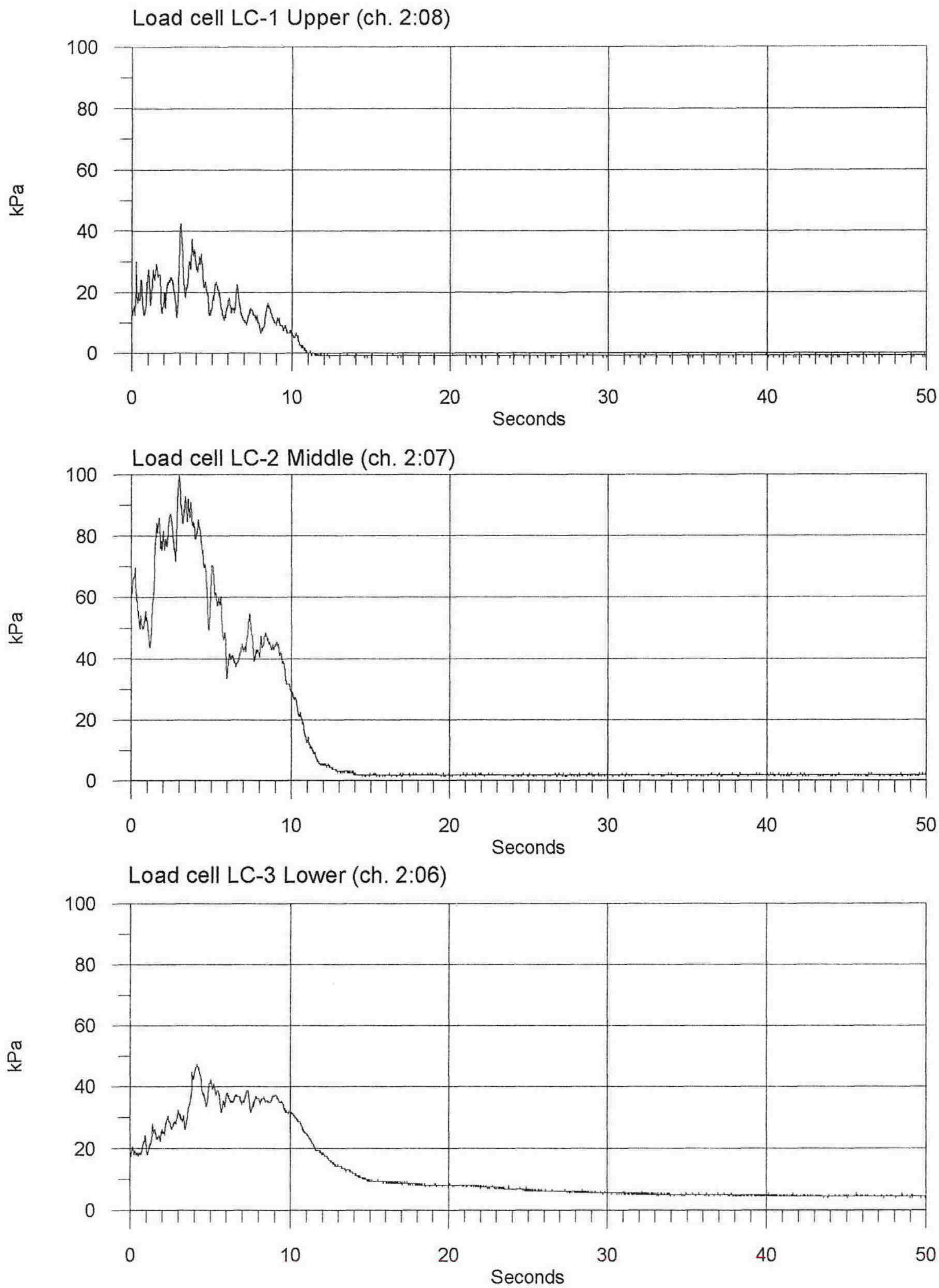

581200 - RYGGFONN

Report No 581200-32

Figure No. 8

Avalanche 95.02.04 03:21, naturally released
Impact pressures on load cells on concrete structure

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Date

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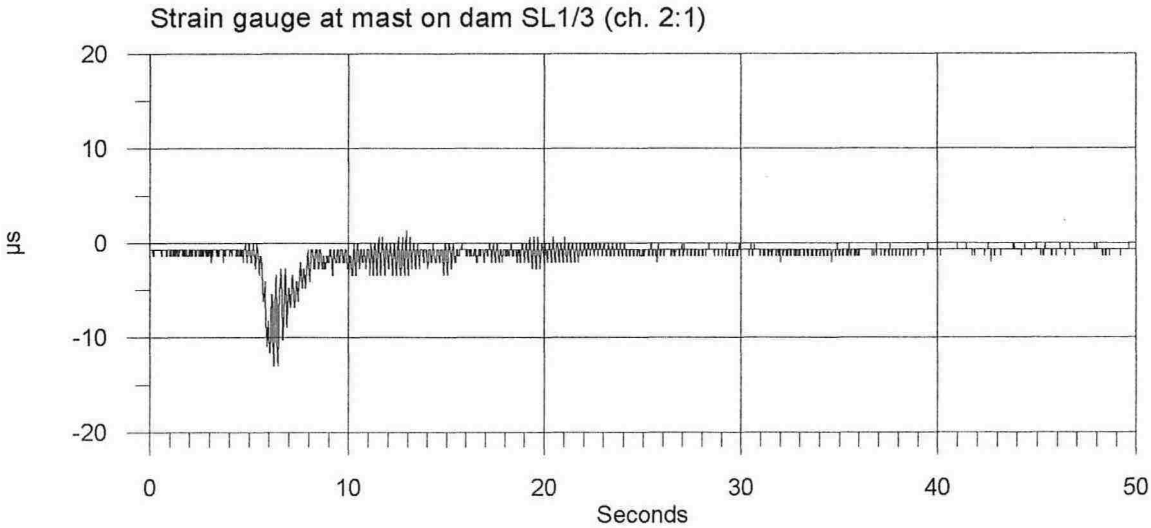

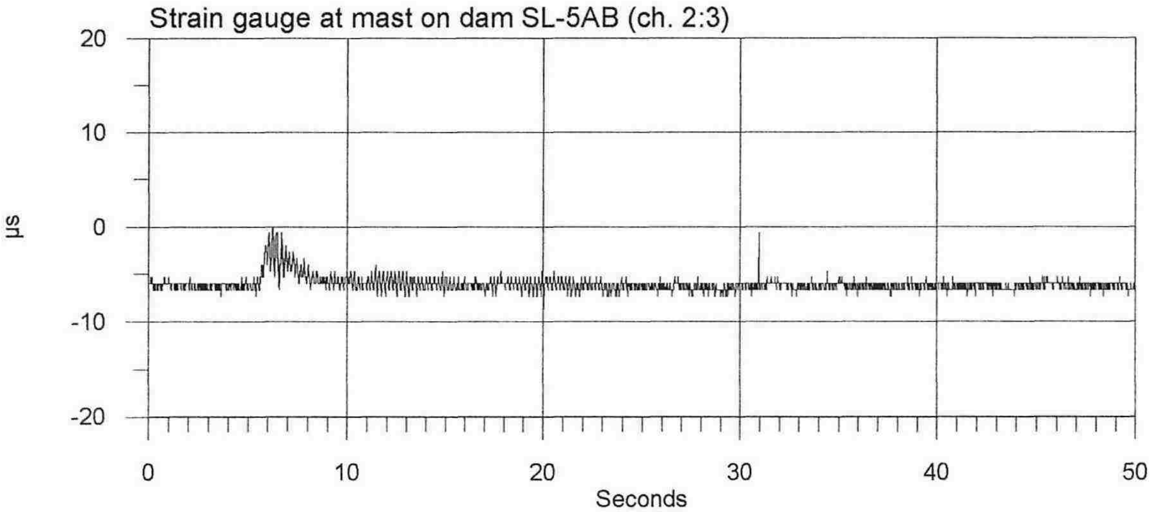

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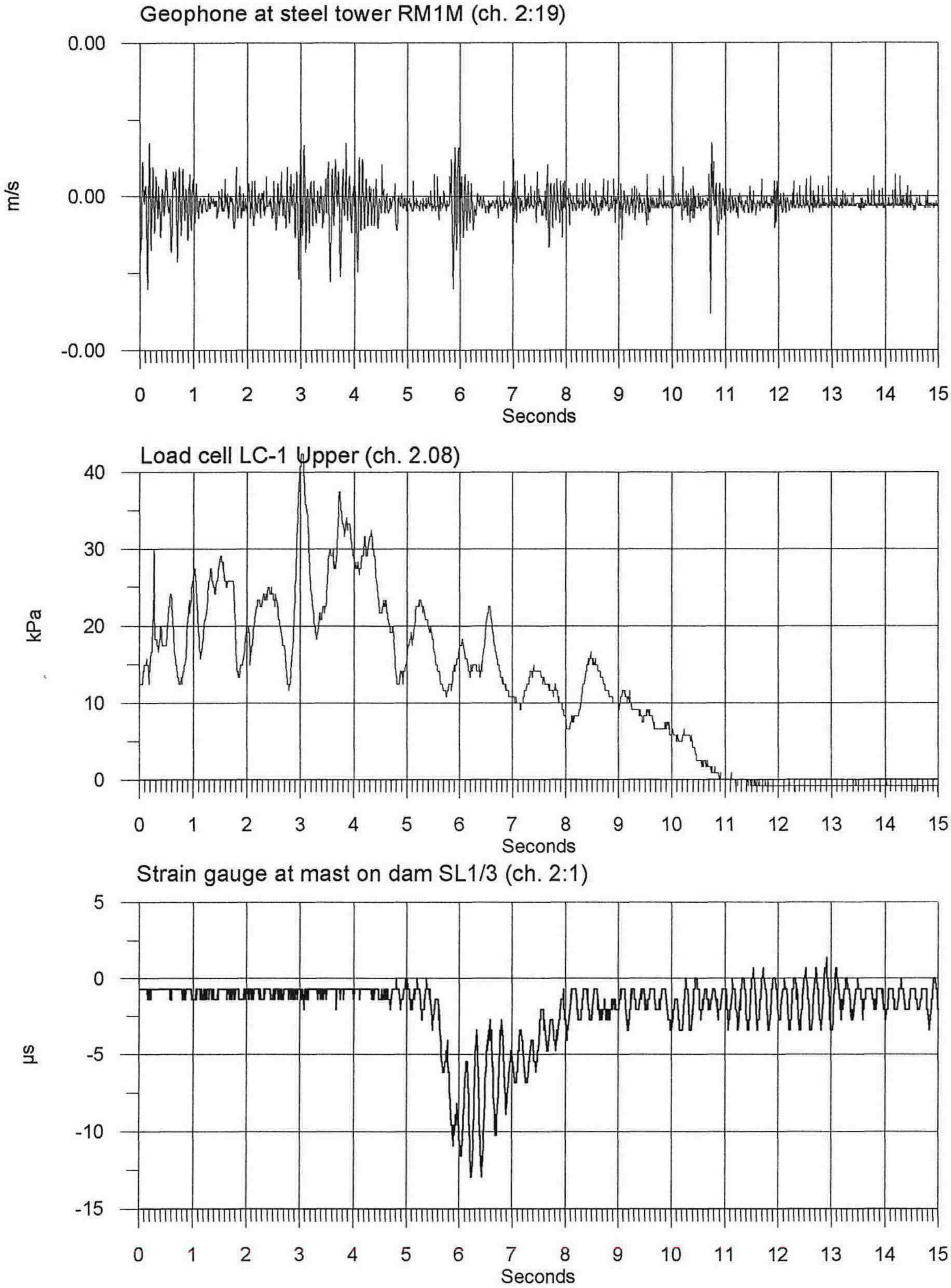

581200 - RYGGFONN	Report No 581200-32	Figure No. 10
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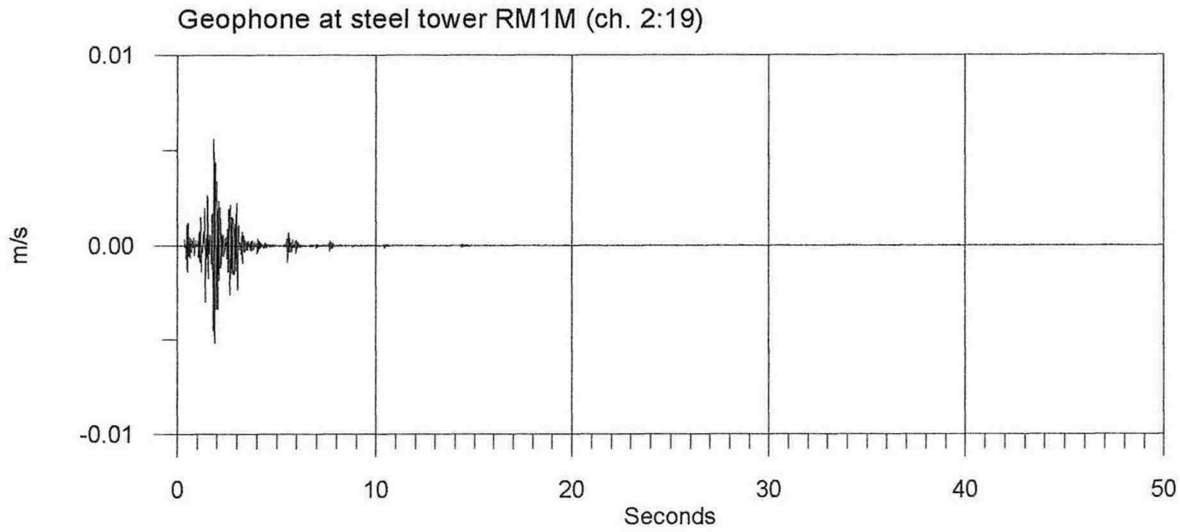

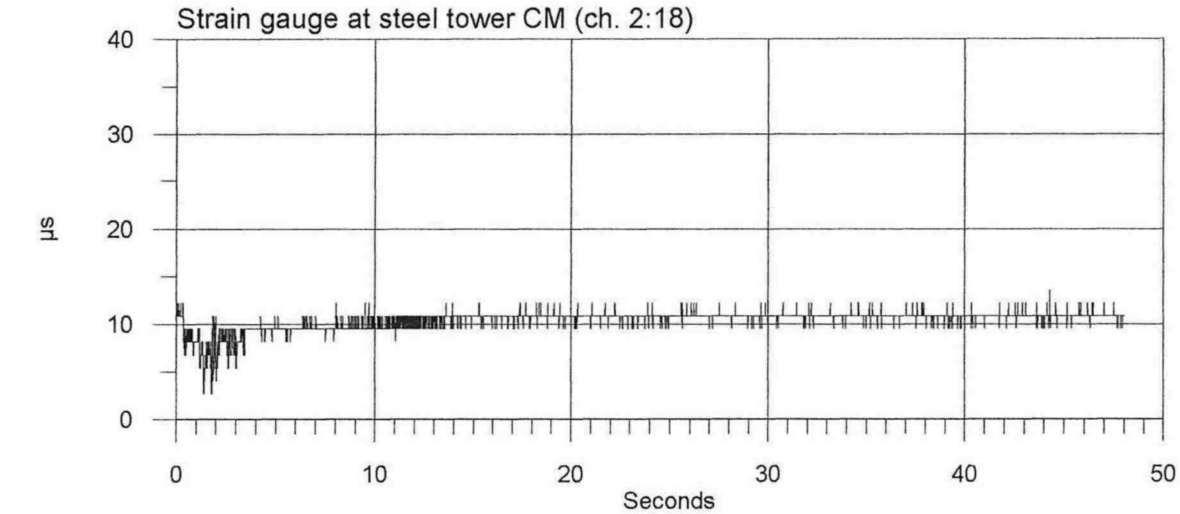

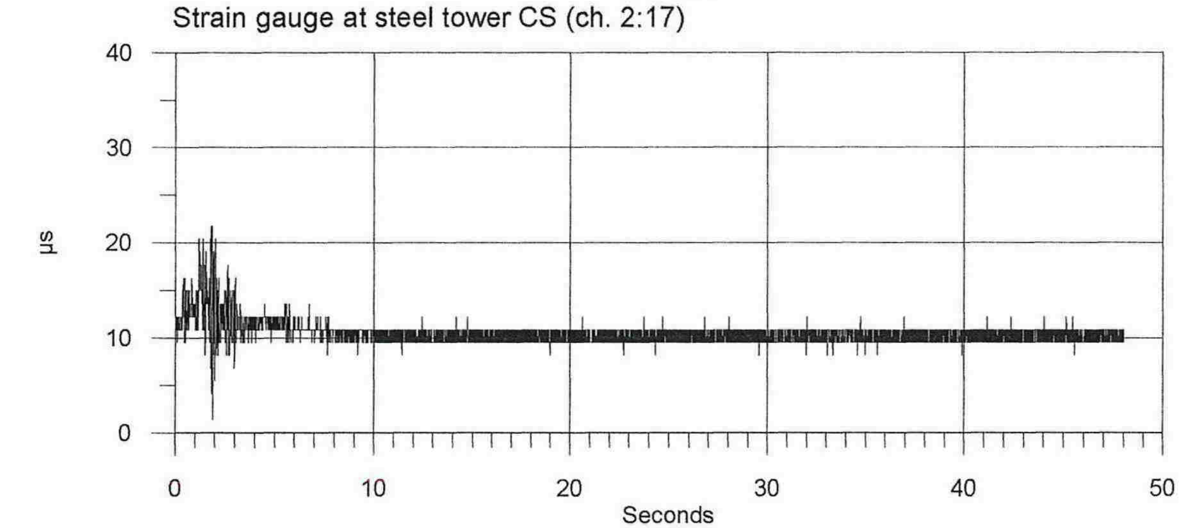

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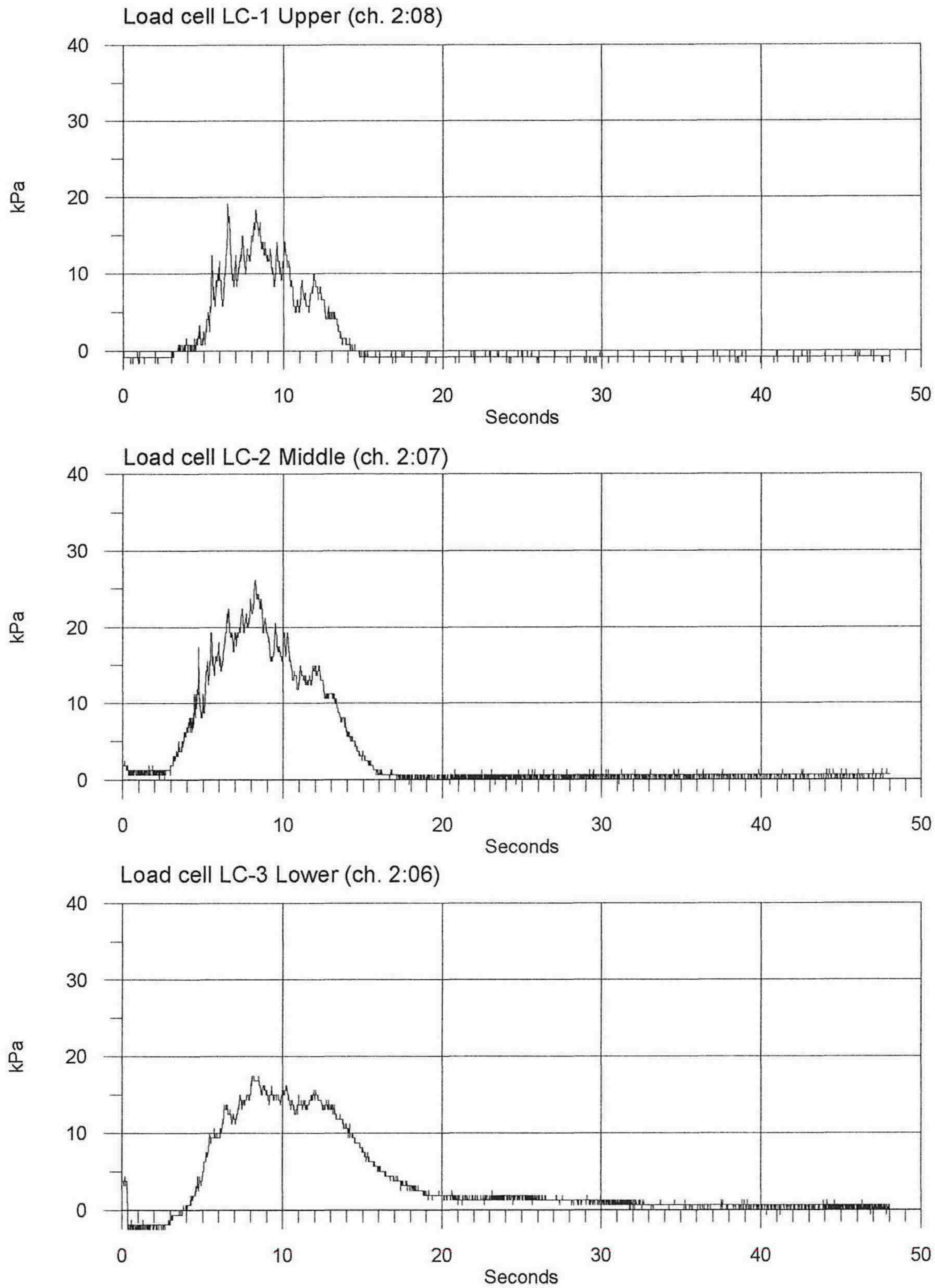

581200 - RYGGFONN	Report No 581200-32	Figure No. **12**
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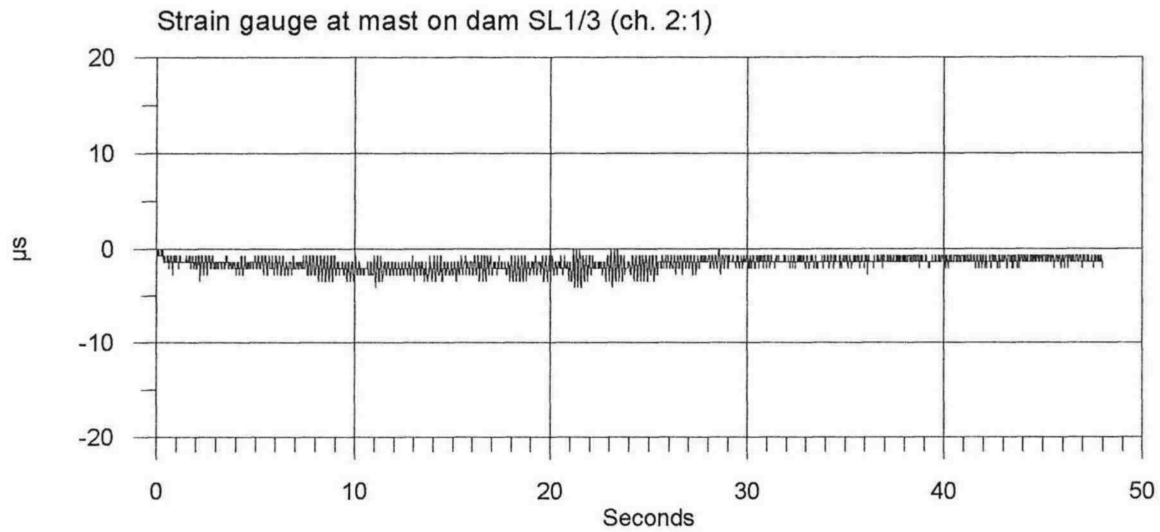

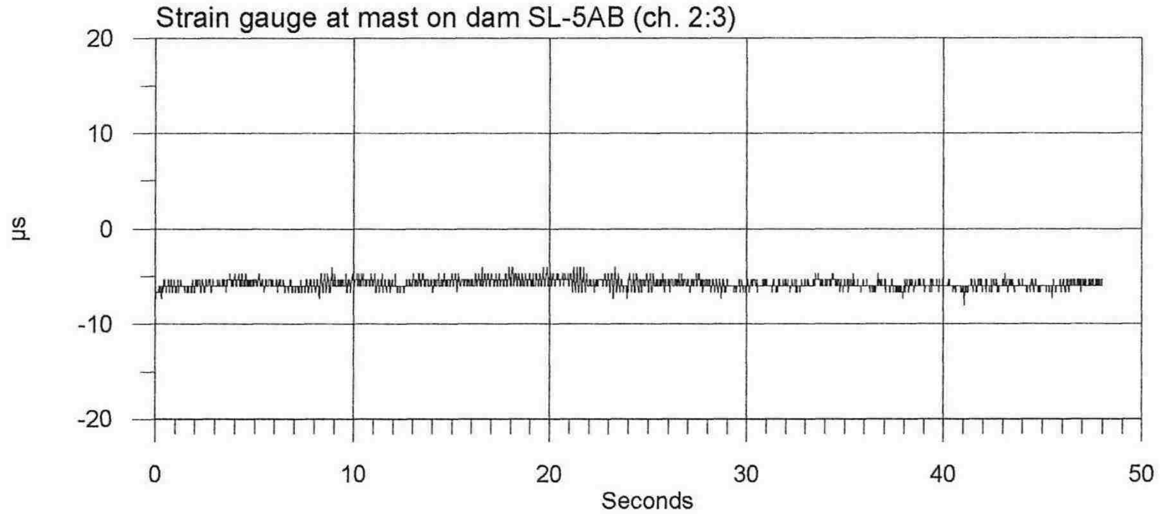

581200 - RYGGFONN	Report No 581200-32	Figure No. **13**
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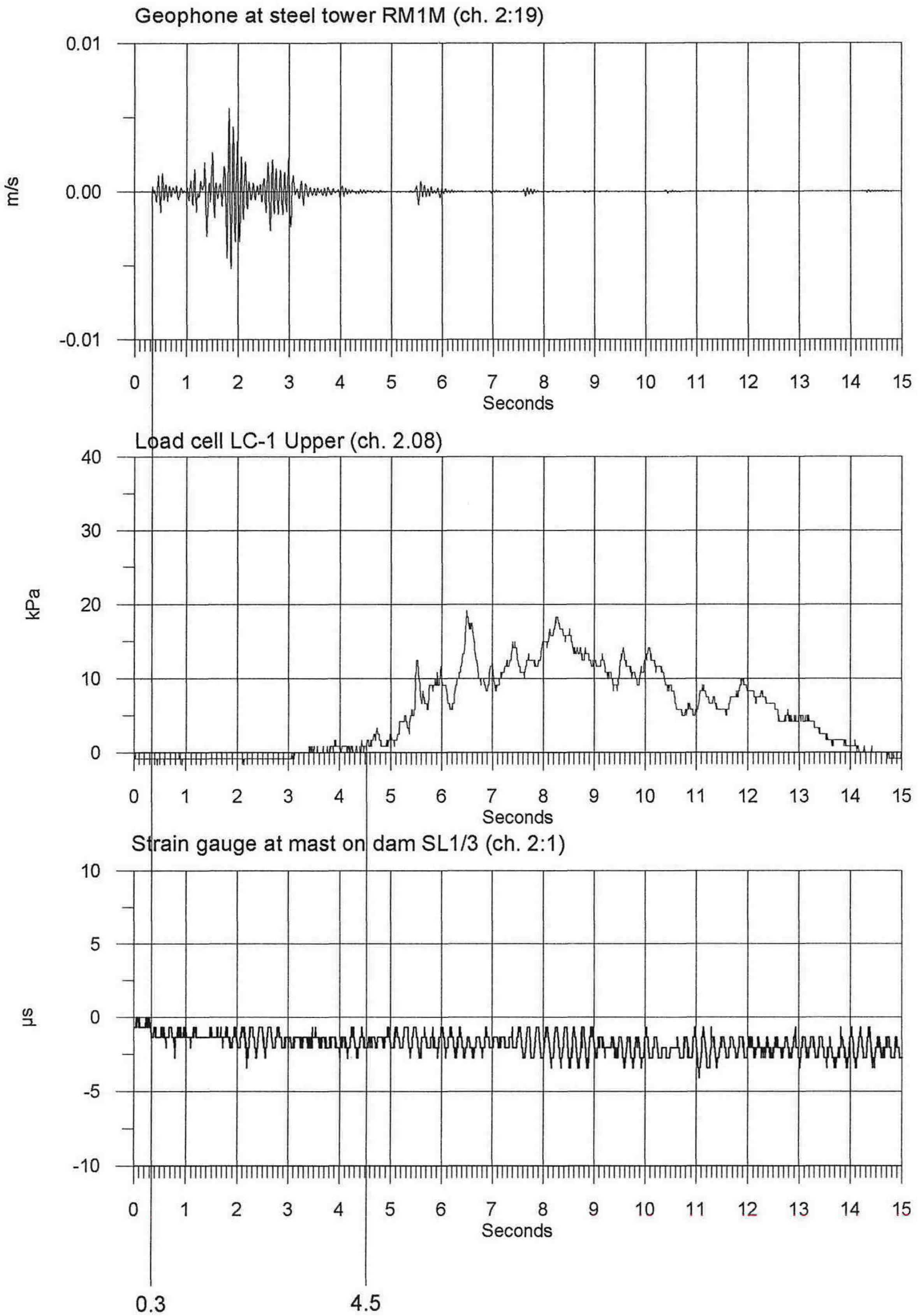

581200 - RYGGFONN	Report No 581200-32	Figure No. 14
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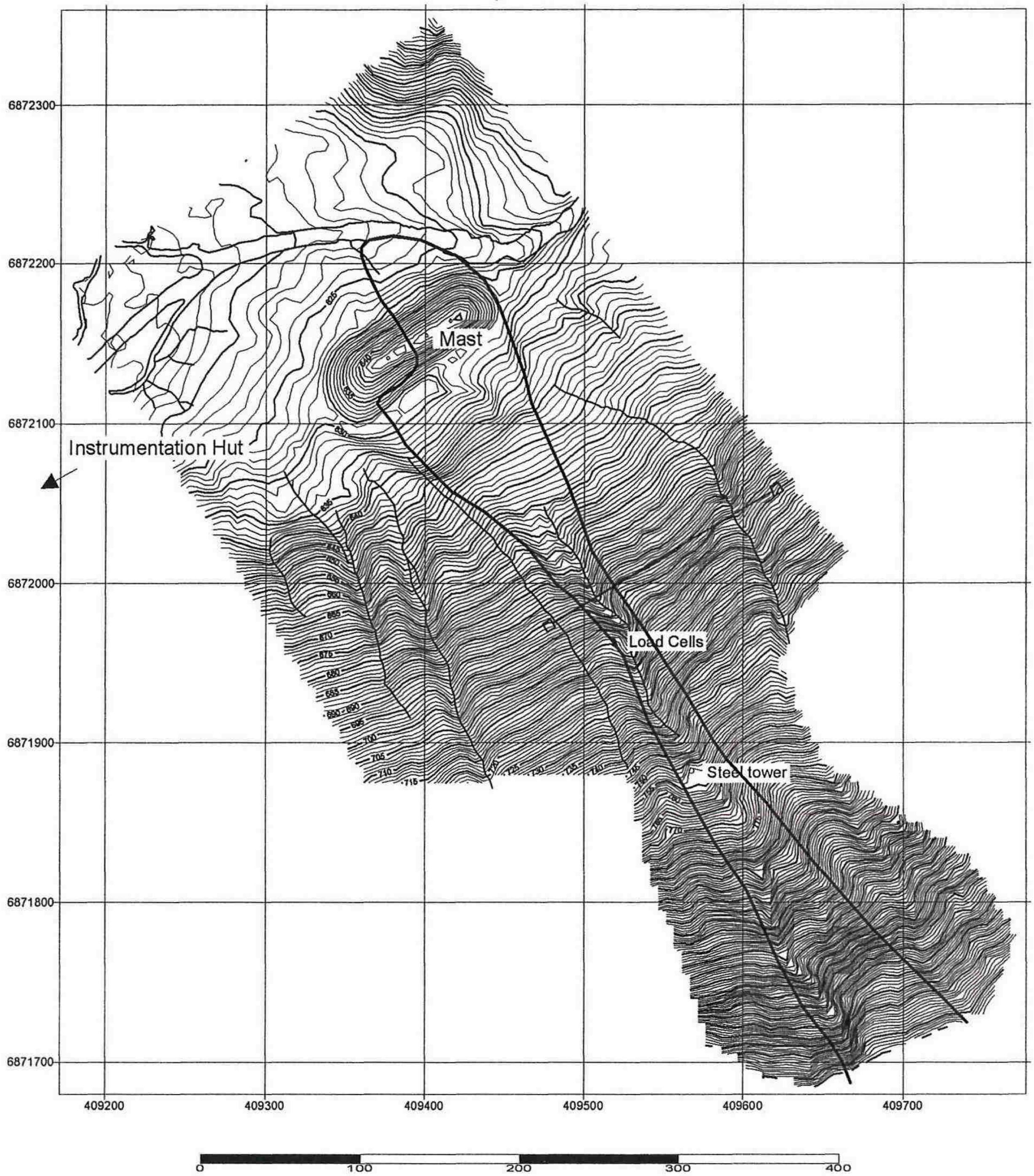
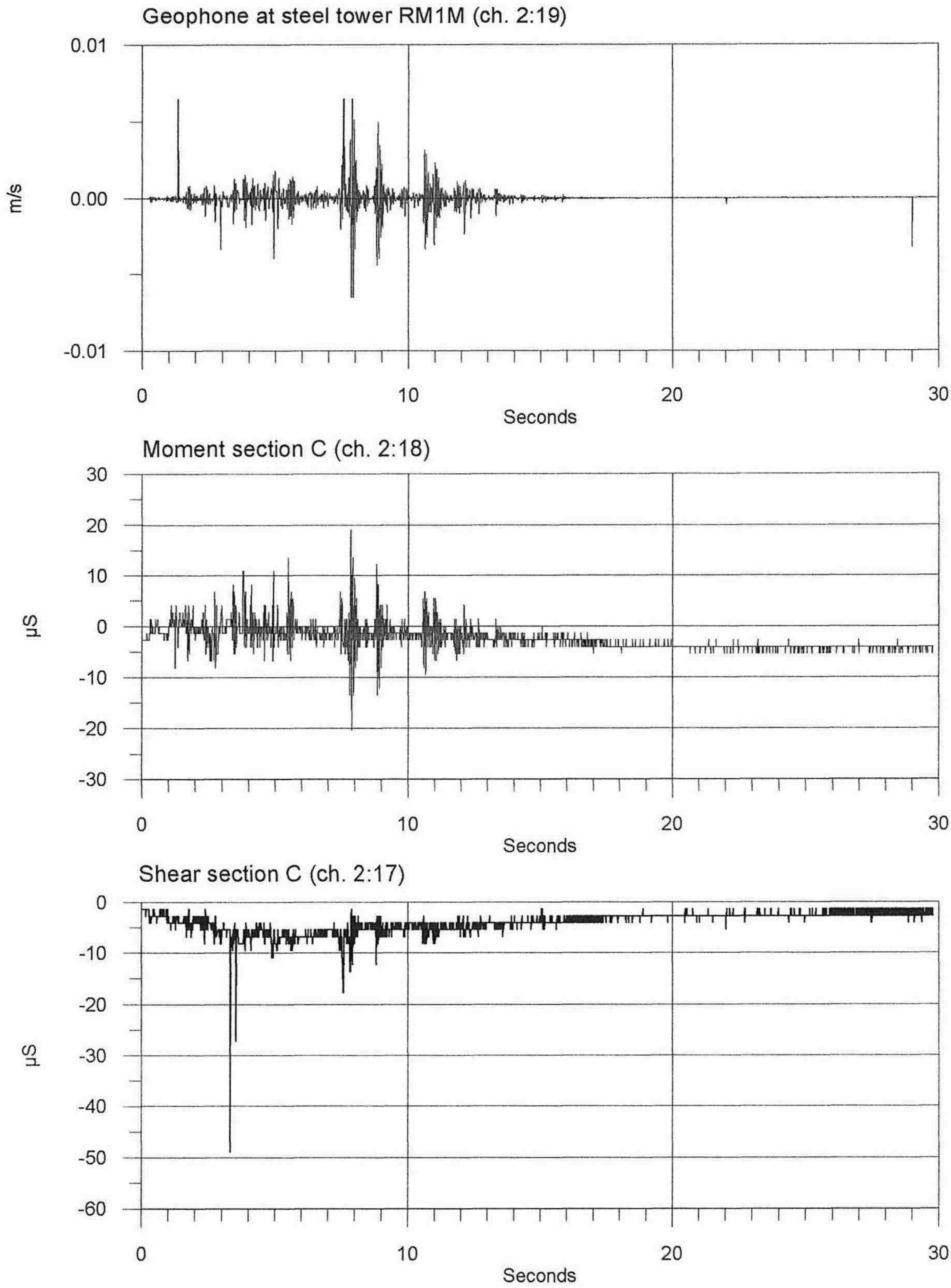


581200 - RYGGFONN	Rapport nr. 581200-32	Figur nr. 15
Map of the avalanche runout area Deposit boundary of the 95.03.03 avalanche Scale 1:4000	Tegner Kontrollert Godkjent	Dato NGI



581200 - RYGGFONN	Report No. 581200-32	Figure No. **16**
Avalanche 95.03.03, artificially released Recordings from sensors at steel tower	Drawn by KK Checked Approved	Date NGI

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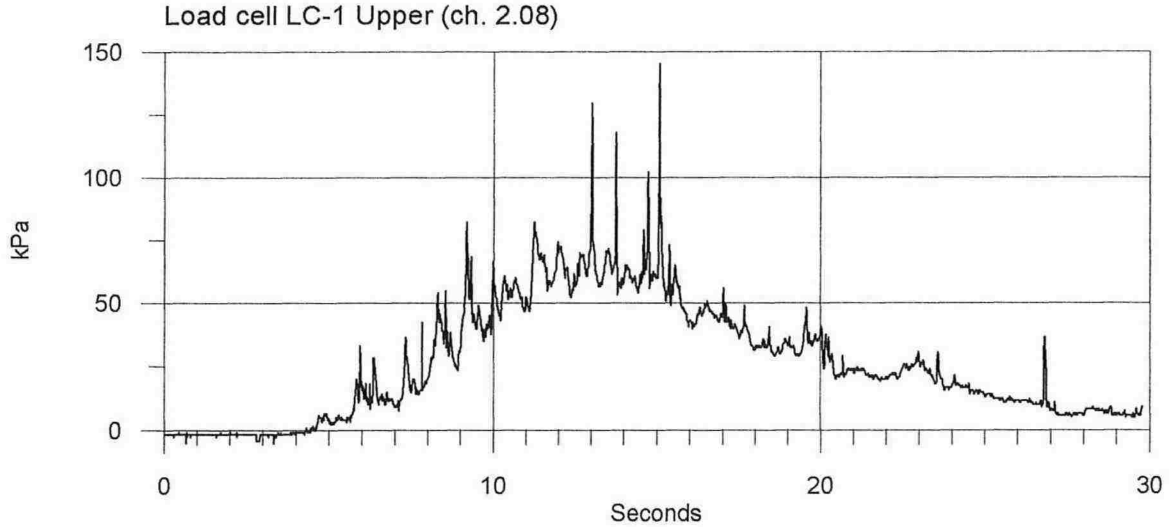

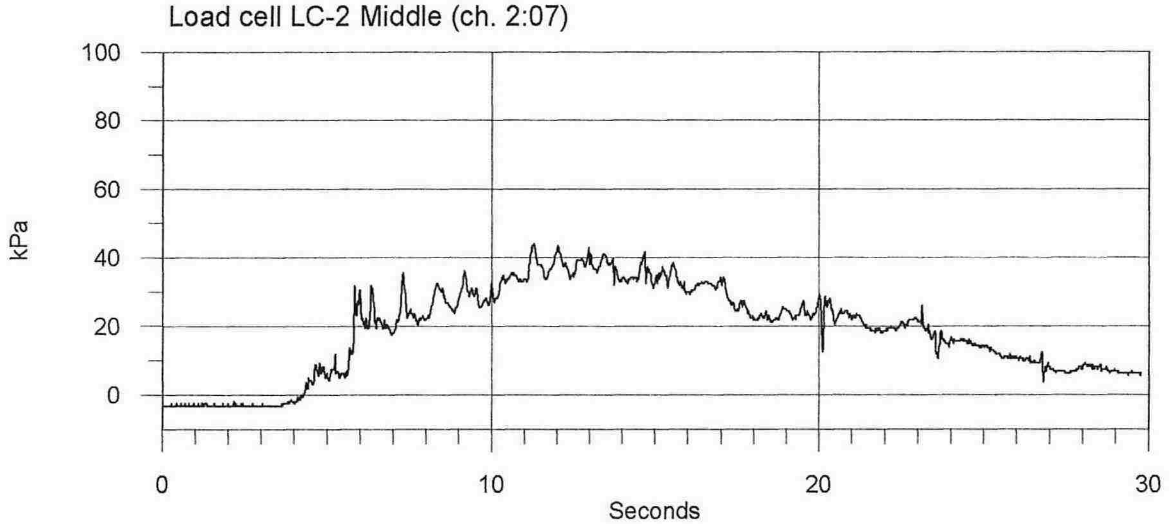

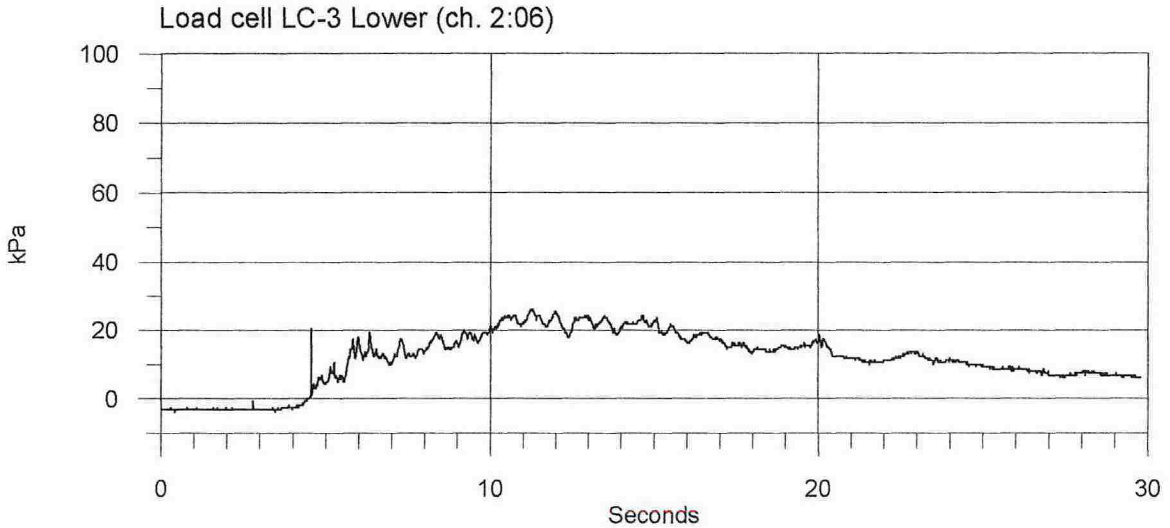

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Avalanche 95.03.03, artificially released Impact pressures on load cells on concrete structure	Drawn by KL Checked Approved	Date NGI

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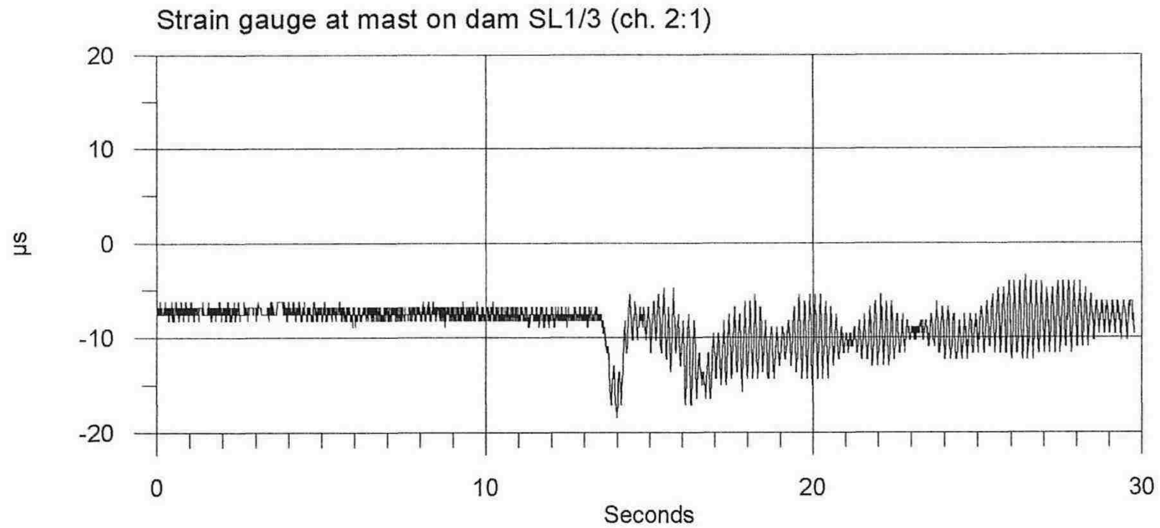

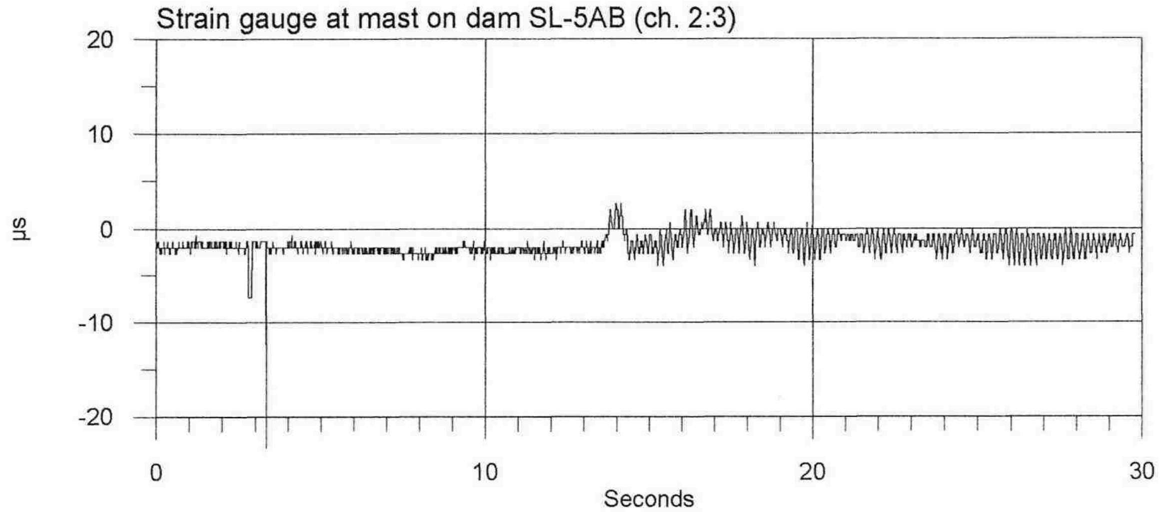

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Avalanche 95.03.03, artificially released Recordings from sensors at mast on dam	Drawn by Checked Approved	Date NGI

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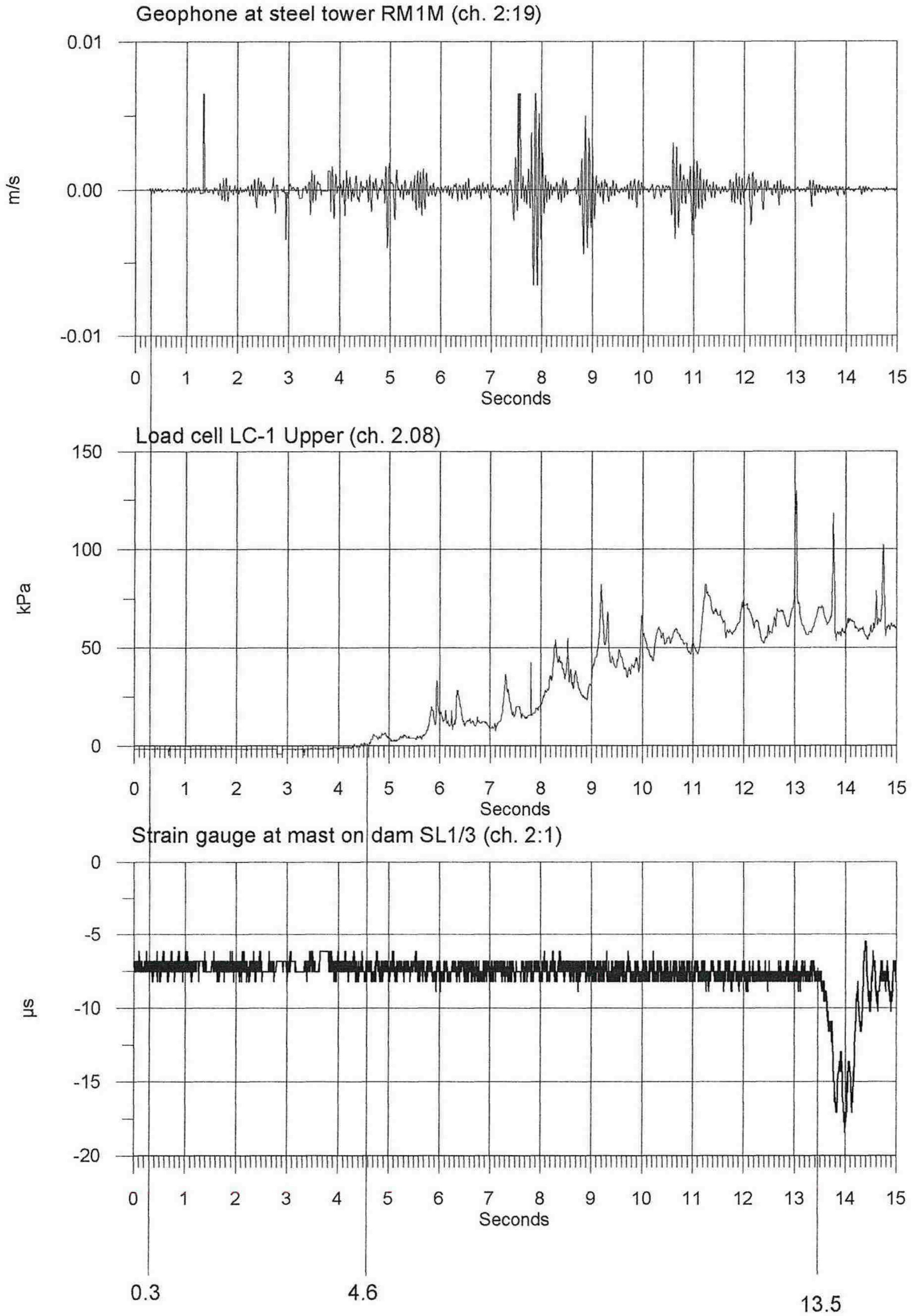
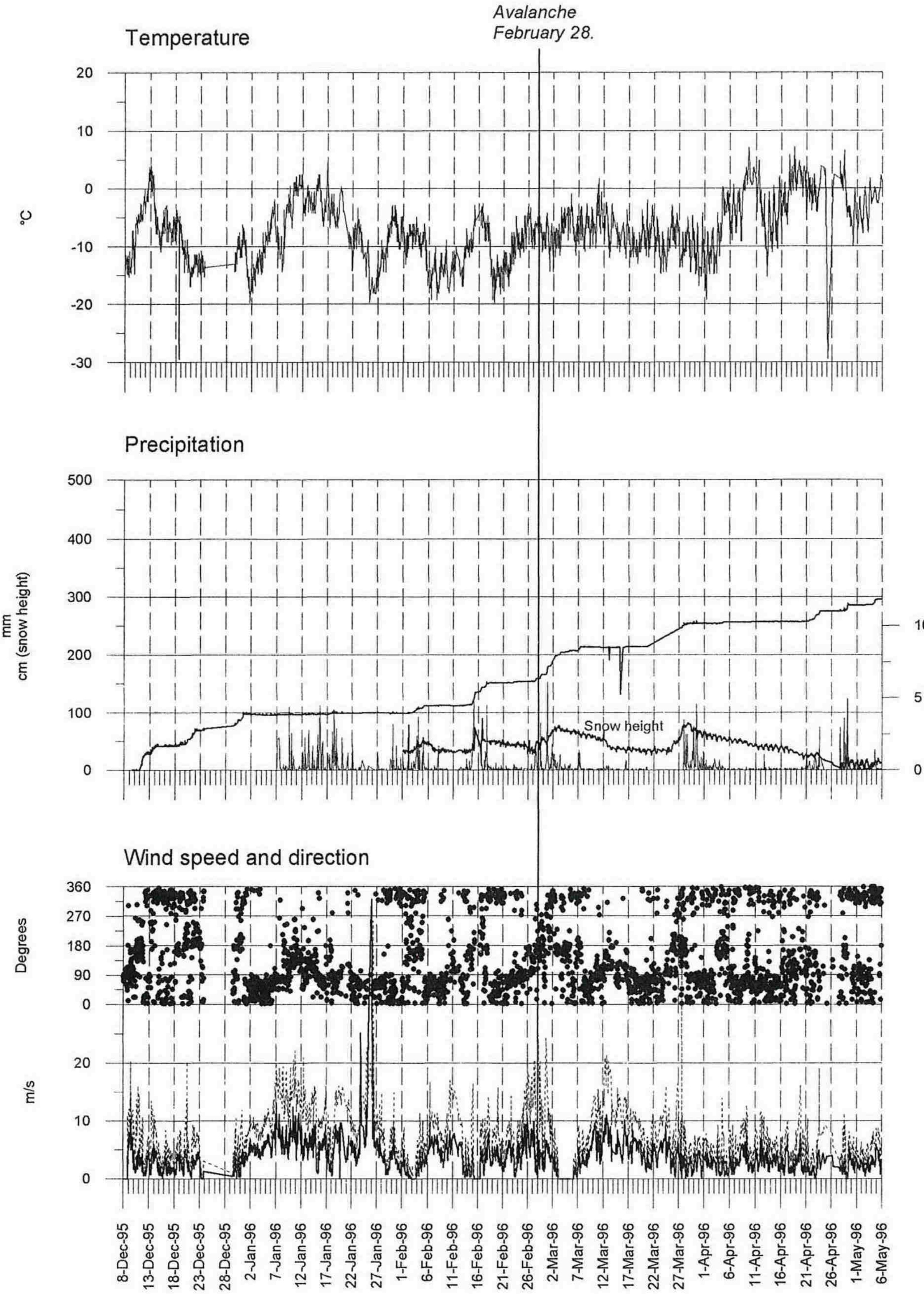


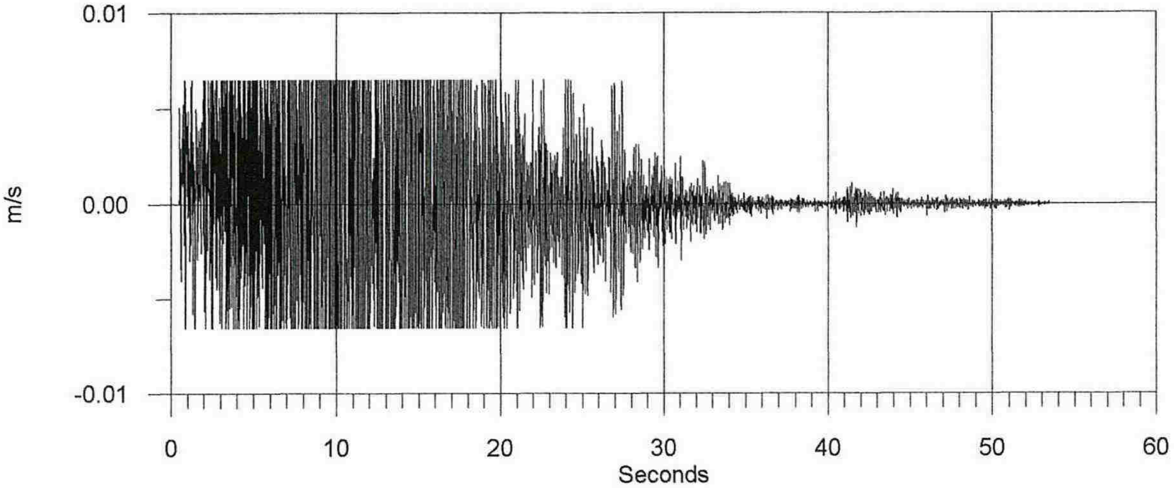
581200 - RYGGFONN	Report No 581200-32	Figure No. 19
Avalanche 95.03.03 13:27, artificially released Impact times at different sensors	Drawn by Checked Approved	Date NGI

d:data.rf.9495.950303.impact.grf

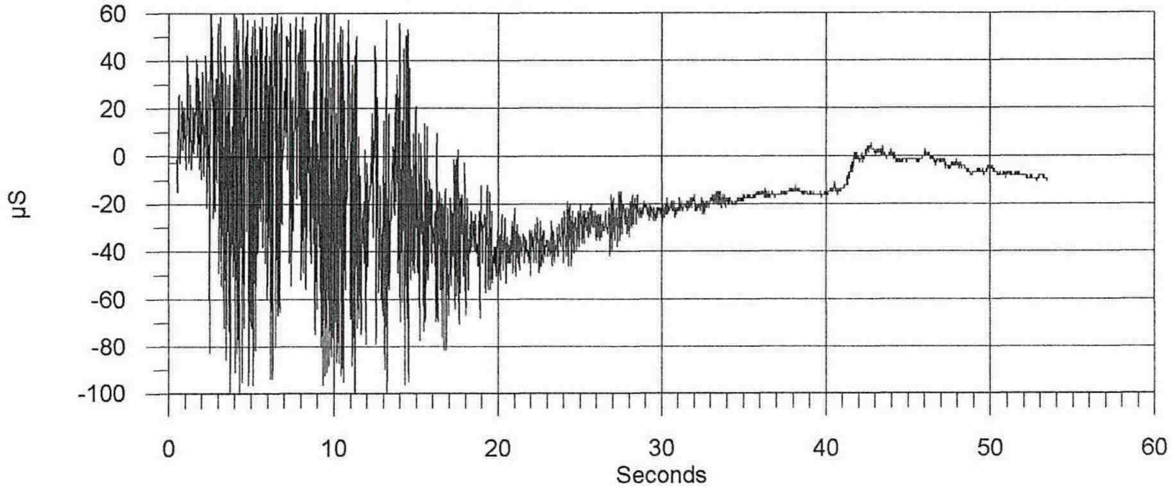


581200 - RYGGFONN	Report No. 581200-32	Figure No. 20
Winter 1995-1996 **Weather conditions at Fonnbu, 930 m a.s.l.**	Drawn by KK	Date
	Checked	NGI
	Approved	

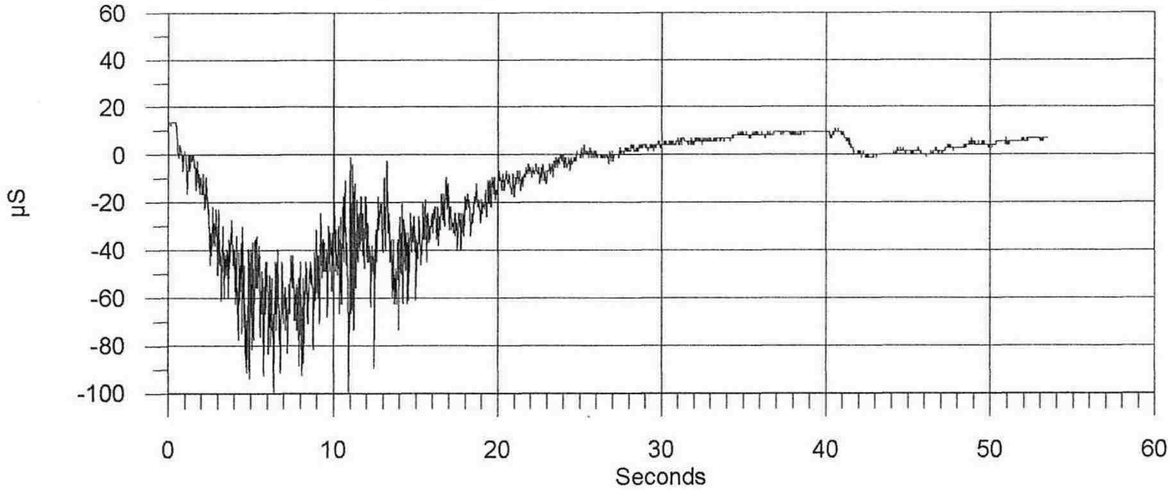
Geophone at steel tower RM1M (ch. 2:19)



Moment section B (ch. 2:16)

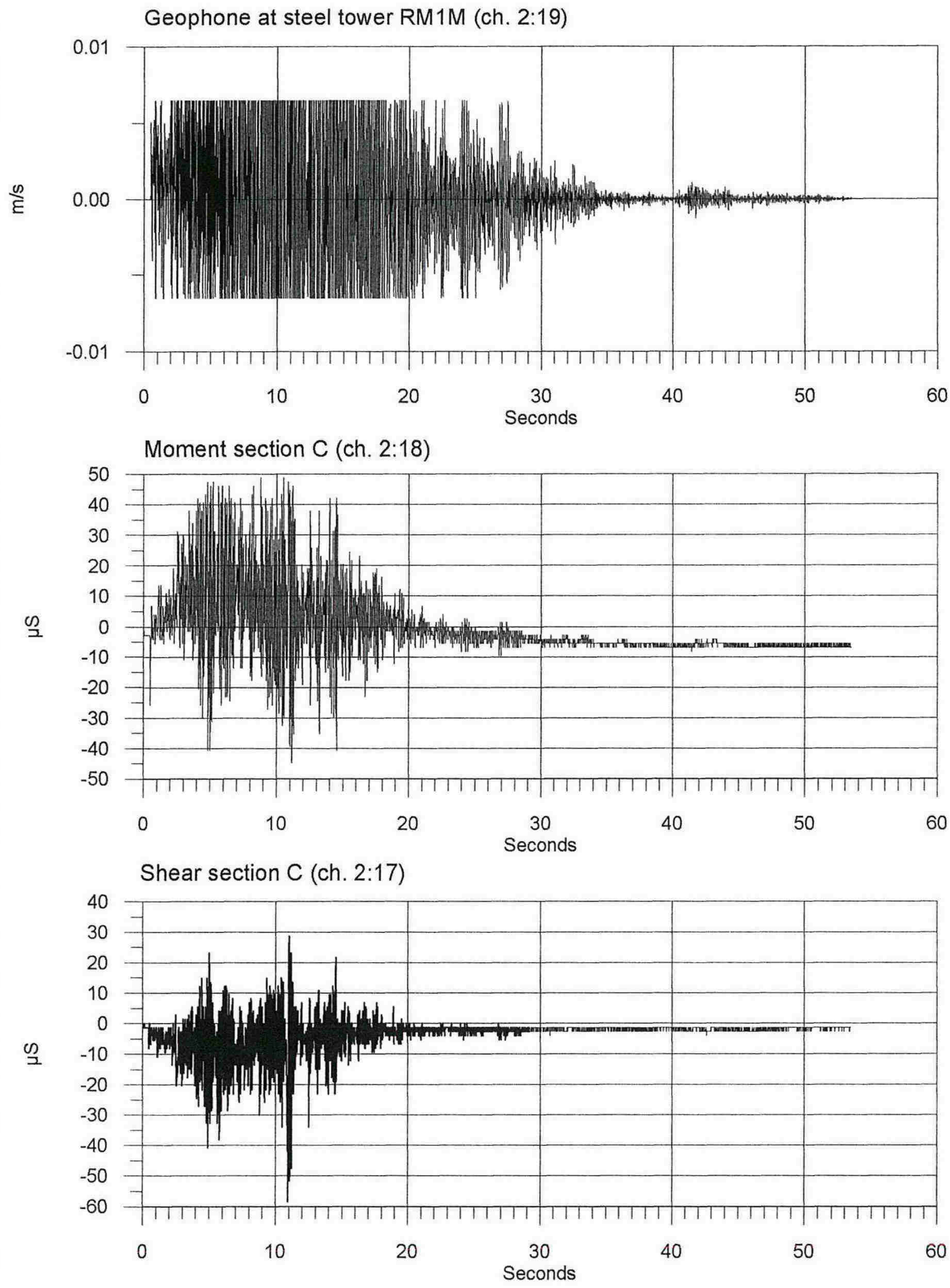


Shear section B (ch. 2:15)



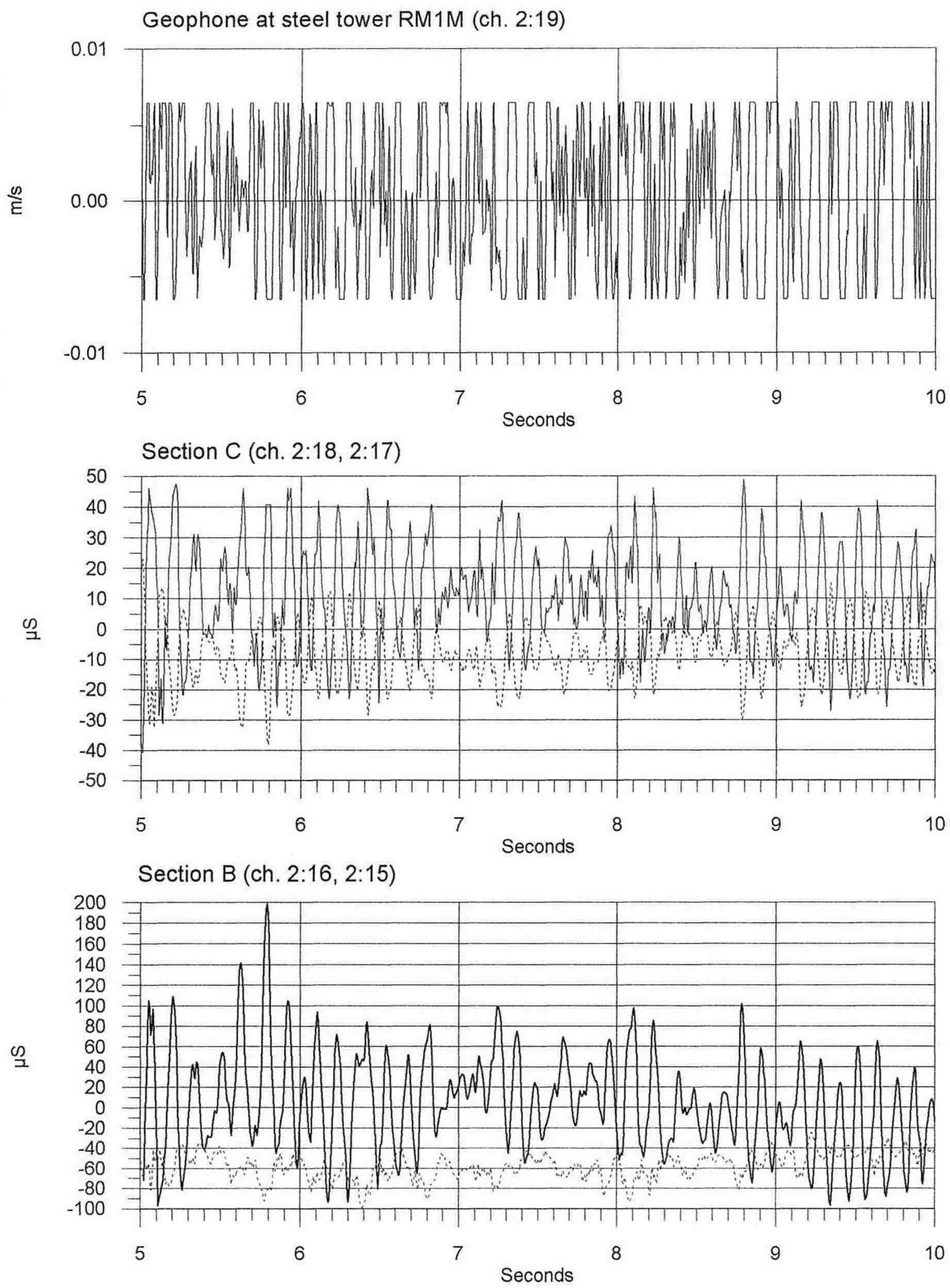
581200 - RYGGFONN	Report No. 581200-32	Figure No. **21**
Avalanche 96.02.28 19:48, naturally released Recordings from sensors at steel tower	Drawn by KK	Date
	Checked	NGI
	Approved	

c:.data.rf.9596.960228.btower.grf



581200 - RYGGFONN	Report No. 581200-32	Figure No. 22
Avalanche 96.02.28 19:48, naturally released Recordings from sensors at steel tower	Drawn by KK Checked Approved	Date NGI

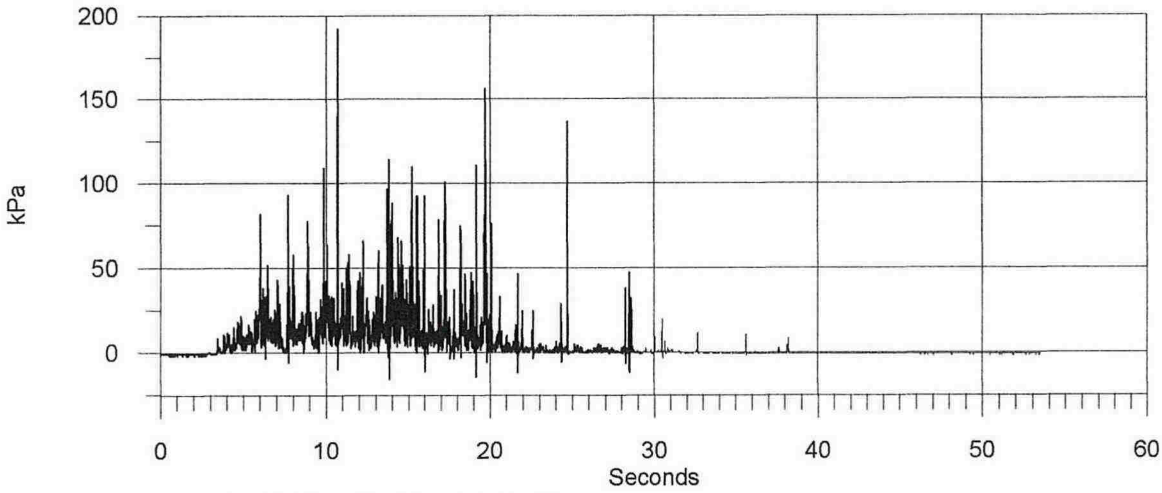
c:.data.rf.9596.960228.stower.grf



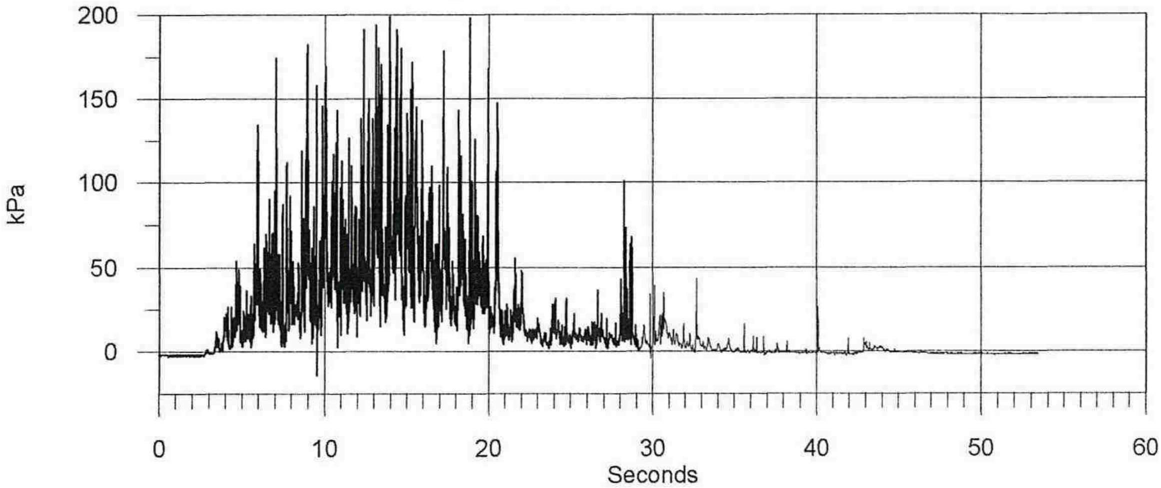
581200 - RYGGFONN	Report No. 581200-32	Figure No. **23**
Avalanche 96.02.28 19:48, naturally released Detail of recordings from sensors at steel tower	Drawn by Checked Approved	Date NGI

c:.data.rf.9596.960228.detower.grf

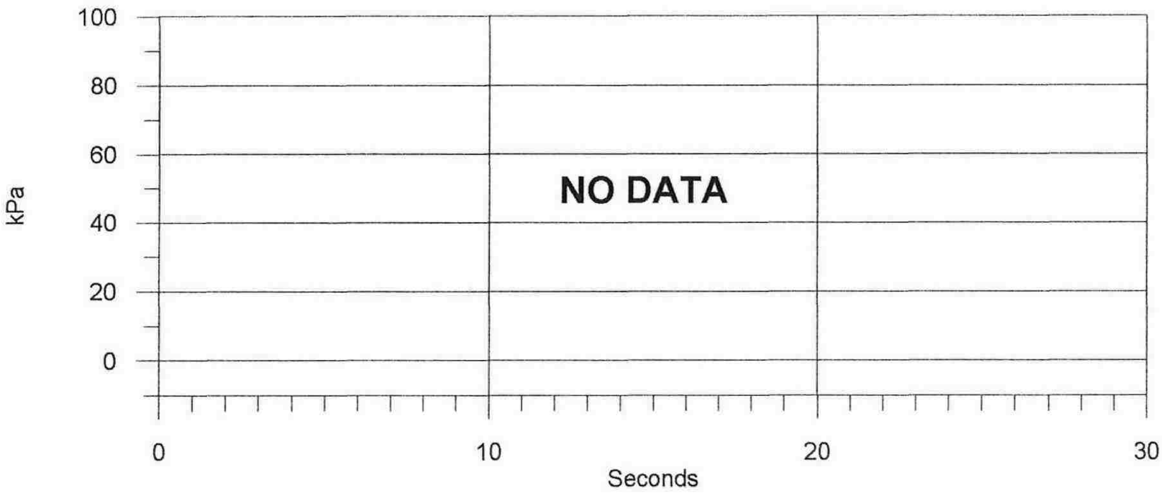
Load cell LC-1 Upper (ch. 2.12)



Load cell LC-2 Middle (ch. 2:10)



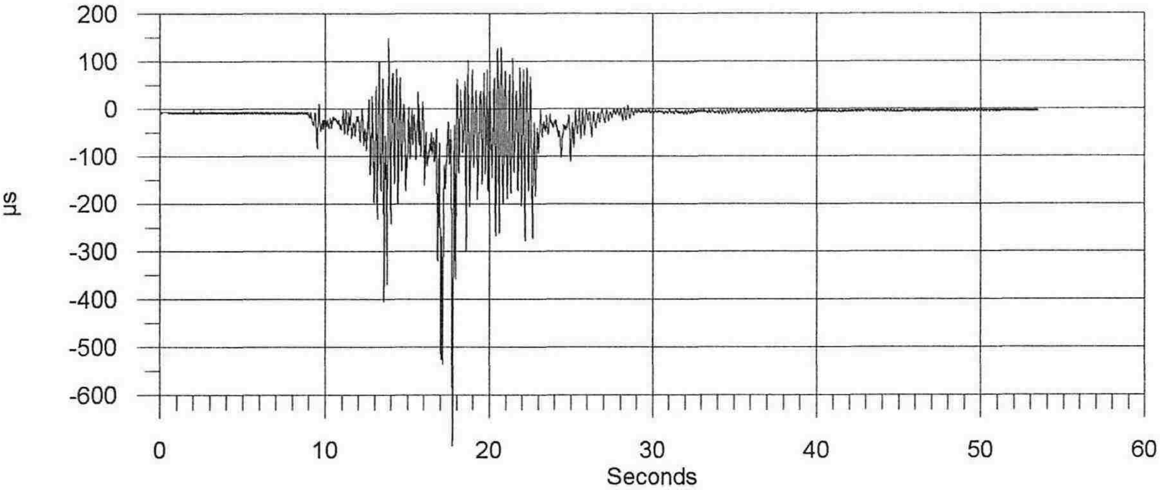
Load cell LC-3 Lower (ch. 2:09)



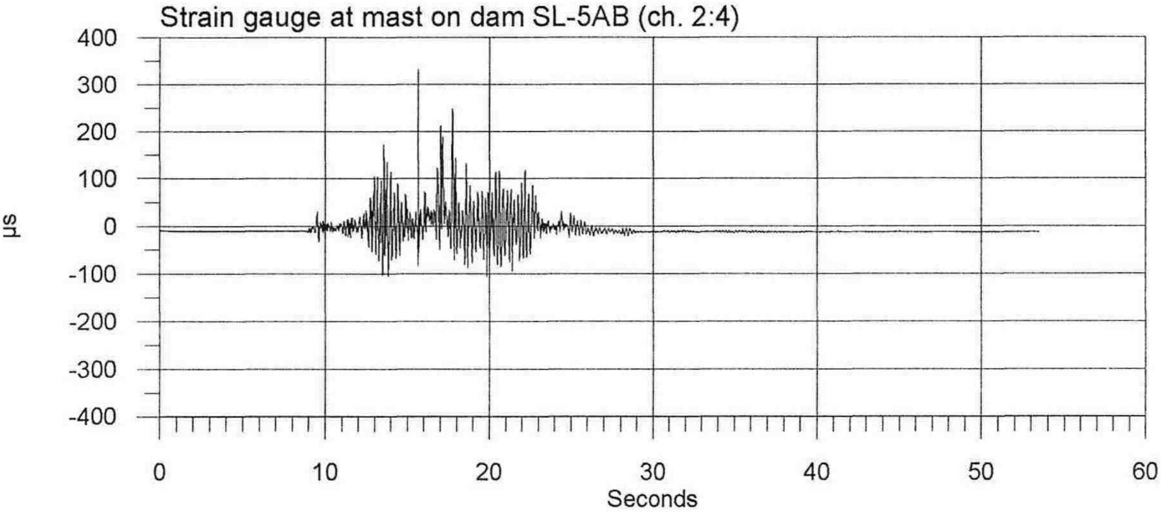
581200 - RYGGFONN	Report No. 581200-32	Figure No. **24**
Avalanche 96.02.28 19:48, naturally released Impact pressures on load cells on concrete structure	Drawn by Checked Approved	Date NGI

c:.data.rf.9596.960228.lc.grf

Strain gauge at mast on dam SL1/3 (ch. 2:1)



Strain gauge at mast on dam SL-5AB (ch. 2:4)

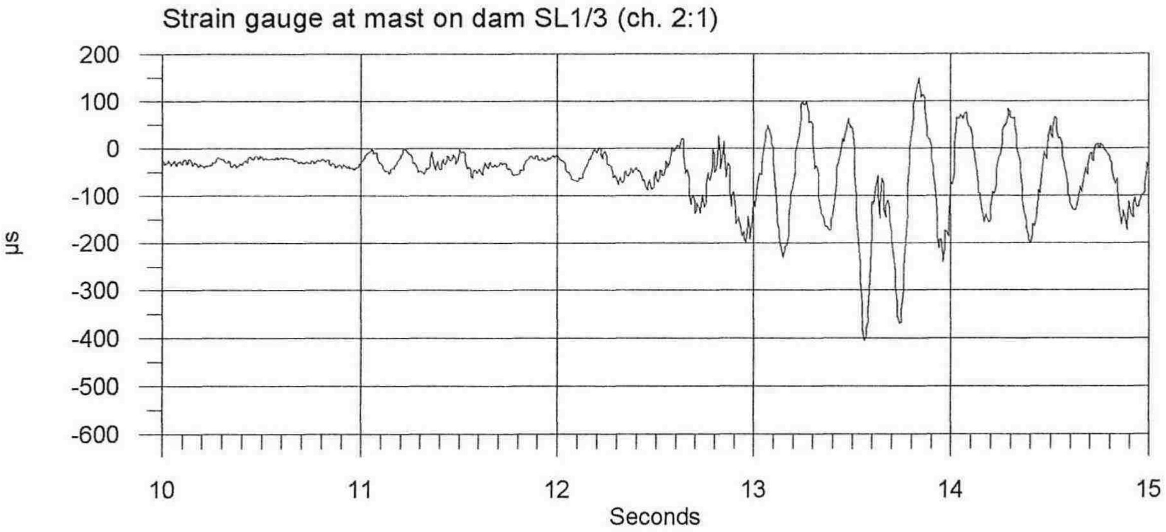


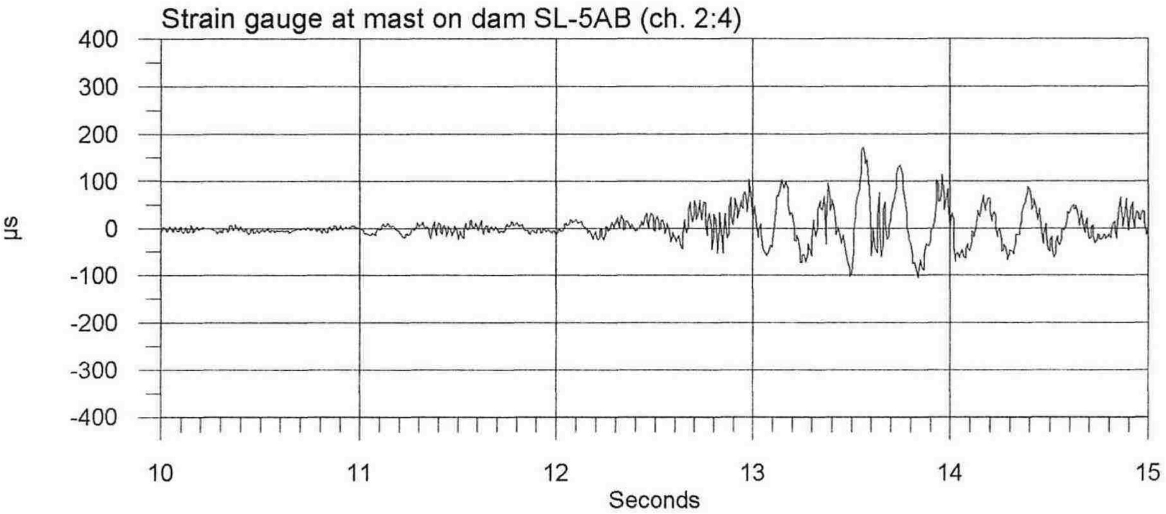
581200 - RYGGFONN

Avalanche 96.02.28 19:48, naturally released
Recordings from sensors at mast on dam

Report No	Figure No.
581200-32	**25**
Drawn by KK	Date
Checked FS	NGI
Approved GL	

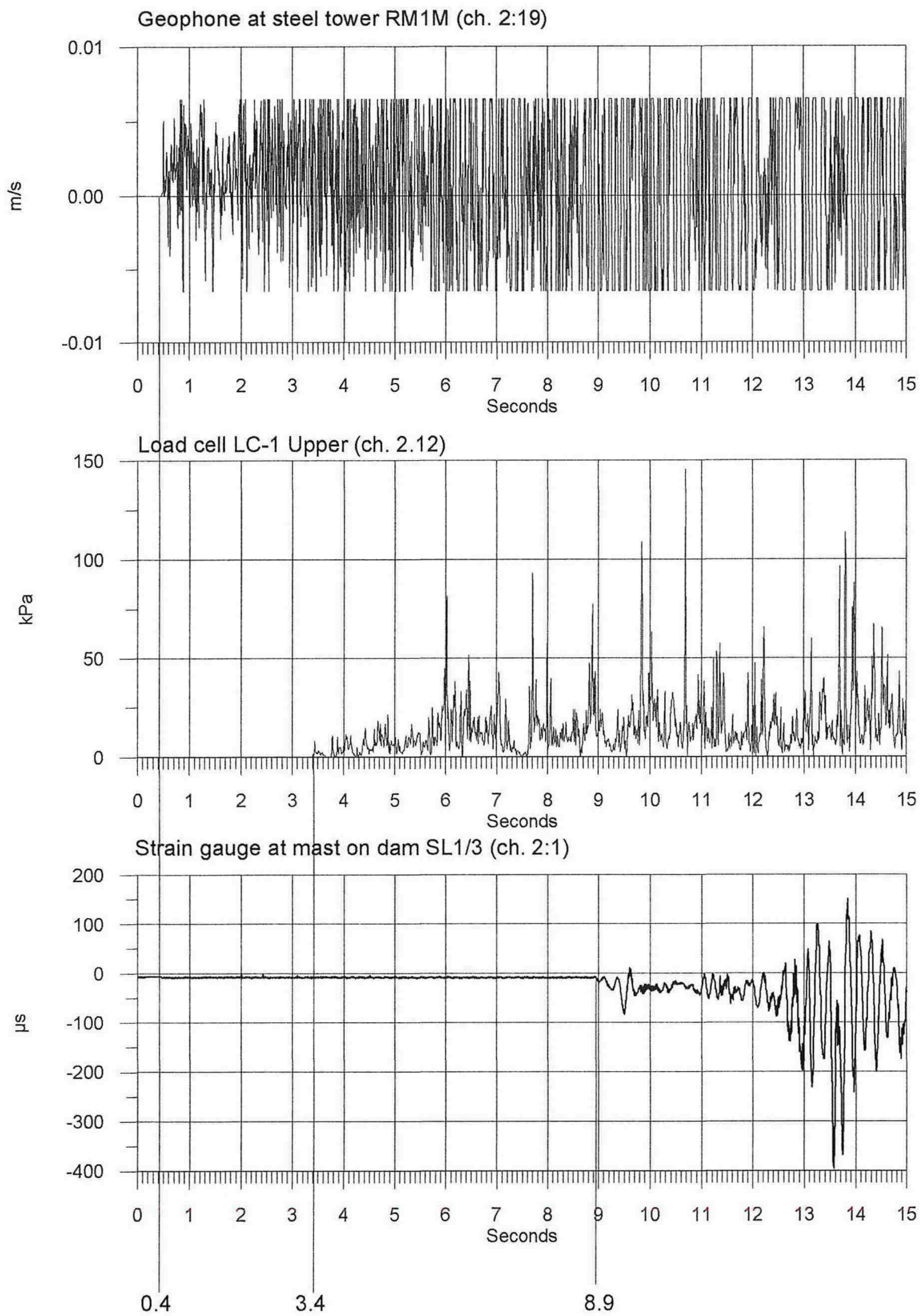
c:.data.rf.9596.960228.dam.grf





581200 - RYGGFONN	Report No 581200-32	Figure No. **26**
Avalanche 96.02.28 19:48, naturally released Detail of recordings from sensors at mast on dam	Drawn by KK Checked Approved	Date NGI

c:.data.rf.9596.960228.detdam.grf



581200 - RYGGFONN

Report No 581200-32

Figure No. 27

Drawn by

Date

Avalanche 96.02.28 19:48, naturally released
Impact times at different sensors

Checked

Approved

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d:data.rf.9596.960228.impact.grf

Kontroll- og referanseside/
Review and reference page

NGI

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Kommune/*Municipality*	Feltnavn/*Field name*
Sted/*Location*	Sted/*Location*
Kartblad/*Map*	Felt, blokknr./*Field, Block No.*
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Kvalitetssikring i henhold til/*Quality assurance according to* NS-EN ISO9001

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FS	Helhetsvurdering/ *General Evaluation* *	4/2-98	FS				
	Språk/*Style*						
FS	Teknisk/Technical - Skjønn/*Intelligence* - Total/*Extensive* - Tverrfaglig/ *Interdisciplinary*	4/2-98	FS				
WUT	Utforming/*Layout*						
FS	Slutt/*Final*	4/2-98	FS				
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