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DECICE simulation of ice gouging by breakable ice ridges: a brief data report

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DECICE SIMULATION OF ICE GOUGING BY BREAKABLE ICE RIDGES: A BRIEF DATA REPORT

LM-2006-08

Michael Lau

November 2006

ABSTRACT

The Cambridge University has sought assistance from IOT for computer simulations of the gouging process using DECICE. The objective of this project was to study the conditions in which an ice keel will break up, partially or completely, when in contact with the seabed during the process of ice gouging. The ice friction angle and the cohesion of ice were the two key parameters investigated, as they have a significant effect on the fracture of breakable ice ridges. The data obtained from DECICE aimed to establish a relationship between the fracture of ice ridges and their mechanical properties.

IOT was primarily responsible for the DECICE simulations of the problem and the transfer of results obtained for analysis work. At the writing of this memorandum, we have only completed simulations with varying ice friction, seabed inclination and trajectory angle. This memorandum documents the results of these simulations.

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DECICE SIMULATION OF ICE GOUGING

1.0 INTRODUCTION

Seabed gouging by ice is a potentially serious problem for Arctic marine pipelines and other seabed structures. Due to the influence of large deformations that extend below the gouge base, a pipeline may need to be trenched well below the maximum expected gouging depth. The cost of deep trenching is high enough to threaten to make some projects uneconomic.

The Institute for Ocean Technology (IOT), in collaboration with C-CORE and MUN, has conducted a preliminary study of the problem using DECICE, discrete element software. Details of the modeling and results were published by Lau et al (2000).

Dr. Palmer and Mr. Paul Lee of Cambridge University have sought assistance from IOT for additional computer simulations of the gouging process using DECICE. The objective of this project was to study the conditions in which an ice keel will break up, partially or completely, when in contact with the seabed during the process of ice gouging. The ice friction angle and the cohesion of ice were the two key parameters investigated, as they have a significant effect on the fracture of breakable ice ridges. The data obtained from DECICE aimed to establish a relationship between the fracture of ice ridges and their mechanical properties.

IOT was primarily responsible for the DECICE simulations of the problem and the transfer of results obtained for analysis work. At the writing of this memorandum, we have only completed simulations with varying ice friction, seabed inclination and trajectory angle. This memorandum documents the results of these simulations.

2.0 PROBLEM SET-UP

The DECICE model developed in the preliminary DECICE study (Lau et al, 2000) was used in this investigation. Lau et al's paper gives details of the model. Table 1 shows the test matrix with the following standard ridge characteristics:

- Density of ice: 900kg/m³
- Density of water: 1024kg/m³
- Rigid plate boundary at sea level: ice blocks compact due to buoyancy force
- Keel width: 81m
- Keel depth: 13m
- Repose angle: 24°
- Ice block thickness: 0.5m
- Ice block width: 1m
- Number of blocks: 950
- Seabed load plate: 37.5m (Runs 2-1 to 2-5) and 75m (Runs 3-1 to 3-5)

Table 1: Test matrix

Test Number (#)	Seabed Inclination α (°)	Cohesion c (kPa)	Ice Friction μ	Horizontal Velocity V_h (m/s)	Vertical Velocity V_v (m/s)	Trajectory Angle β (deg)
2-1	5	0	0.4	0.4	0.1	15
2-2	5	0	0.6	0.4	0.1	15
2-3	5	0	0.8	0.4	0.1	15
2-4	10	0	0.8	0.4	0.1	15
2-5	1	0	0.8	0.4	0.1	15
3-1	5	0	0.4	0.4	0.03	5
3-2	5	0	0.6	0.4	0.03	5
3-3	5	0	0.8	0.4	0.03	5
3-4	10	0	0.8	0.4	0.07	10
3-5	1	0	0.8	0.4	0.07	1

The simulations began at $t = 28.2s$; enough time to allow the loading plate to move vertically to contact the ridge keel with an initial width of 7.76m, 6.96m, and 5.45m for seabed inclination angles of 5°, 10°, and 1°, respectively. This resulted in pre-stress in the keel. Once the plate was allowed to move horizontally at the start of the stimulations, this pre-stress was rapidly released. Hence, this pre-stress is artificial and does not have any influence on subsequent contact pressure. The simulations were conducted until the load plate completely penetrated the keel base. Runs 2-1 to 2-5

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have a trajectory angle of 15 degrees, while Runs 3-1 to 3-5 have trajectory angles equal to the respective seabed inclinations. Figure 1 shows a typical initial configuration of the ridge keel/sea bed system.

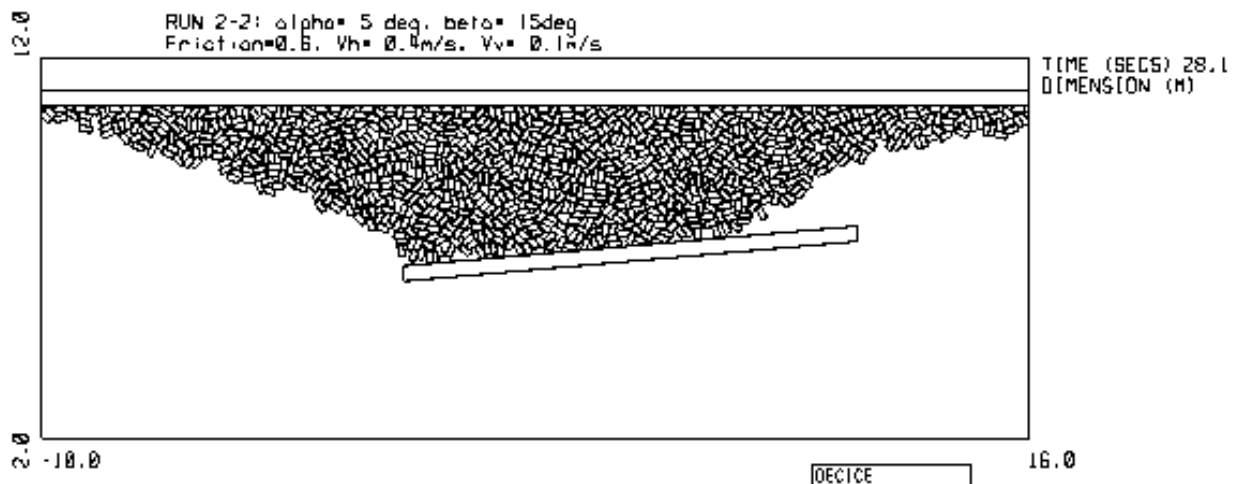


Figure 1: Typical initial configuration of ridge keel/sea bed system

3.0 RESULTS

The required outputs were: maximum nominal pressure, pressure at peak events, pressure-time history graph, and snap shots of the different initial configurations of the ridge keel/sea bed system.

The pressure data is summarized in Table 2. A typical force-time history (Run 2-2) is shown in Figure 2. The ice forces increased with increase contact. Individual peak events can be identified in the time history. The contact force at each peak event was identified from the time histories and the corresponding contact width was then estimated from the geometry snapshots. This information was used to compute the contact pressure.

Table 2: Summary of pressure data

Run	Time (s)	F_h (kN)	F_v (kN)	F_n (kN)	Base (nom)	W_{nom} (m)	P_{nom} (KPa)
2-1	39.3	180	-680	120	11.72	11.76	10.20
	41.7	240	-710	177	11.95	12.00	14.77
	43.3	301	-1140	200	11.86	11.91	16.84
	44.6	180	-770	112	11.77	11.81	9.50
	49.1	609	-1850	445	11.77	11.81	37.70
	49.9	490	-1970	316	11.95	12.00	26.38
2-2	35.7	120	-350	89	10.81	10.85	8.21
	40.2	250	-740	185	11.51	11.55	15.97
	44.4	610	-1490	478	11.95	12.00	39.83
	45.5	430	-1370	309	11.95	12.00	25.76
	46.6	430	-1130	330	11.95	12.00	27.50
	49.3	550	-1720	398	11.60	11.64	34.18
2-3	33.5	170	-380	136	11.07	11.11	12.26
	40.6	400	-1240	290	11.95	12.00	24.21
	45.3	1150	-2530	925	11.60	11.64	79.45
	48.2	1340	-3890	996	11.42	11.46	86.87
	49.9	1890	-4570	1485	11.77	11.81	125.65
2-4	31.3	140	-410	67	9.22	9.36	7.12
	35.7	450	-960	276	10.41	10.57	26.15
	37.9	300	-1190	89	10.50	10.66	8.33
	39.3	220	-690	97	10.01	10.16	9.53
	43.3	300	-880	143	10.89	11.06	12.90
	49.1	1320	-2840	807	10.63	10.79	74.74

DECICE SIMULATION OF ICE GOUGING

Table 2: Summary of pressure data (cont'd)

Run	Time (s)	F _h (kN)	F _v (kN)	F _n (kN)	Base (nom)	W _{nom} (m)	P _{nom} (KPa)
2-5	38.0	230	-550	220	11.60	11.60	18.99
	43.4	500	-220	496	11.16	11.16	44.45
	45.1	414	-992	397	11.07	11.07	35.82
	45.7	486	-956	469	11.24	11.24	41.74
	46.6	341	-992	324	11.42	11.42	28.34
	47.3	370	-956	353	11.46	11.46	30.82
	48.2	402	-992	385	11.51	11.51	33.41
	49.8	472	-1300	449	11.95	11.95	37.59
3-1	34.9	23	-48	19	6.46	6.48	2.89
	37.6	59	-84	51	11.45	11.49	4.46
	40.1	45	-56	39	12.46	12.51	3.16
	42.6	30	-56	25	10.33	10.37	2.43
	44.6	45	-56	39	8.21	8.24	4.79
	52.0	273	-513	227	13.68	13.73	16.55
	57.0	416	-827	342	14.19	14.24	24.03
	59.0	244	-584	193	14.09	14.14	13.61
	60.8	202	-470	160	13.98	14.03	11.38
	62.0	216	-470	174	15.05	15.11	11.52
	65.4	230	-427	192	15.96	16.02	11.98
	68.9	244	-541	196	15.81	15.87	12.37
	73.4	202	-456	161	14.39	14.44	11.15
	79.8	430	-1070	335	12.38	12.43	26.99
	81.3	316	-898	236	13.68	13.73	17.21
	86.3	330	-770	262	12.92	12.97	20.19
	88.8	273	-756	206	13.07	13.12	15.71
3-2	34.2	16	-33	13	6.08	6.10	2.21
	36.1	29	-45	25	9.73	9.77	2.53
	39.4	90	-181	74	11.55	11.59	6.39
	41.1	115	-169	100	11.39	11.43	8.72
	55.5	311	-638	255	16.27	16.33	15.59
	59.0	201	-416	164	15.20	15.26	10.72
	62.0	385	-736	319	15.65	15.71	20.34
	63.5	324	-711	260	15.88	15.94	16.33
	67.9	225	-452	185	16.34	16.40	11.27
	69.9	250	-489	206	15.66	15.72	13.12
	74.9	373	-859	297	14.64	14.70	20.18
	76.4	361	-687	299	14.59	14.65	20.43
	81.3	238	-489	194	14.87	14.93	12.99
	86.3	299	-452	258	13.38	13.43	19.24

DECICE SIMULATION OF ICE GOUGING

Table 2: Summary of pressure data (cont'd)

Run	Time (s)	F _h (kN)	F _v (kN)	F _n (kN)	Base (nom)	W _{nom} (m)	P _{nom} (KPa)
3-3	33.4	28	-56	23	6.95	6.98	3.30
	38.6	14	-70	8	10.34	10.38	0.76
	41.1	42	-84	35	12.00	12.05	2.87
	44.6	126	-304	99	13.38	13.43	7.37
	46.6	154	-325	125	13.38	13.43	9.31
	49.6	126	-304	99	13.98	14.03	7.06
	51.6	140	-360	108	14.59	14.65	7.38
	55.6	234	-402	198	16.11	16.17	12.25
	57.1	178	-388	144	16.01	16.07	8.93
	59.1	192	-409	156	16.05	16.11	9.66
	61.6	318	-566	267	15.81	15.87	16.85
	64.1	395	-856	319	15.81	15.87	20.09
	66.0	290	-559	240	16.57	16.63	14.44
	69.5	444	-1010	354	16.11	16.17	21.91
	73.5	388	-814	316	12.92	12.97	24.33
	78.0	220	-402	184	13.22	13.27	13.87
	80.5	206	-388	171	15.50	15.56	11.02
	85.5	248	-706	186	15.00	15.06	12.32
	87.5	206	-360	174	15.10	15.16	11.47
3-4	38.6	310	-776	171	13.38	13.59	12.55
	41.6	853	-1500	580	13.68	13.89	41.72
	43.0	672	-1500	401	15.35	15.59	25.75
	46.3	1577	-2947	1041	16.11	16.36	63.65
	50.1	2300	-4700	1449	19.15	19.45	74.50
	53.0	3000	-5700	1965	19.15	19.45	101.03
	54.7	2400	-5900	1339	19.46	19.76	67.76
	57.5	3400	-7700	2011	19.15	19.45	103.43
	60.2	4400	-9700	2649	19.15	19.45	136.22
	62.9	5400	-12600	3130	19.15	19.45	160.96
	64.6	6000	-12800	3686	19.15	19.45	189.56
	65.6	5400	-12300	3182	19.15	19.45	163.64
	67.9	4800	-9300	3112	18.54	18.83	165.31
	69.2	3700	-7600	2324	17.63	17.90	129.82
3-5	41.2	2	-4	1.63	5.28	5.28	0.31
	46.3	4	-6	3.54	5.85	5.85	0.61
	49.1	5	-8	4.48	5.77	5.77	0.78
	50.4	19	-38	18.33	5.47	5.47	3.35
	52.9	11	-33	10.42	4.86	4.86	2.14
	58.0	6	-10	5.42	3.04	3.04	1.78
	60.8	11	-17	10.70	3.34	3.34	3.20
	63.1	13	-23	12.60	3.65	3.65	3.45
	71.9	11	-23	10.60	9.12	9.12	1.16
	78.0	15	-28	14.51	5.17	5.17	2.81
	82.2	31	-77	29.65	4.70	4.70	6.31

DECICE SIMULATION OF ICE GOUGING

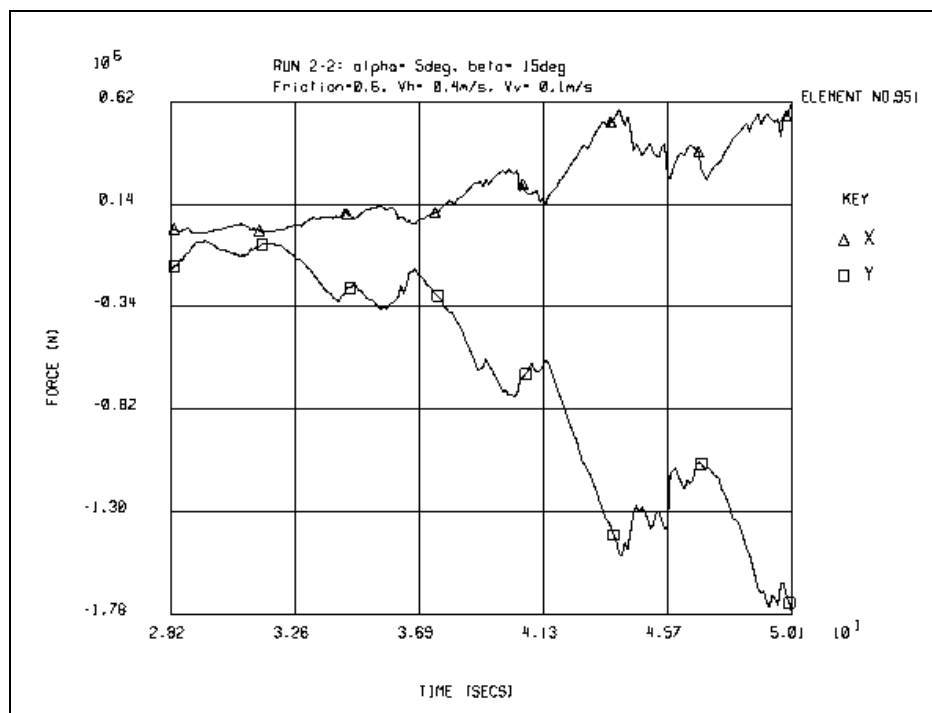


Figure 2: Typical force-time history

Time histories for the forces and the moment for each run are documented in Appendix A. A selected set of snapshots for each run is given in Appendix B.

4.0 DISCUSSIONS AND CONCLUSIONS

These series of simulations supplement the previous work (Lau et al, 2000). For background information and additional analysis, the reader should refer to Lau et al (2000). When modeling the keel as a frictional material (with zero cohesion), the functional relationship given in Lau et al between the internal friction and the ice friction coefficient should be used.

Data documented in Table 2 is of a preliminary nature. For example, the pressure values given at times beyond $t=42$ for Run 3-4 were suspicious as the loading plate was substantially interacting with the fixed top plate. For the 3* series, an extra data reduction at an earlier part of the interaction may give a better comparison with the 2* series. We will revise Table 2 accordingly.

The pressure development over time for each run is given in Figure 3. (Run 3-4 was not plotted based on the reason stated above.). The figure suggests a large influence of trajectory angle on pressure development.

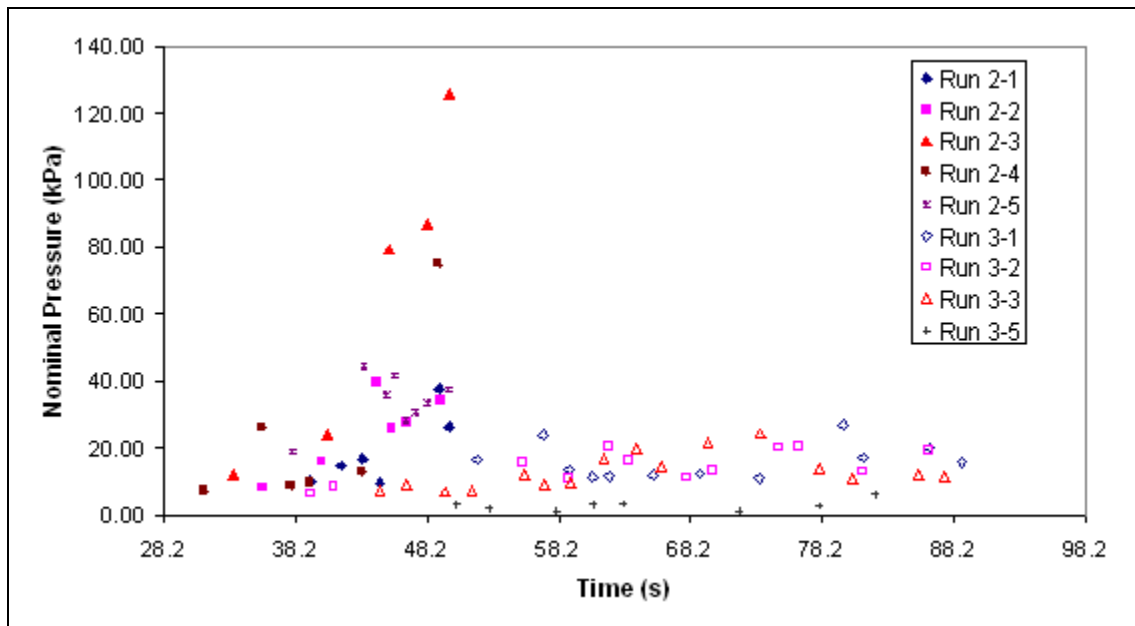


Figure 3: Pressure development over time

5.0 REFERENCES

Lau, M., Phillips, R., McKenna, R.F., and S.J. Jones, "Discrete Element Simulation of Ridge Keel Resistance during Scouring: A Preliminary Study," Proc. 2nd Ice Scour & Arctic Marine Pipelines Workshop, Mombetsu, Hokkaido, Japan, 2000.

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Appendix A **Force and Moment Time Histories for Each Run**

DECICE SIMULATION OF ICE GOUGING

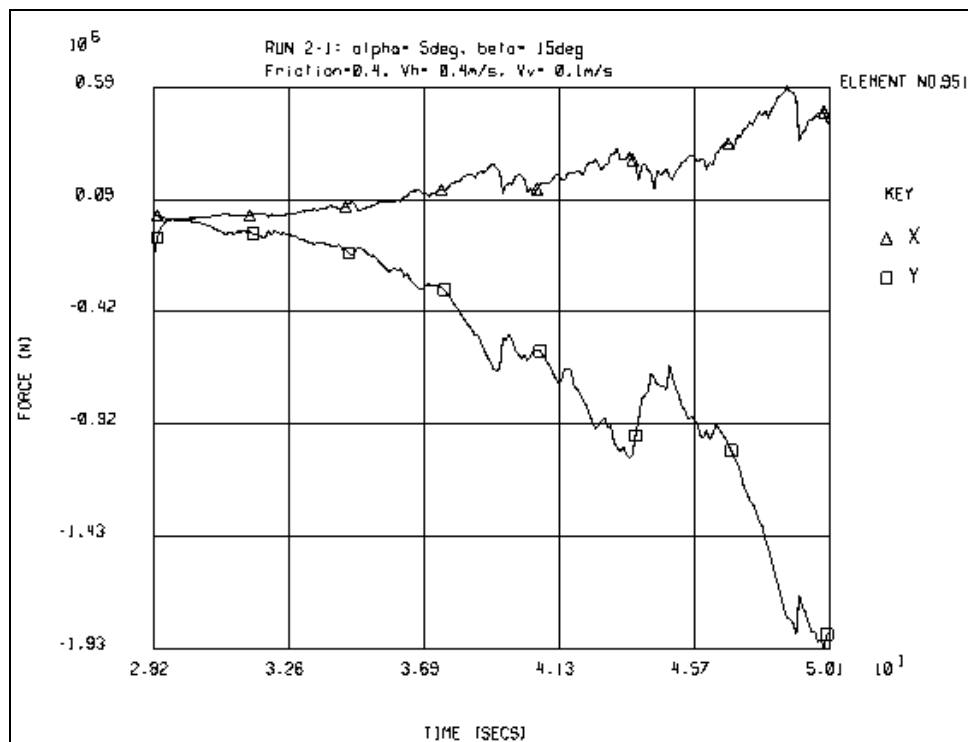


Figure A-1: Force-time history for run 2-1

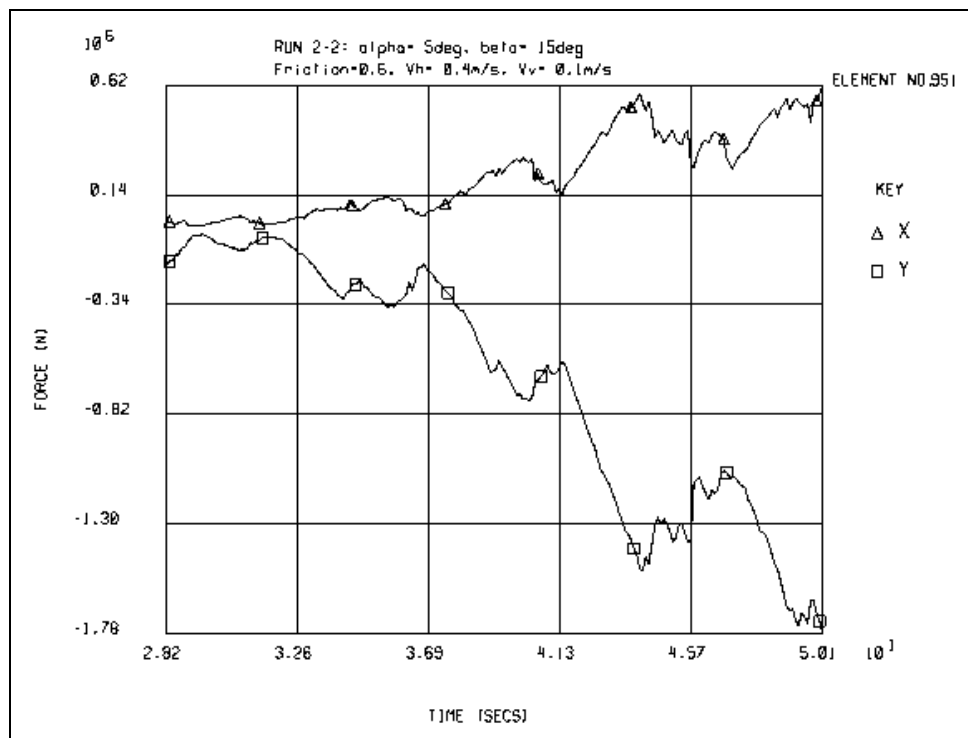


Figure A-2: Force-time history for run 2-2

DECICE SIMULATION OF ICE GOUGING

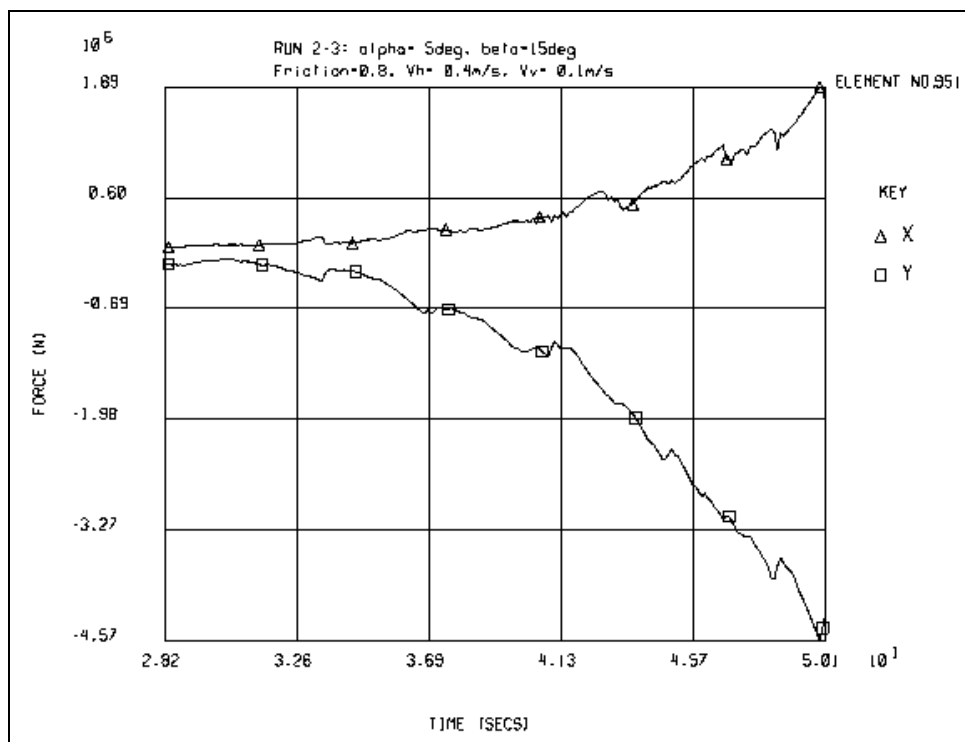


Figure A-3: Force-time history for run 2-3

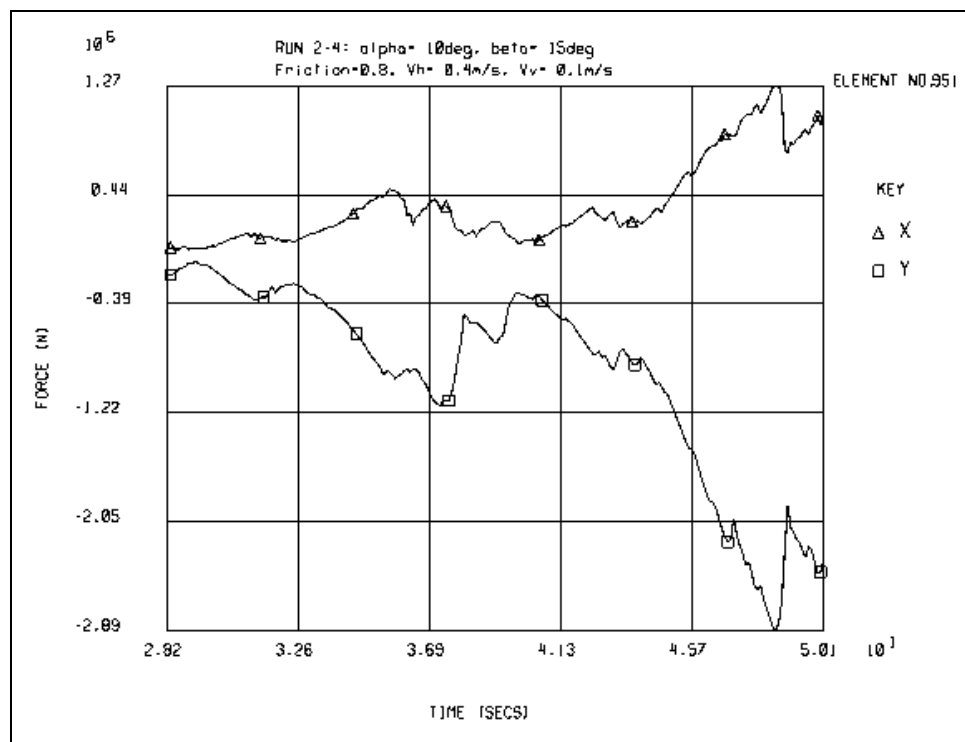


Figure A-4: Force-time history for run 2-4

DECICE SIMULATION OF ICE GOUGING

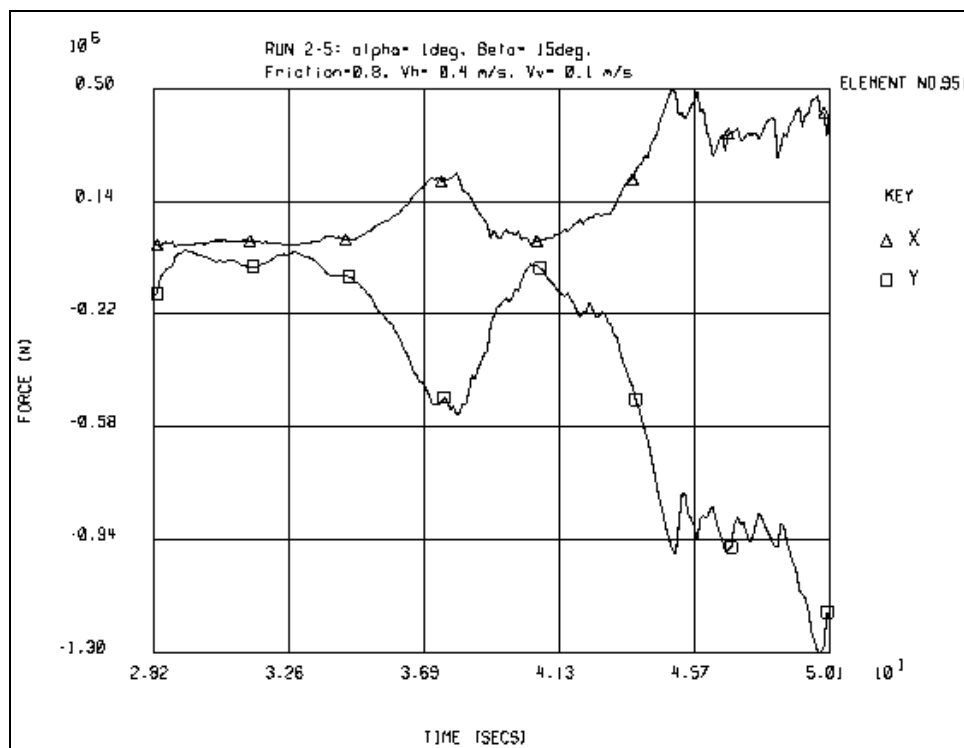


Figure A-5: Force-time history for run 2-5

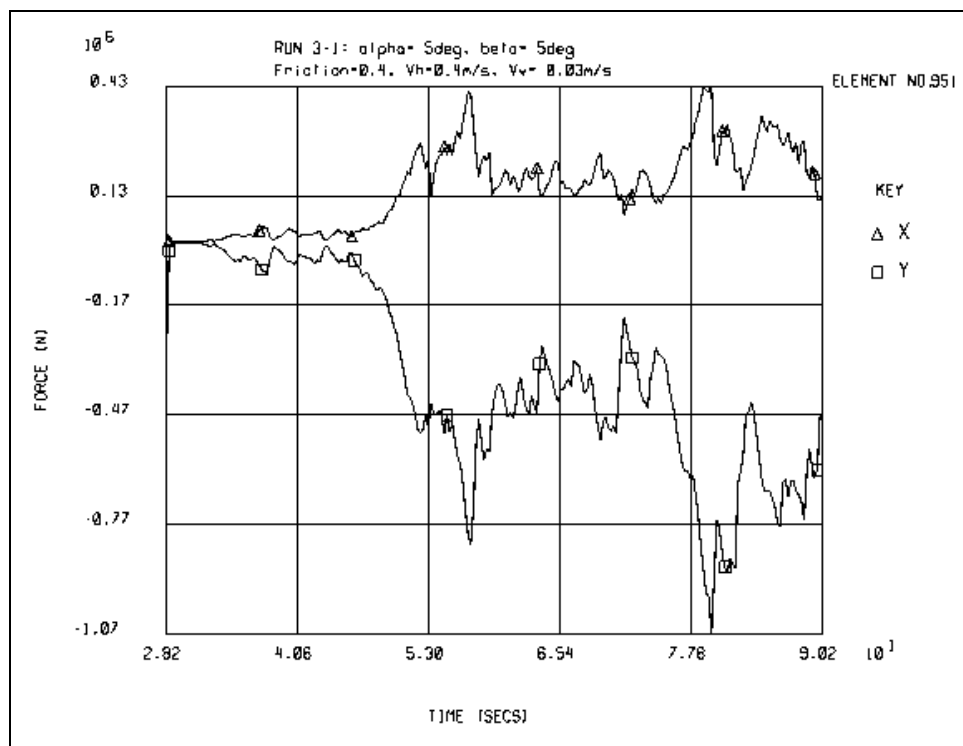


Figure A-6: Force-time history for run 3-1

DECICE SIMULATION OF ICE GOUGING

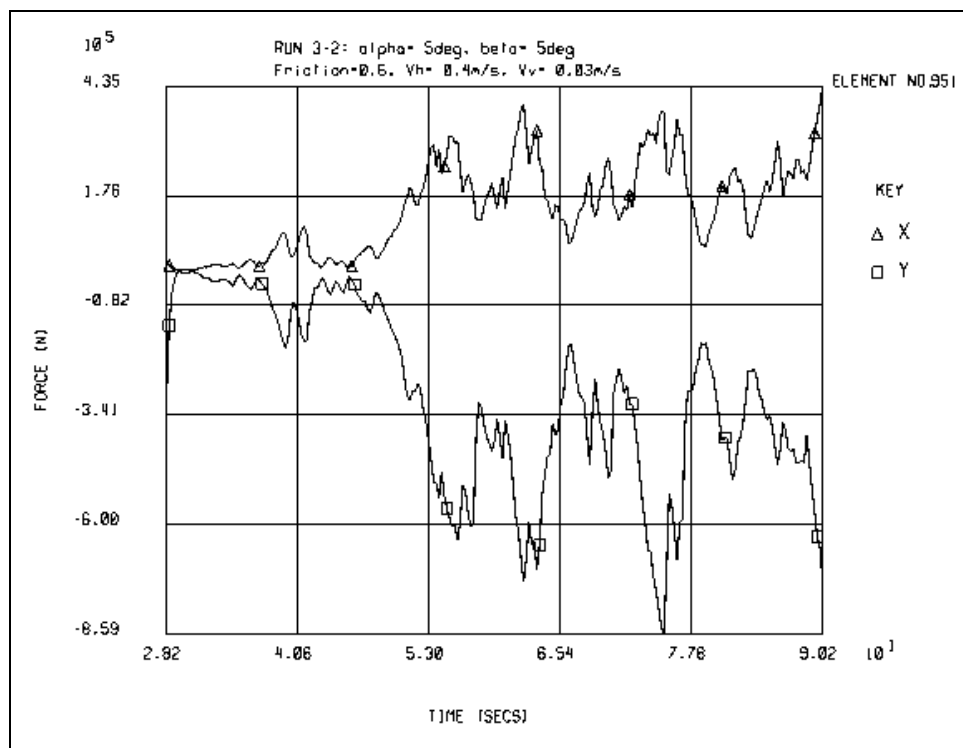


Figure A-7: Force-time history for run 3-2

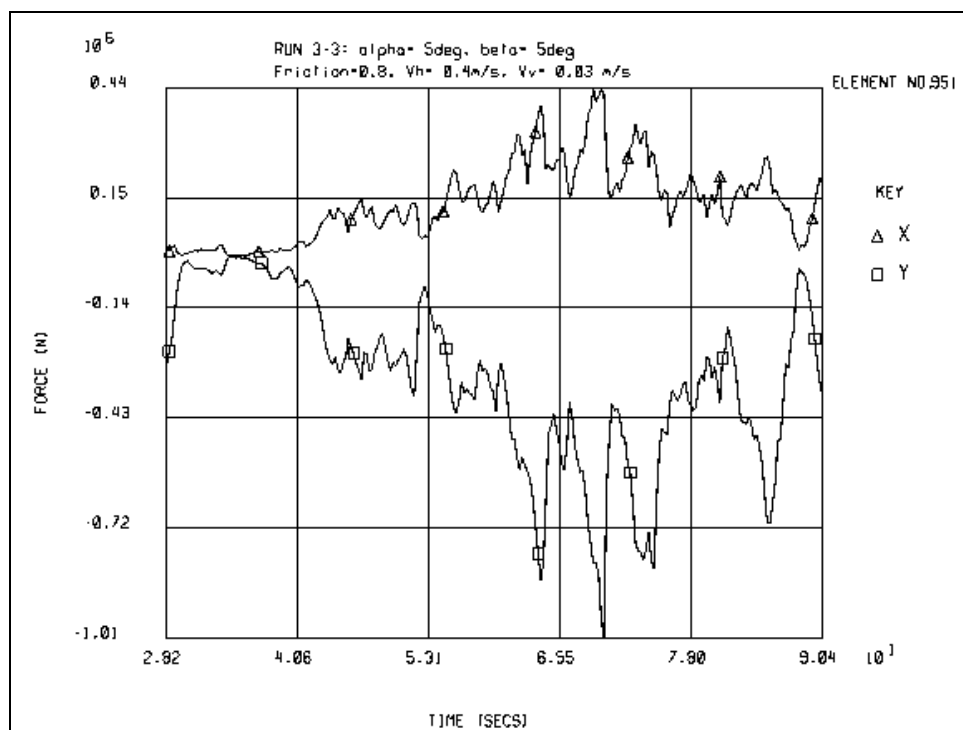


Figure A-8: Force-time history for run 3-3

DECICE SIMULATION OF ICE GOUGING

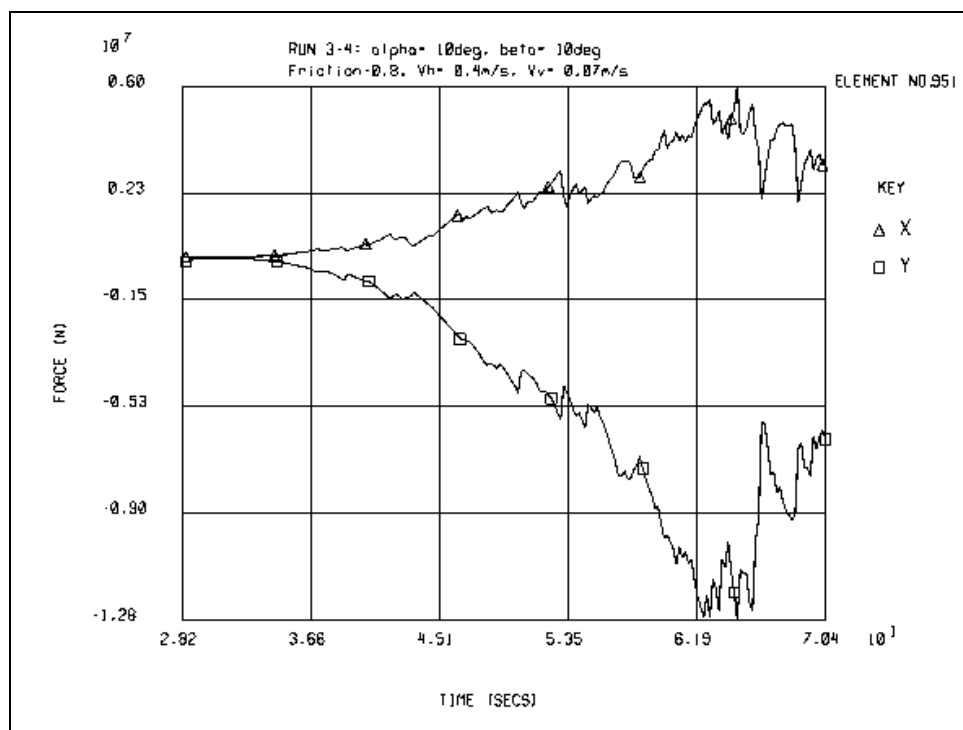


Figure A-9: Force-time history for run 3-4

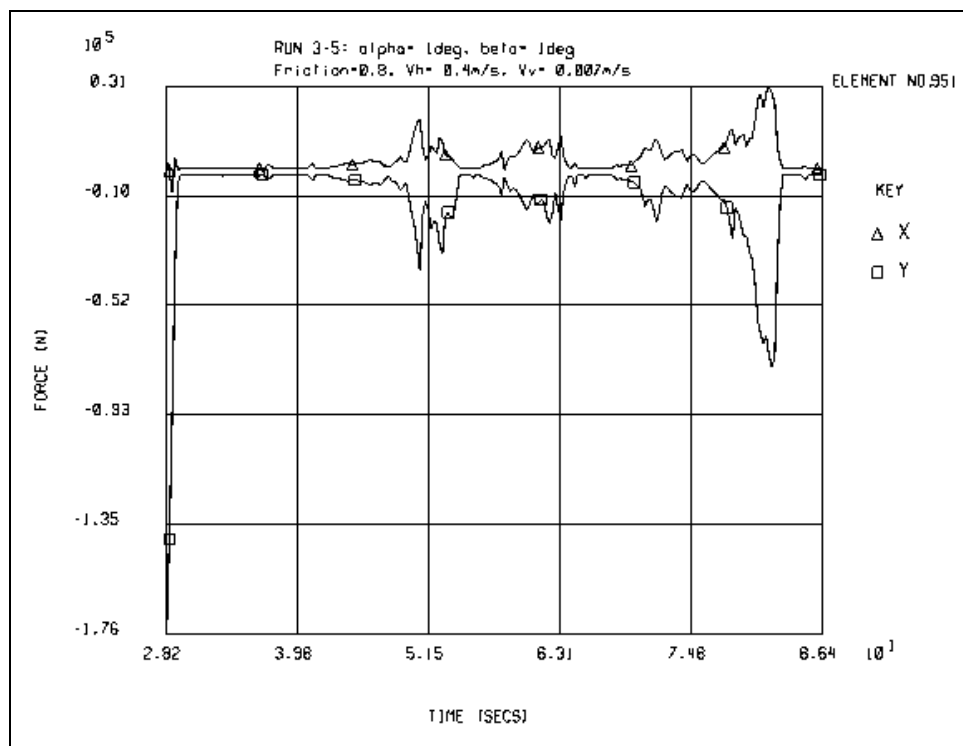


Figure A-10: Force-time history for run 3-5

DECICE SIMULATION OF ICE GOUGING

Appendix B **Selected Snapshots for Each Run**

DECICE SIMULATION OF ICE GOUGING

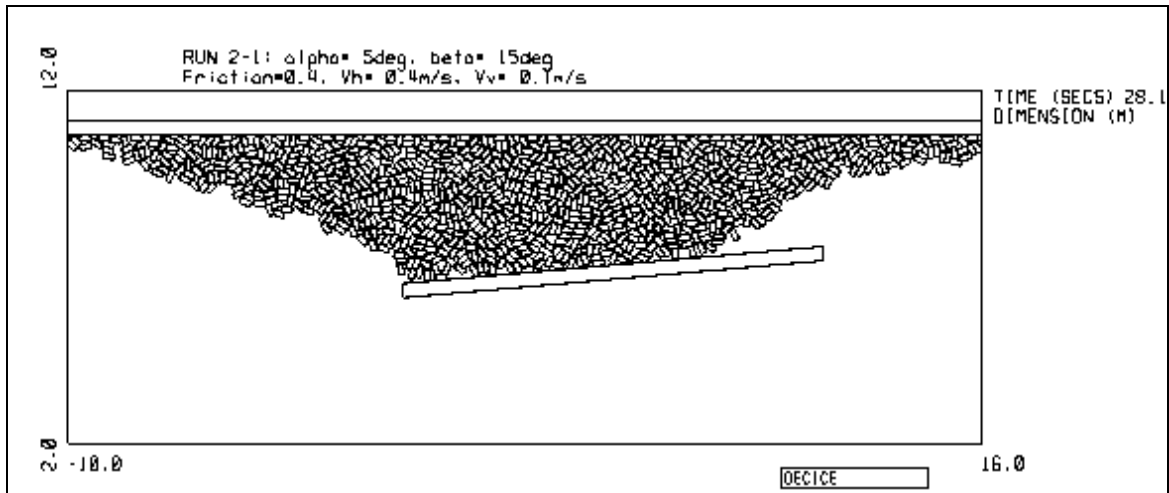


Figure B-1: Snapshot of Run 2-1 at t= 28.19 s

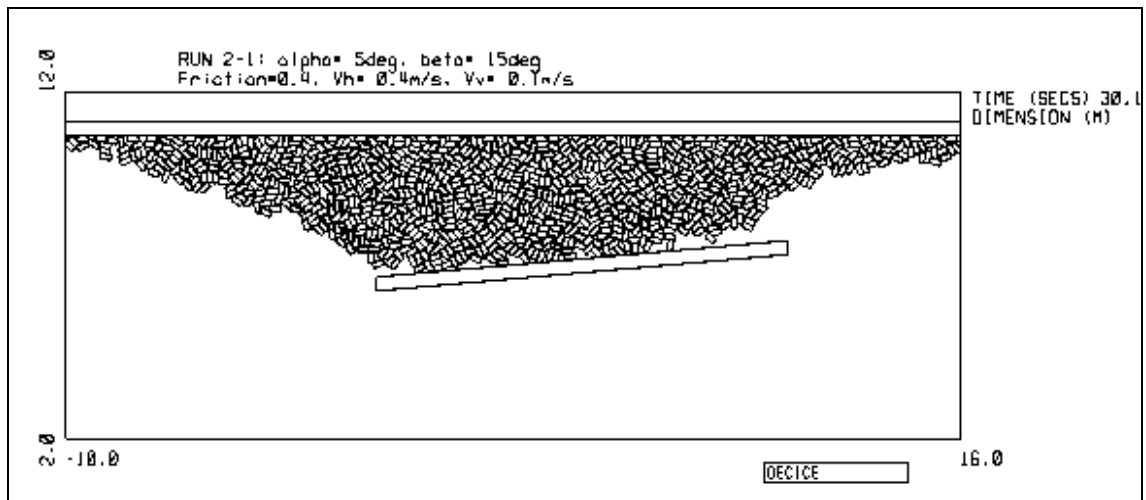


Figure B-2: Snapshot of Run 2-1 at t= 30.19 s

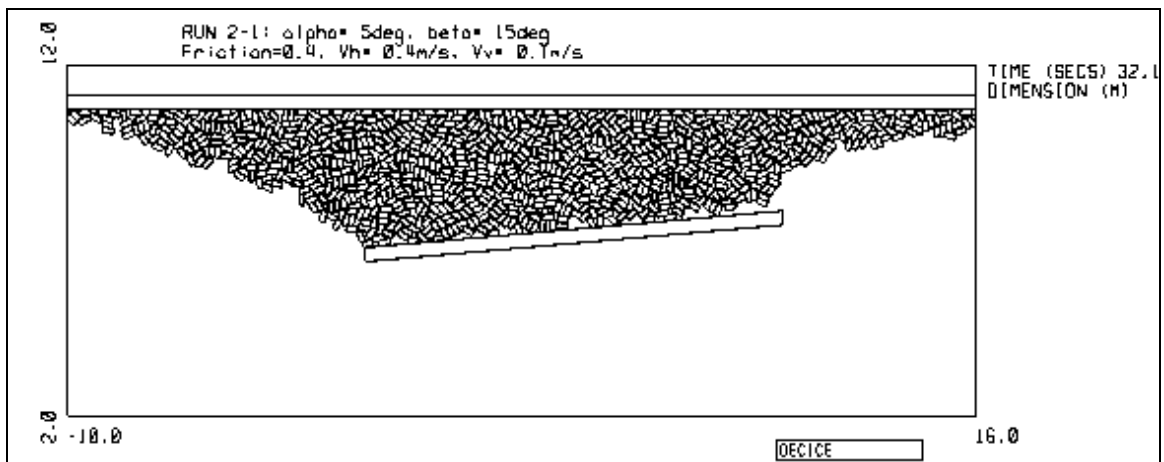


Figure B-3: Snapshot of Run 2-1 at t= 32.19 s

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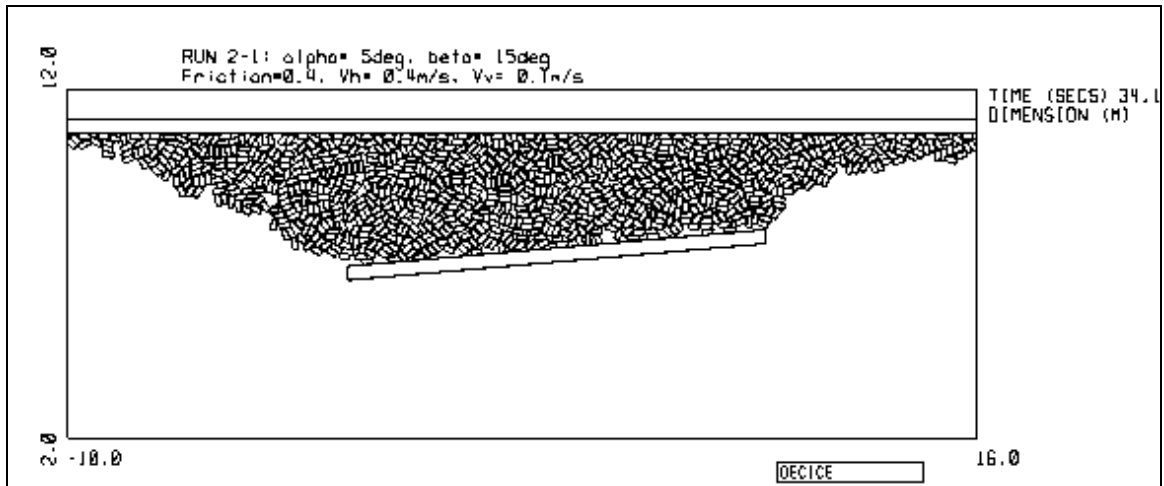


Figure B-4: Snapshot of Run 2-1 at t= 34.19 s

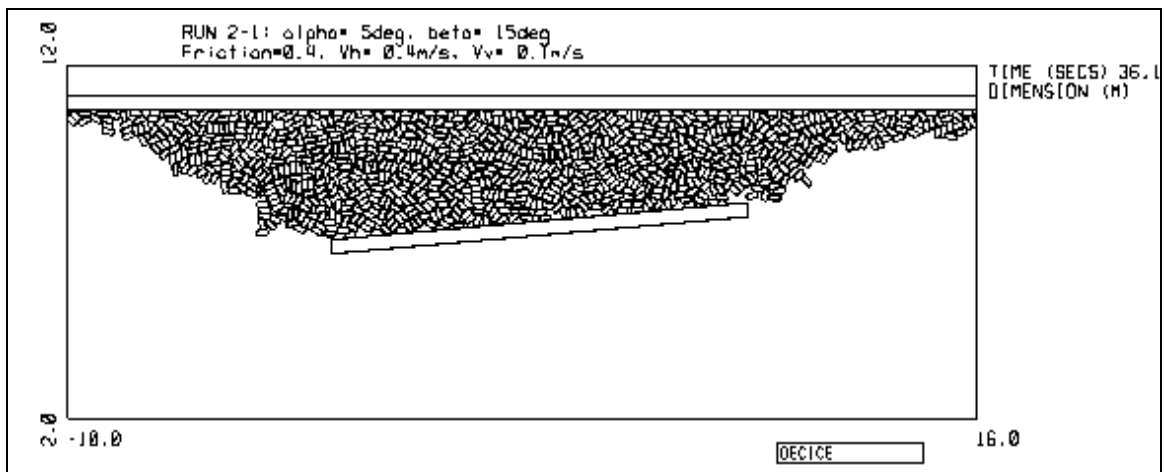


Figure B-5: Snapshot of Run 2-1 at t= 36.19 s

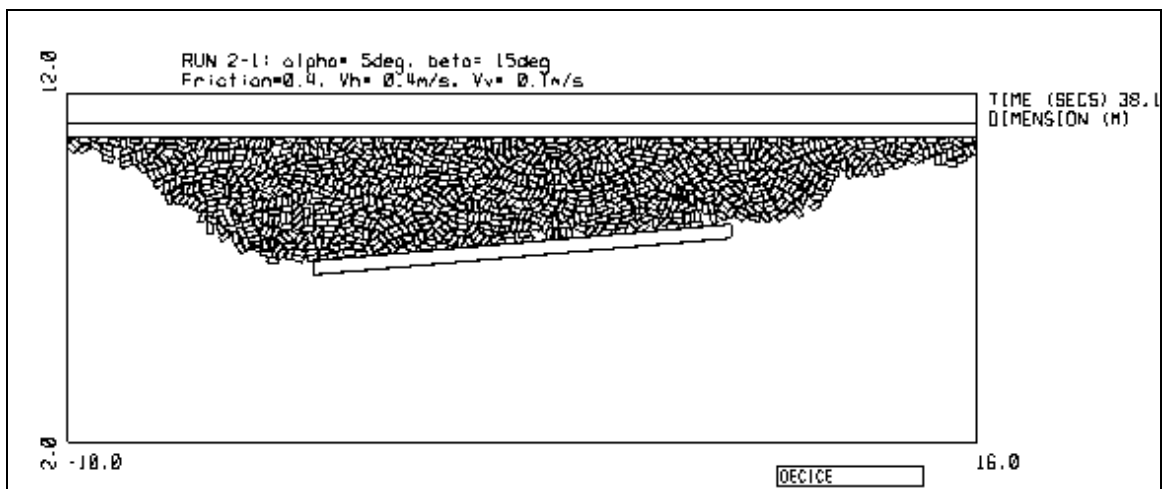


Figure B-6: Snapshot of Run 2-1 at t= 38.19 s

DECICE SIMULATION OF ICE GOUGING

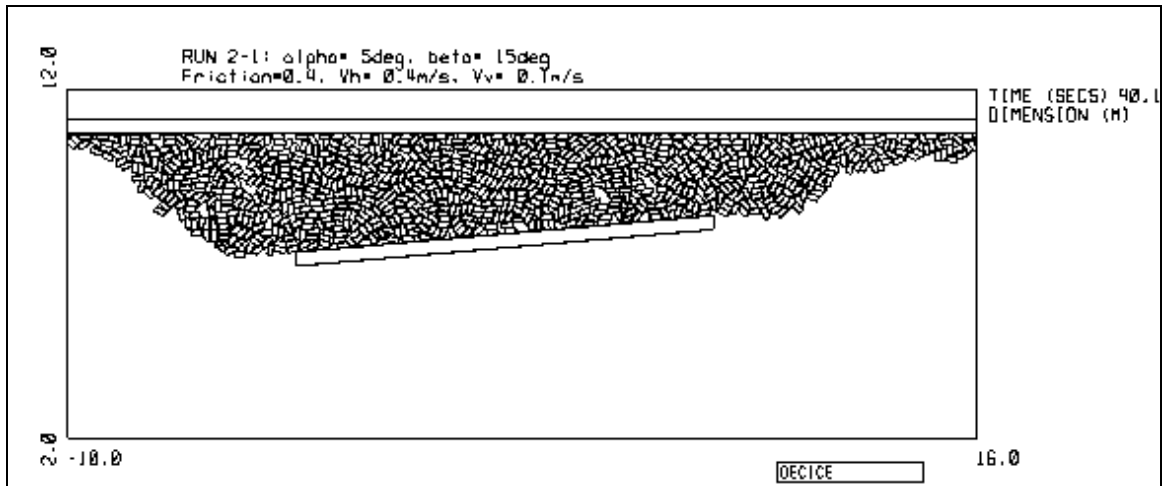


Figure B-7: Snapshot of Run 2-1 at t= 40.19 s

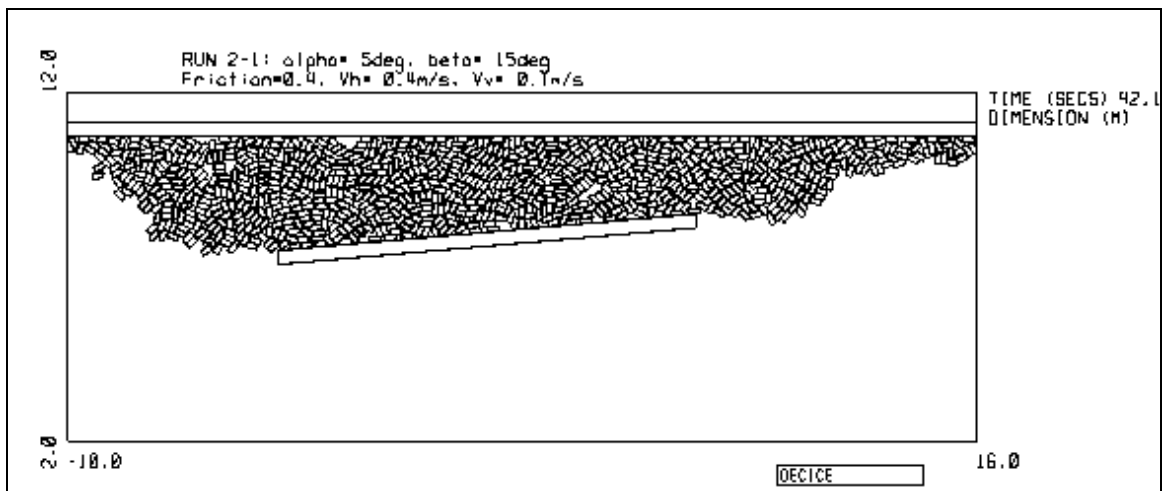


Figure B-8: Snapshot of Run 2-1 at t= 42.19 s

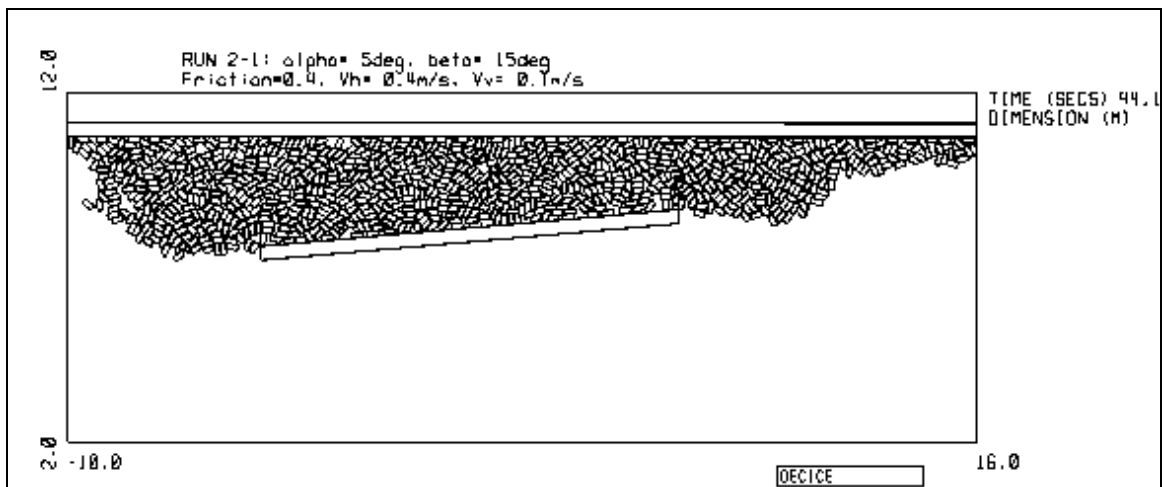


Figure B-9: Snapshot of Run 2-1 at t= 44.19 s

DECICE SIMULATION OF ICE GOUGING

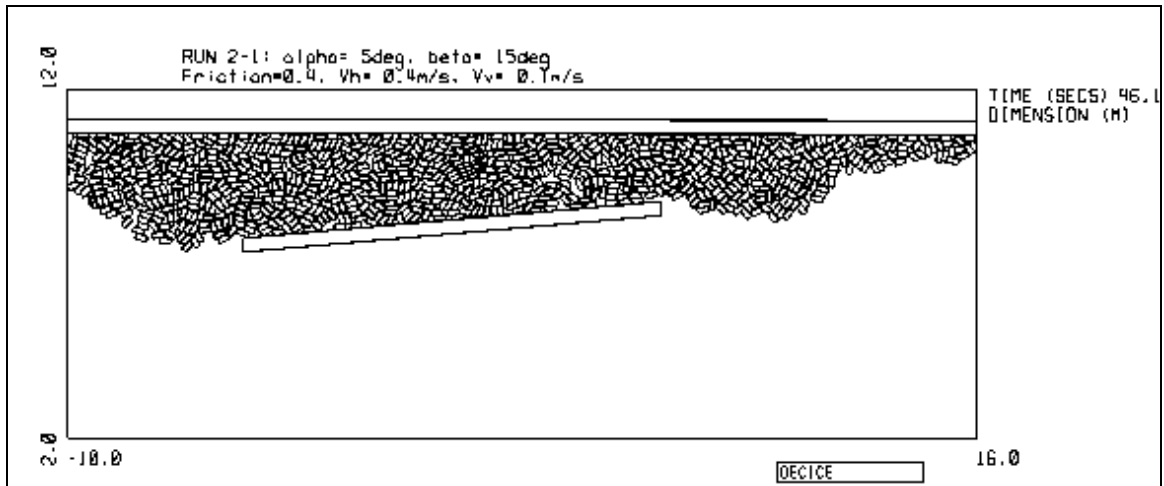


Figure B-10: Snapshot of Run 2-1 at $t = 46.19$ s

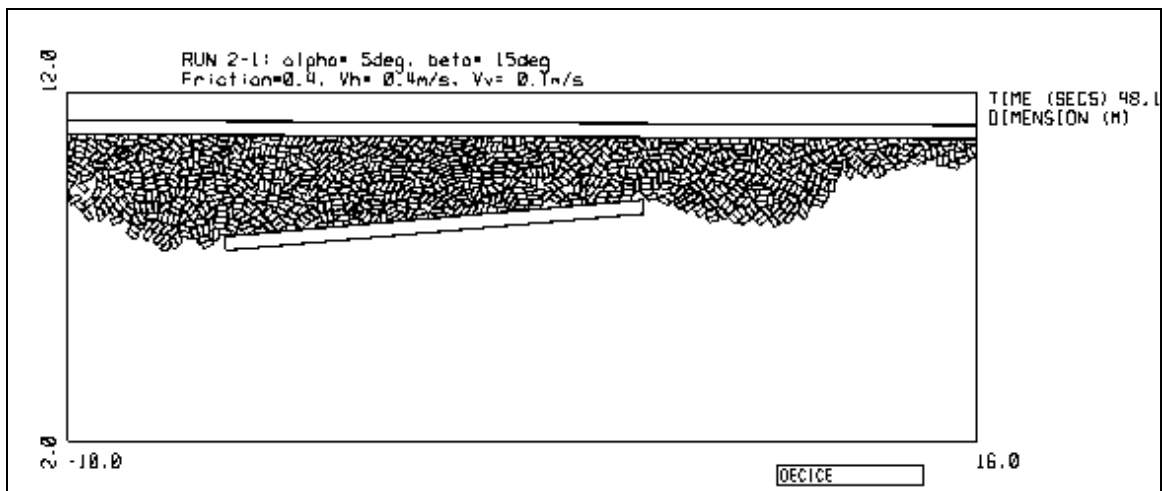


Figure B-11: Snapshot of Run 2-1 at $t = 48.19$ s

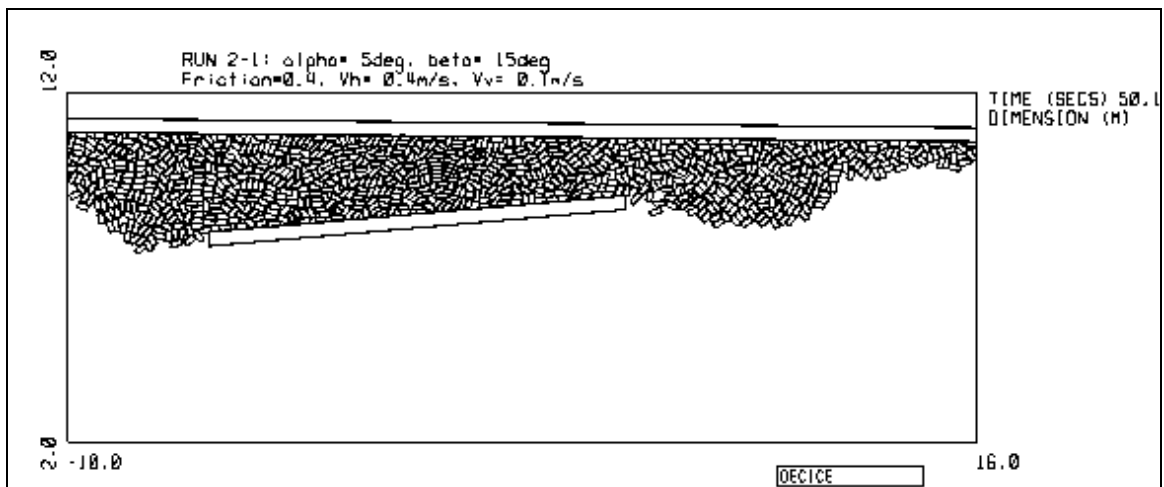


Figure B-12: Snapshot of Run 2-1 at $t = 50.19$ s

DECICE SIMULATION OF ICE GOUGING

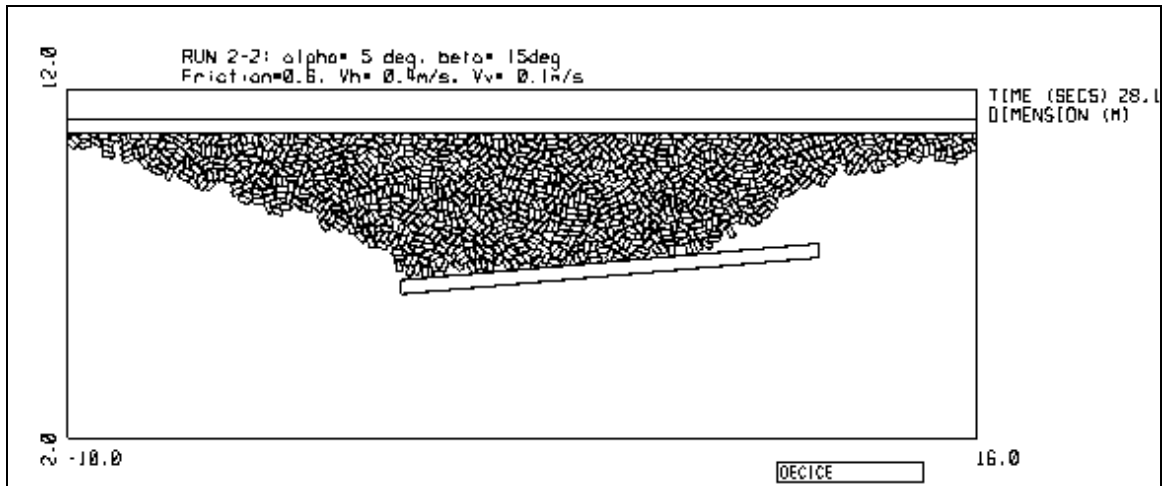


Figure B-13: Snapshot of Run 2-2 at t= 28.19 s

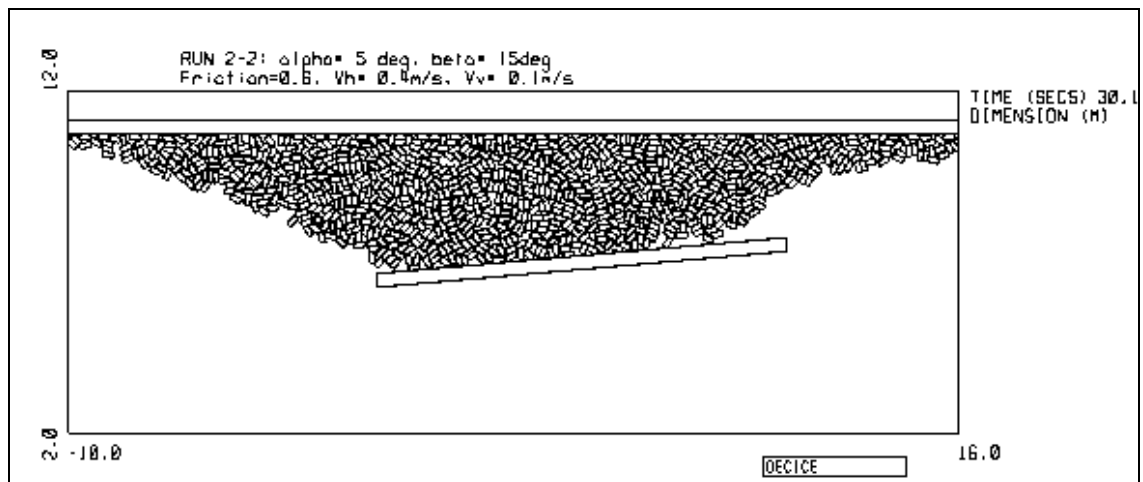


Figure B-14: Snapshot of Run 2-2 at t= 30.19 s

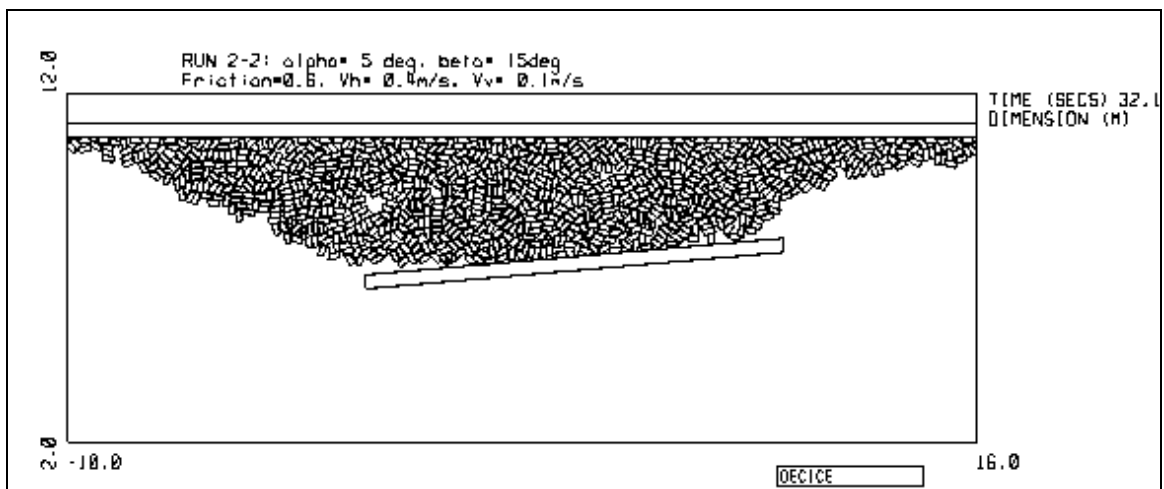


Figure B-15: Snapshot of Run 2-2 at t= 32.19 s

DECICE SIMULATION OF ICE GOUGING

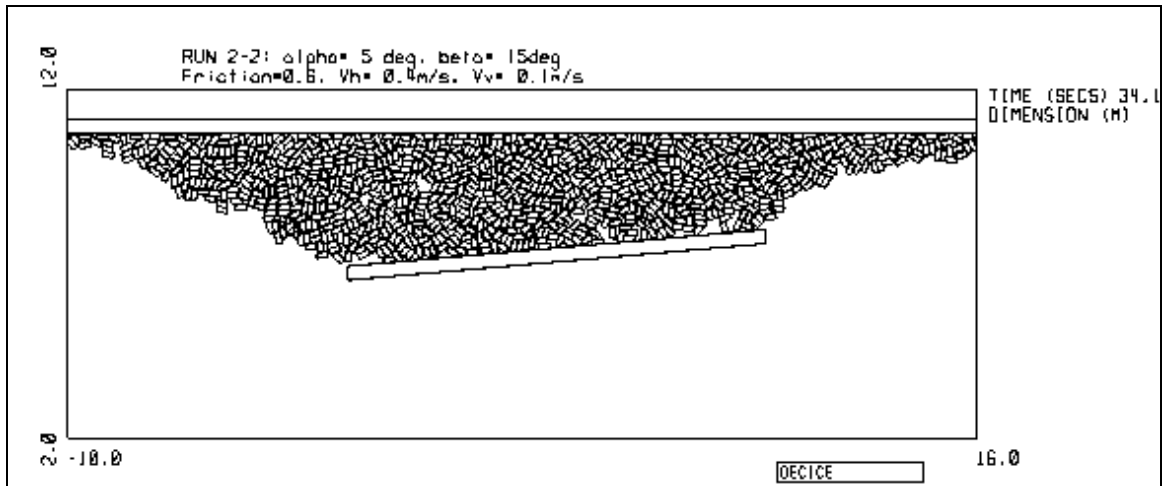


Figure B-16: Snapshot of Run 2-2 at t= 34.19 s

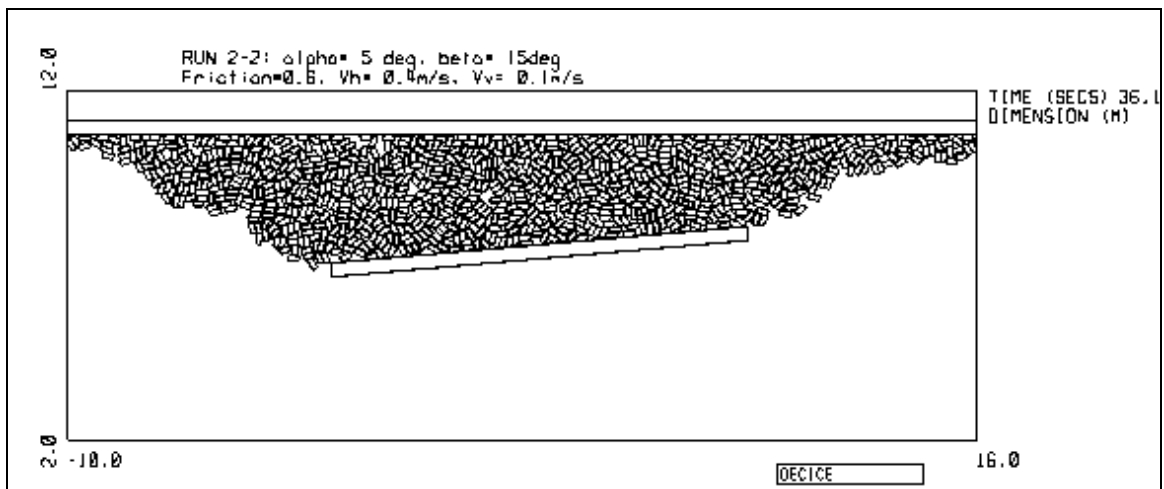


Figure B-17: Snapshot of Run 2-2 at t= 36.19 s

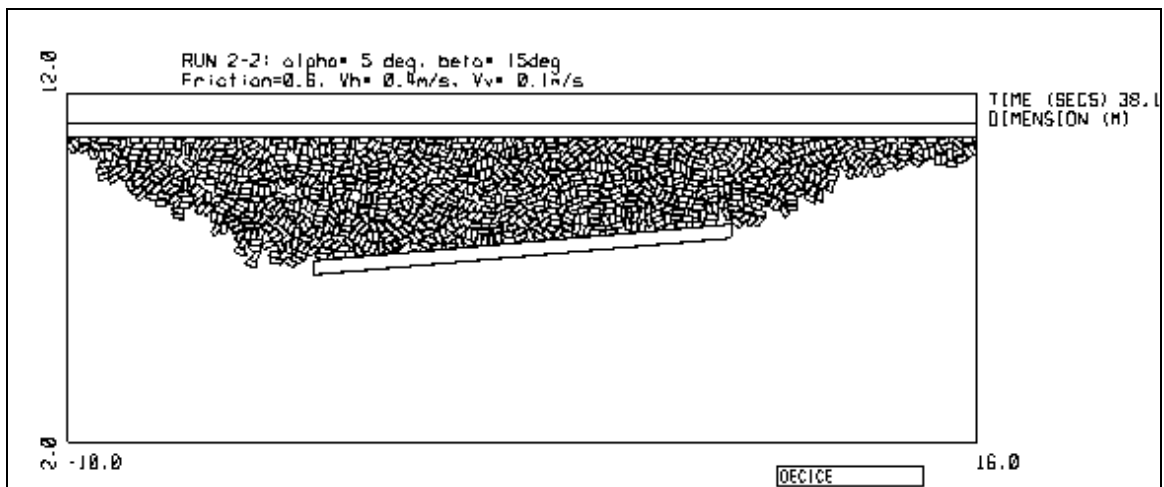


Figure B-18: Snapshot of Run 2-2 at t= 38.19 s

DECICE SIMULATION OF ICE GOUGING

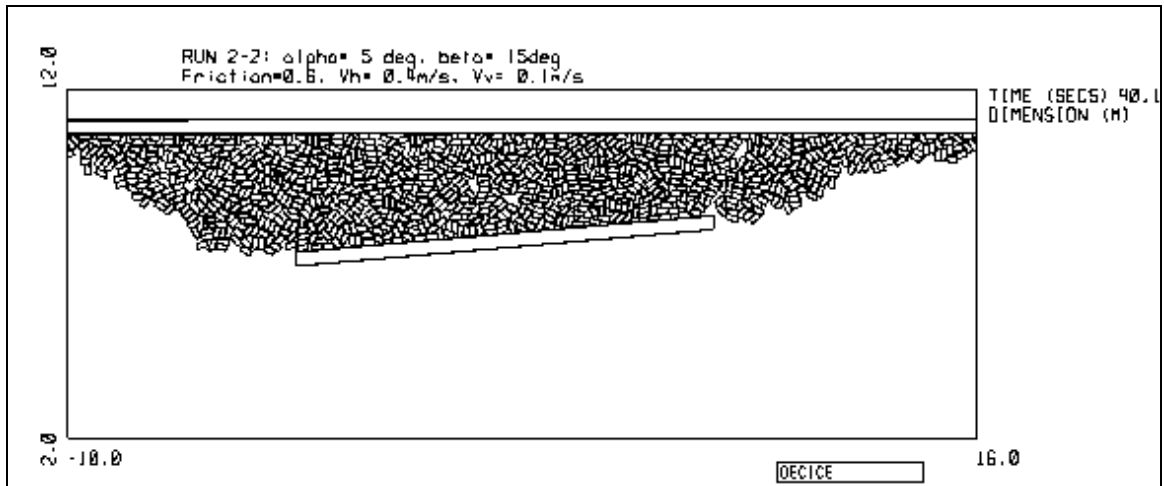


Figure B-19: Snapshot of Run 2-2 at t= 40.19 s

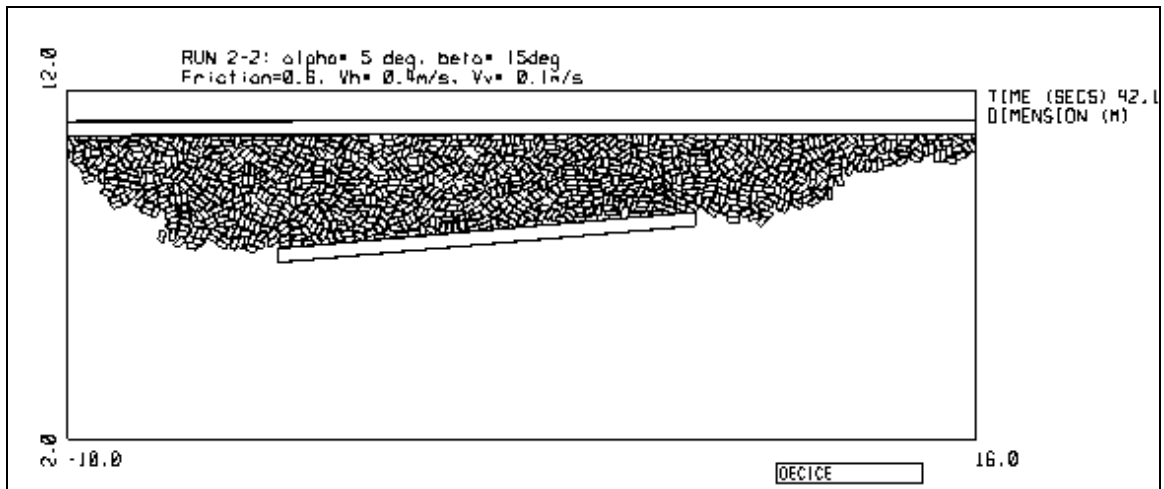


Figure B-20: Snapshot of Run 2-2 at t= 42.19 s

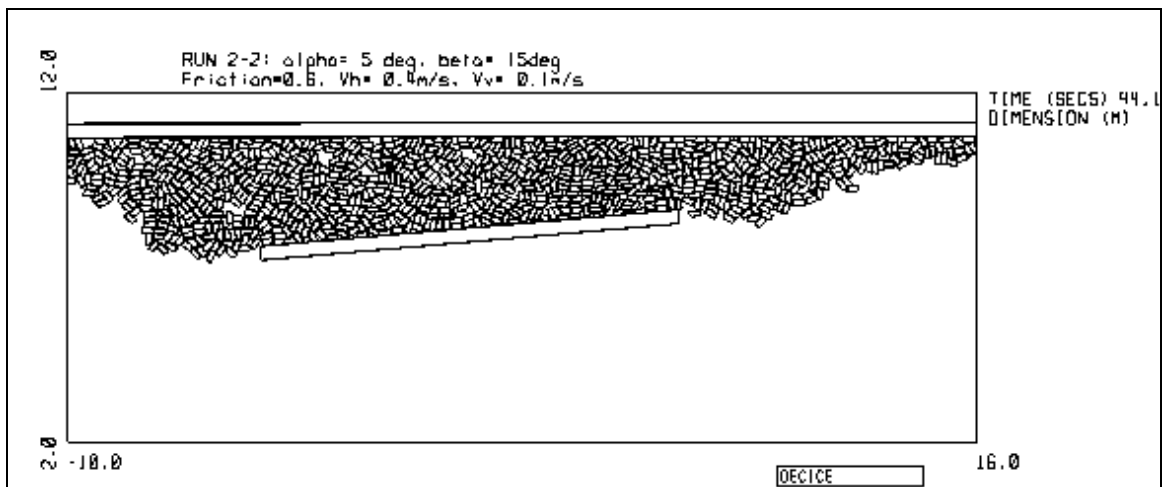


Figure B-21: Snapshot of Run 2-2 at t= 44.19 s

DECICE SIMULATION OF ICE GOUGING

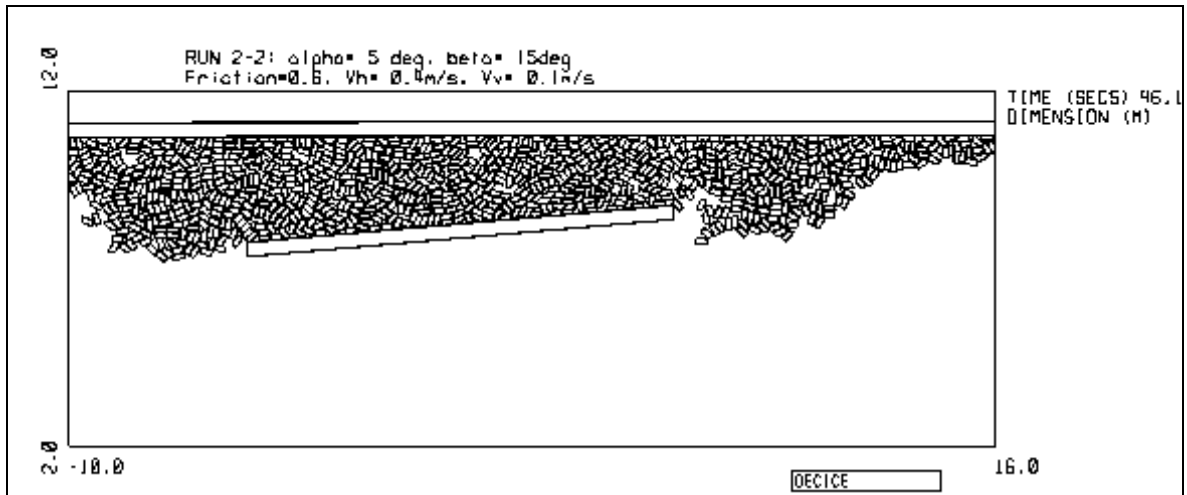


Figure B-22: Snapshot of Run 2-2 at $t = 46.19 \text{ s}$

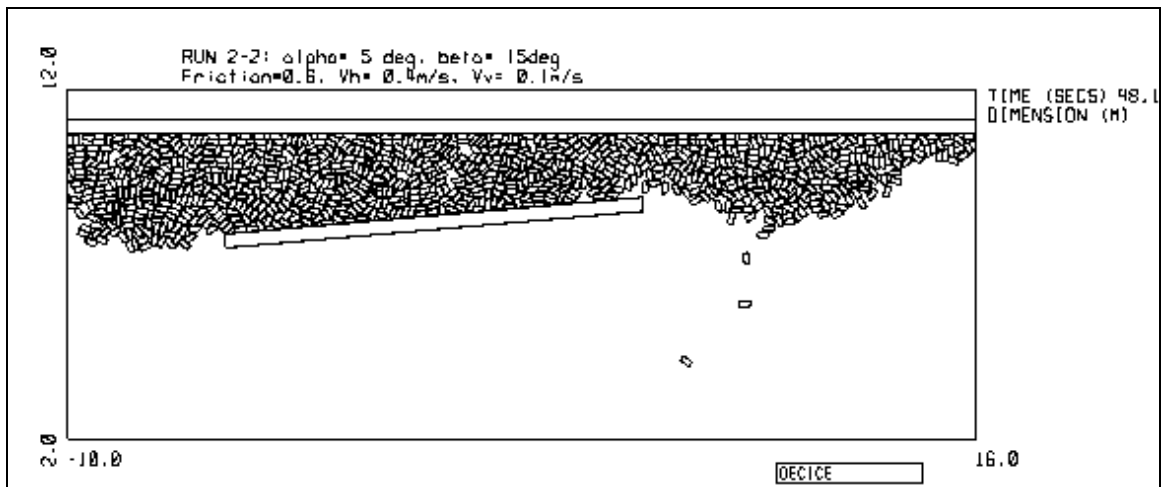


Figure B-23: Snapshot of Run 2-2 at $t = 48.19 \text{ s}$

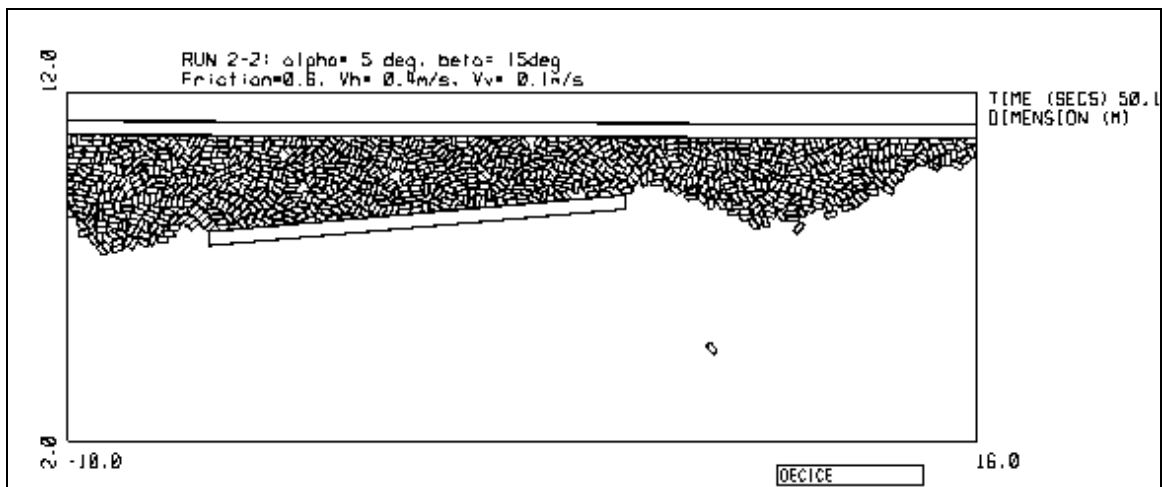


Figure B-24: Snapshot of Run 2-2 at $t = 50.19 \text{ s}$

DECICE SIMULATION OF ICE GOUGING

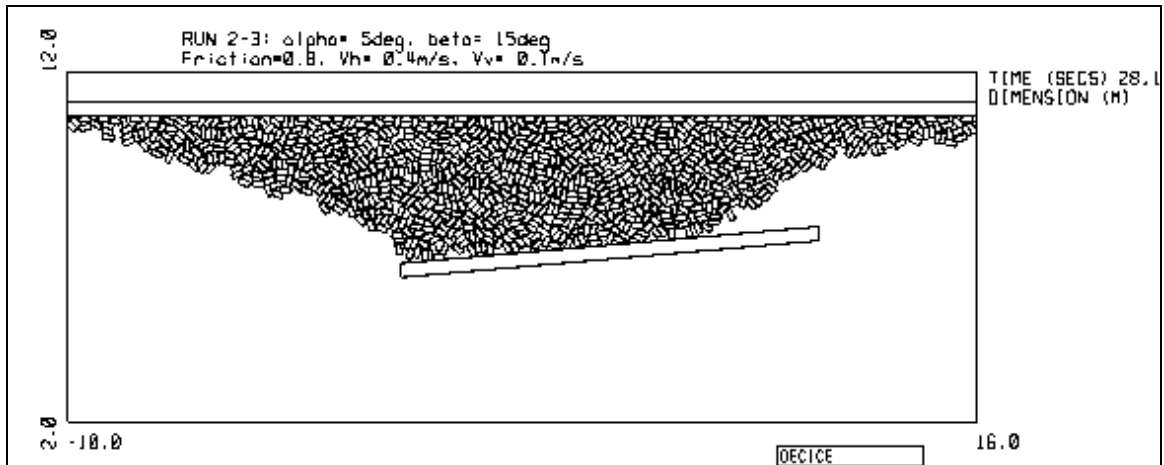


Figure B-25: Snapshot of Run 2-3 at t= 28.19 s

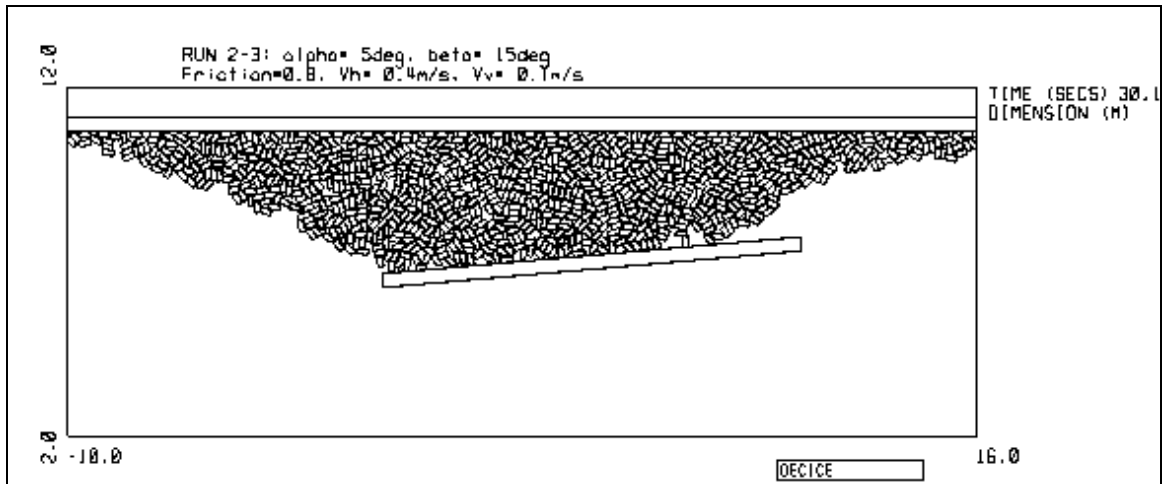


Figure B-26: Snapshot of Run 2-3 at t= 30.19 s

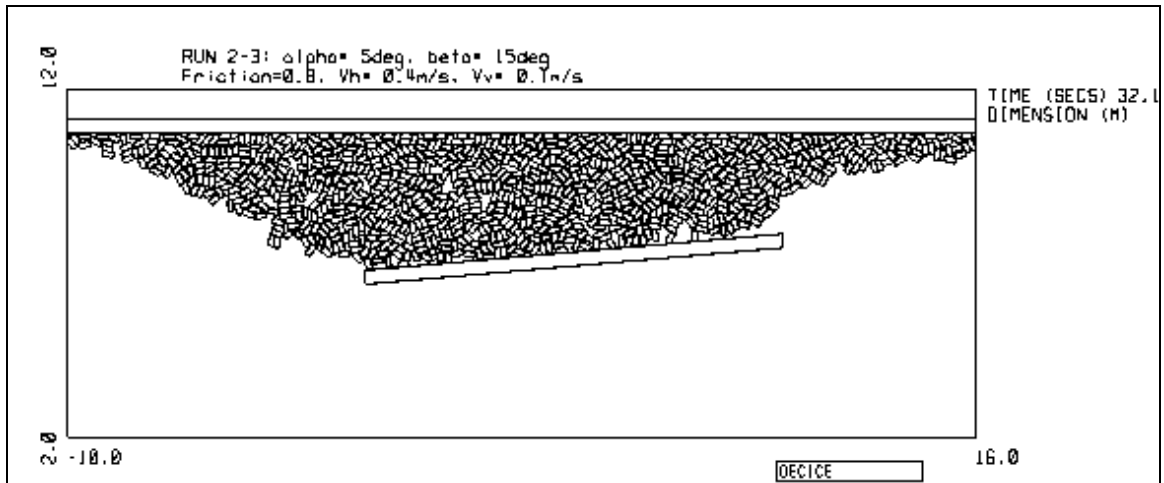


Figure B-27: Snapshot of Run 2-3 at t= 32.19 s

DECICE SIMULATION OF ICE GOUGING

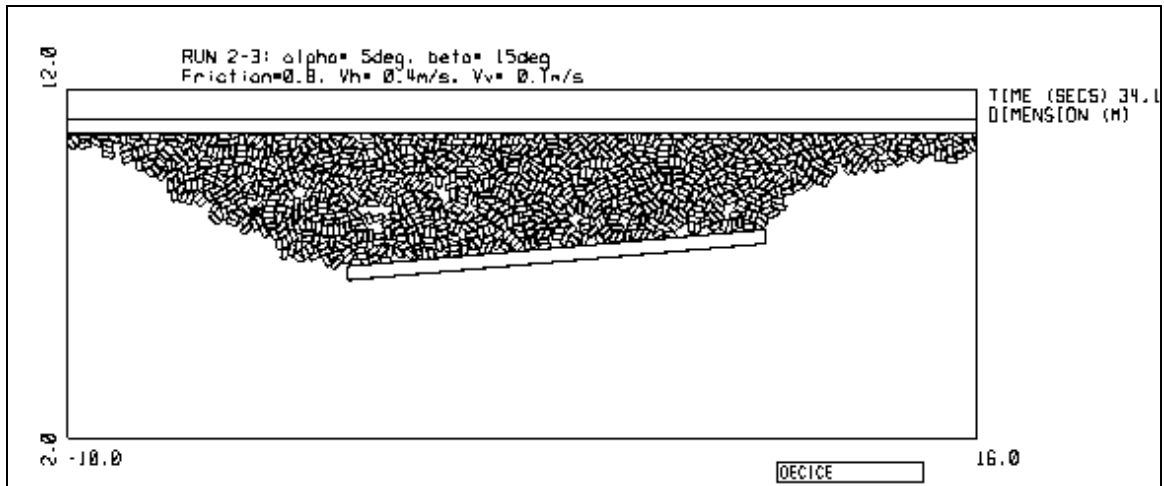


Figure B-28: Snapshot of Run 2-3 at t= 34.19 s

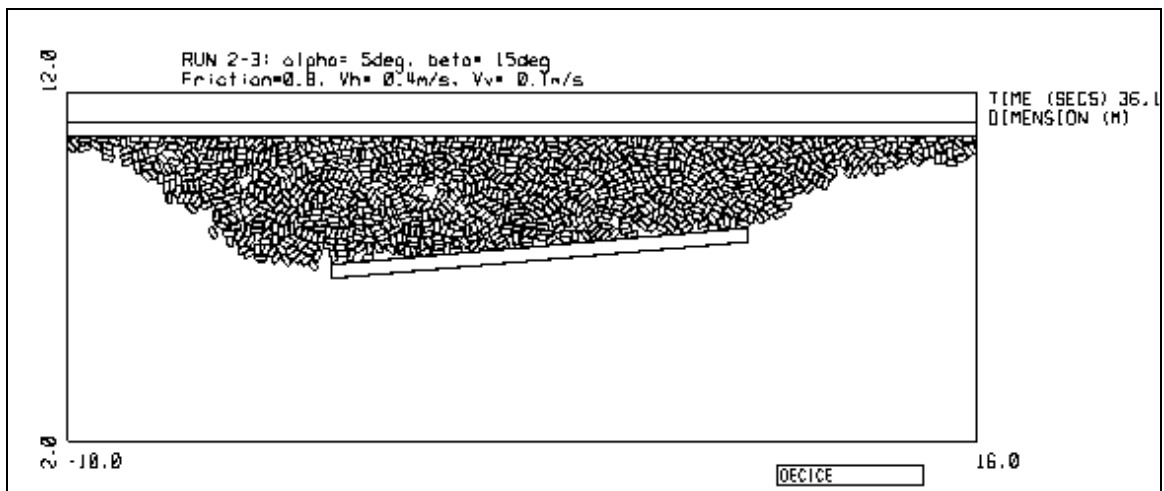


Figure B-29: Snapshot of Run 2-3 at t= 36.19 s

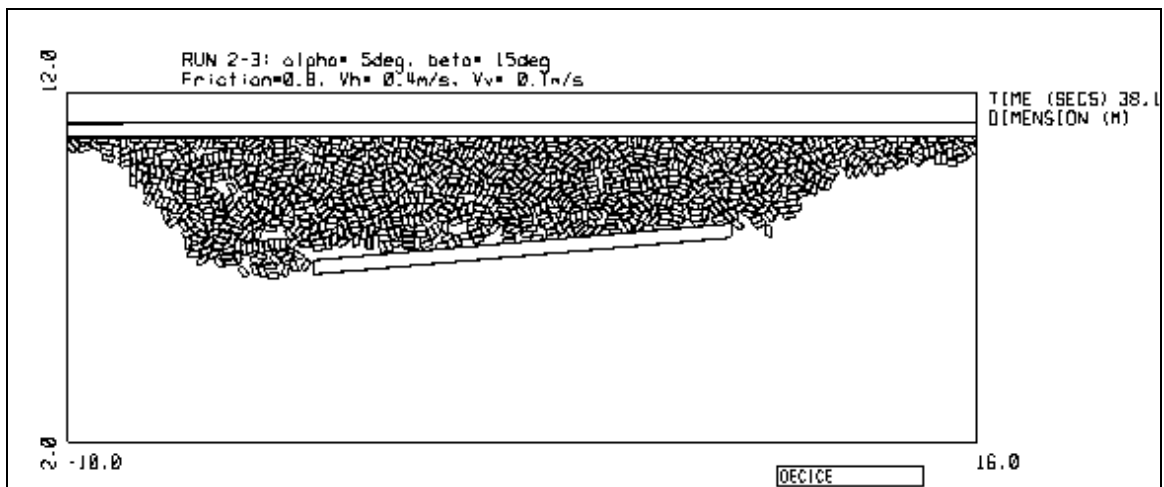


Figure B-30: Snapshot of Run 2-3 at t= 38.19 s

DECICE SIMULATION OF ICE GOUGING

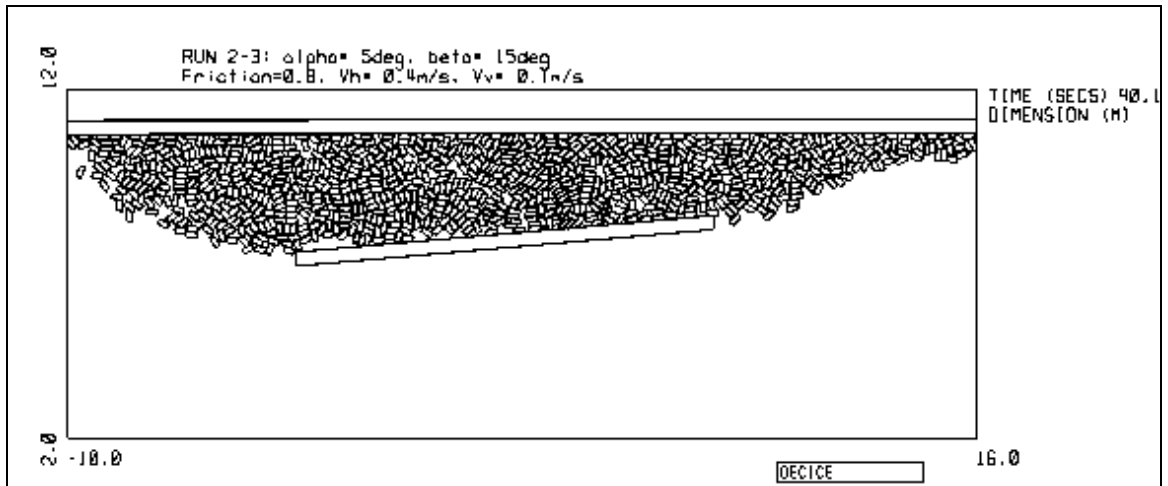


Figure B-31: Snapshot of Run 2-3 at $t= 40.19$ s

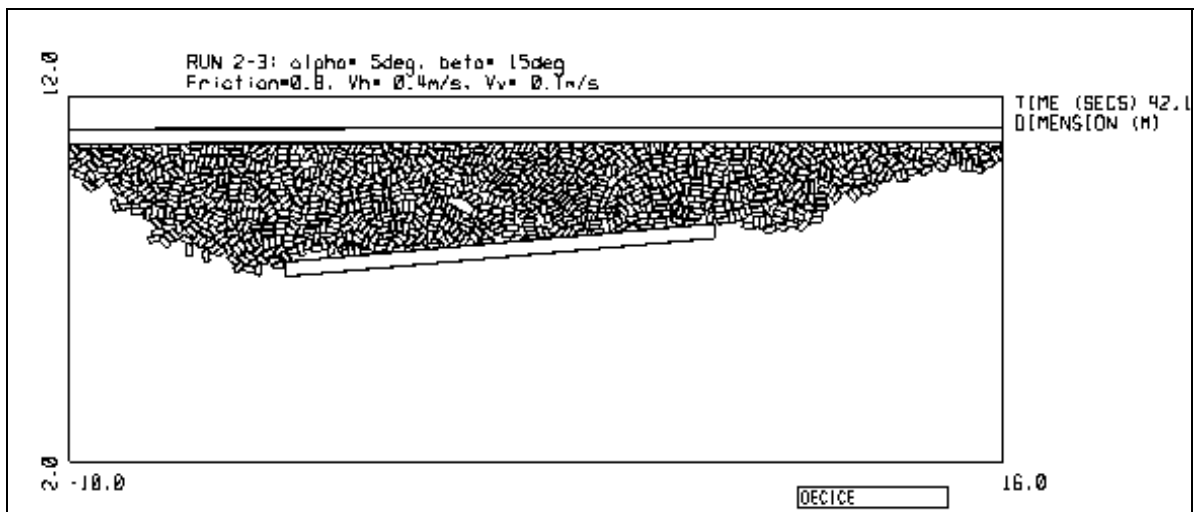


Figure B-32: Snapshot of Run 2-3 at $t= 42.19$ s

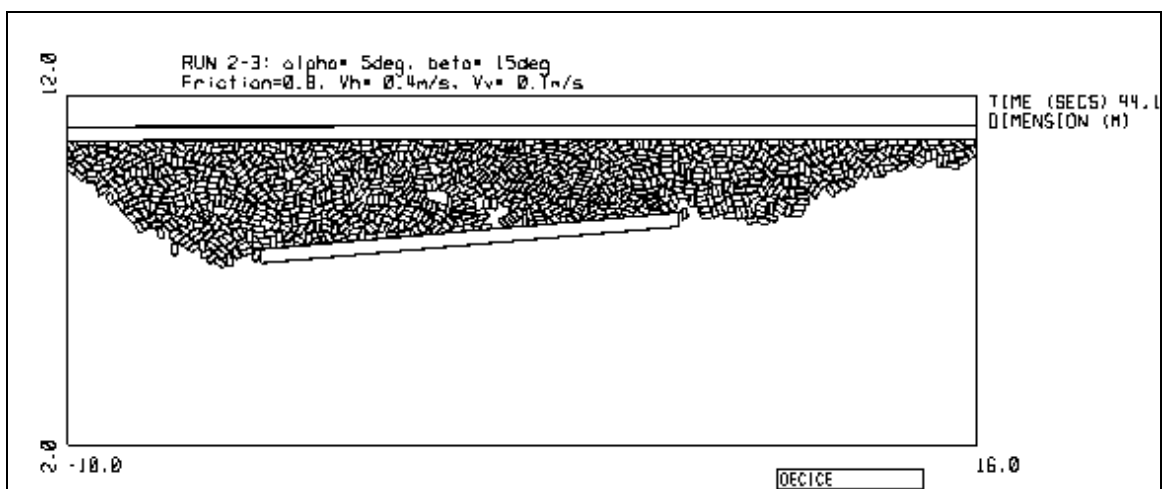


Figure B-33: Snapshot of Run 2-3 at $t= 44.19$ s

DECICE SIMULATION OF ICE GOUGING

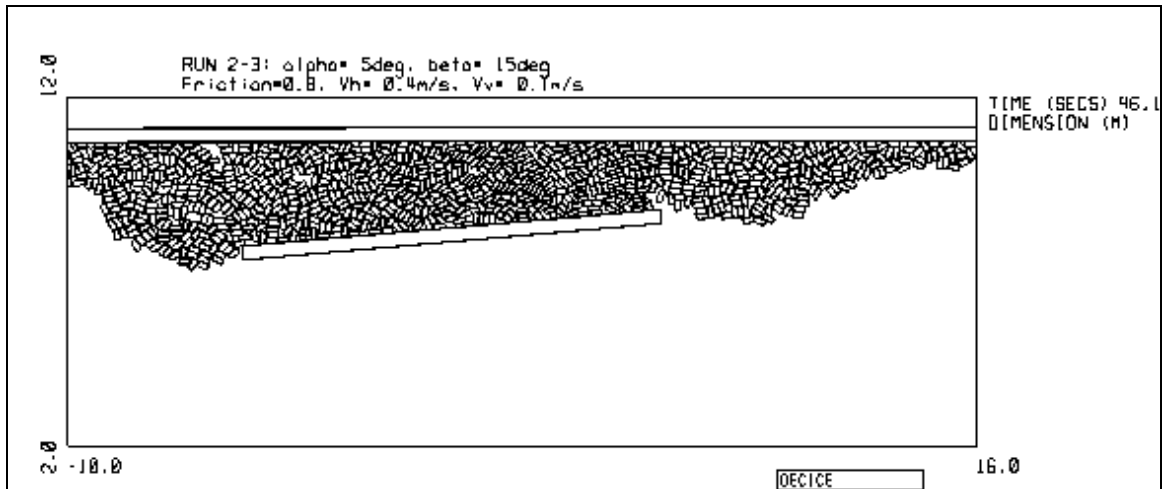


Figure B-34: Snapshot of Run 2-3 at t= 46.19 s

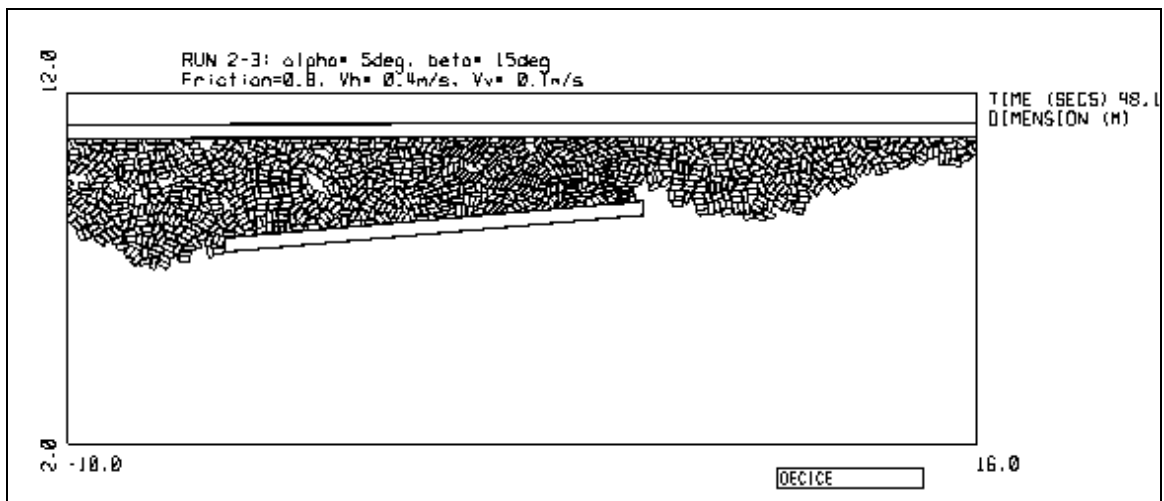


Figure B-35: Snapshot of Run 2-3 at t= 48.19 s

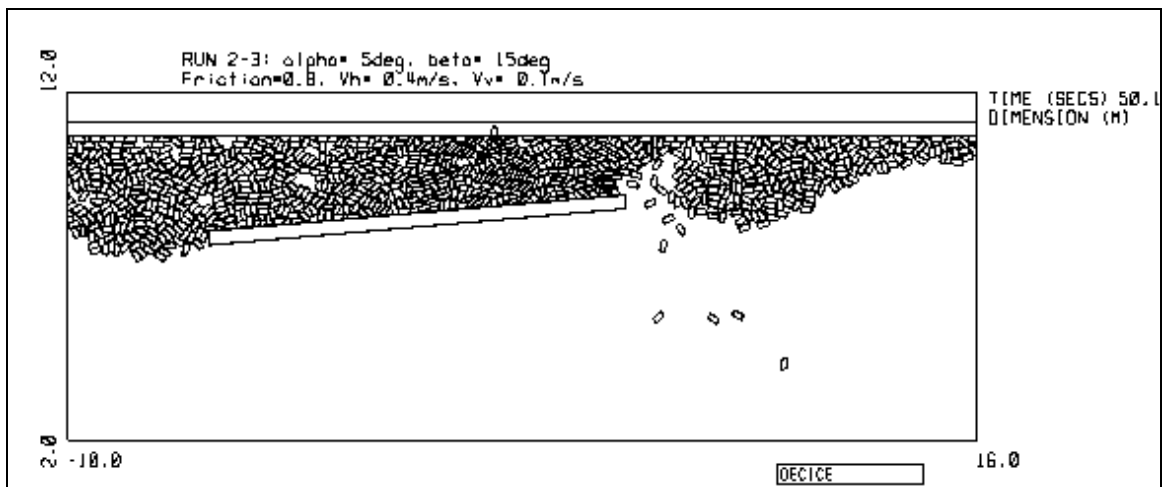


Figure B-36: Snapshot of Run 2-3 at t= 50.19 s

DECICE SIMULATION OF ICE GOUGING

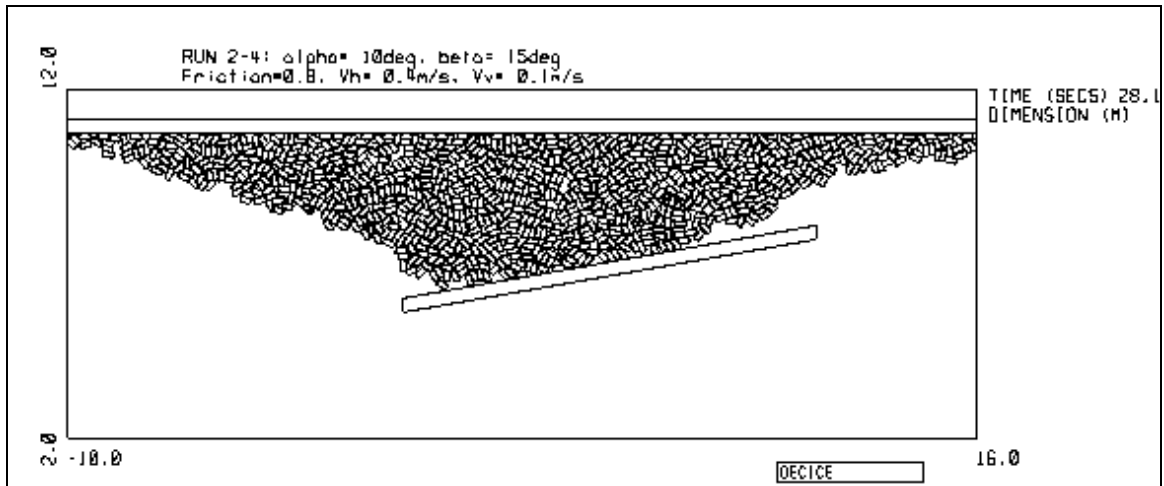


Figure B-37: Snapshot of Run 2-4 at t= 28.19 s

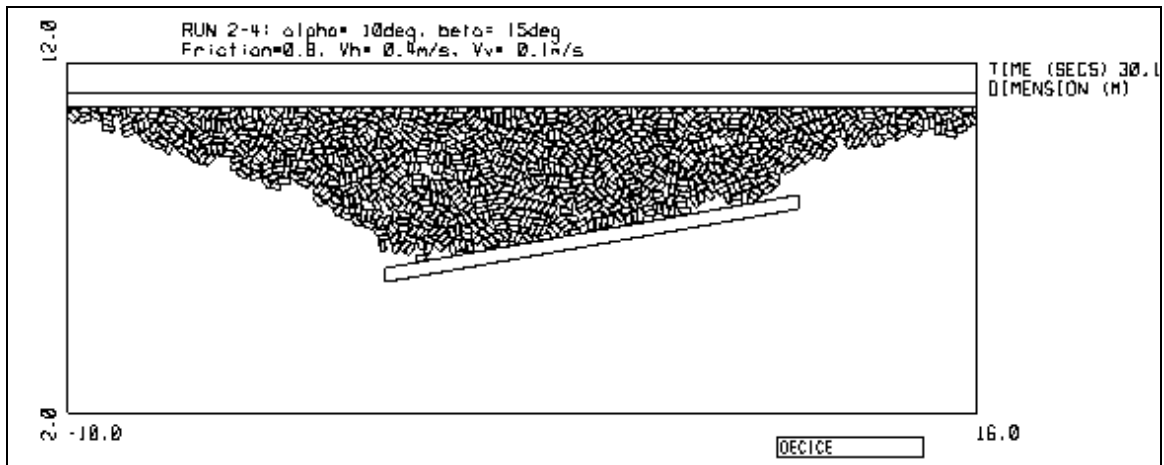


Figure B-38: Snapshot of Run 2-4 at t= 30.19 s

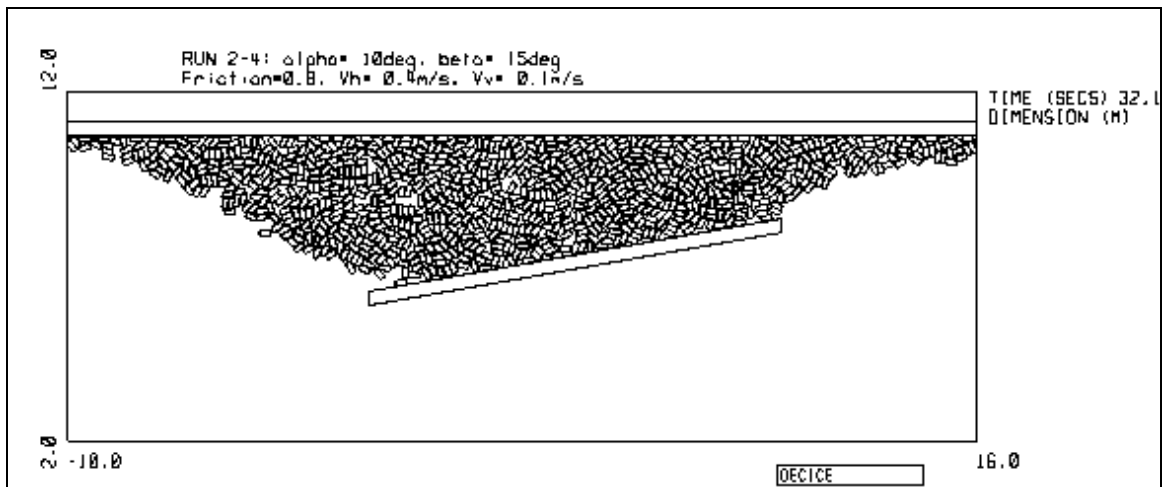


Figure B-39: Snapshot of Run 2-4 at t= 32.19 s

DECICE SIMULATION OF ICE GOUGING

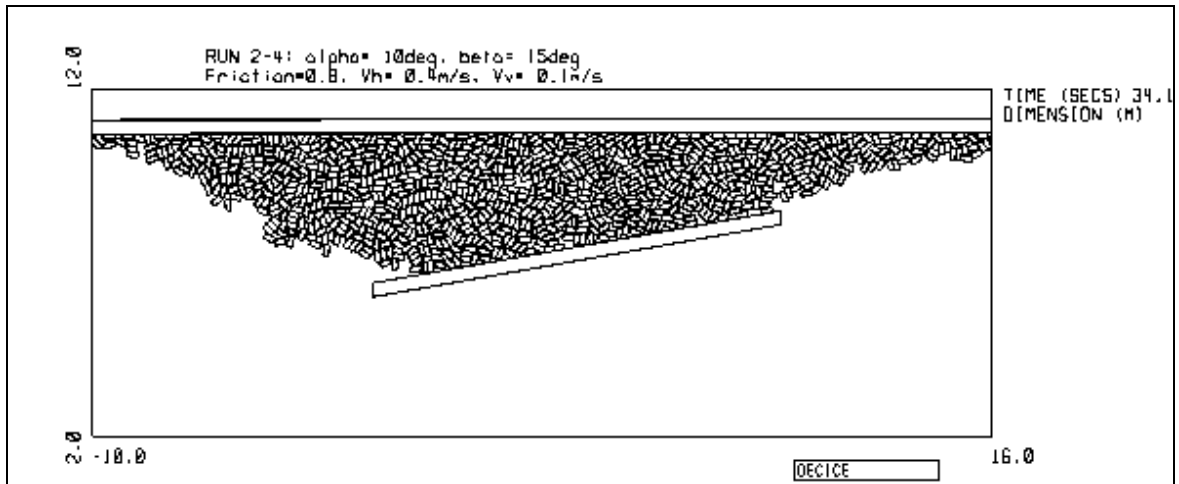


Figure B-40: Snapshot of Run 2-4 at t = 34.19 s

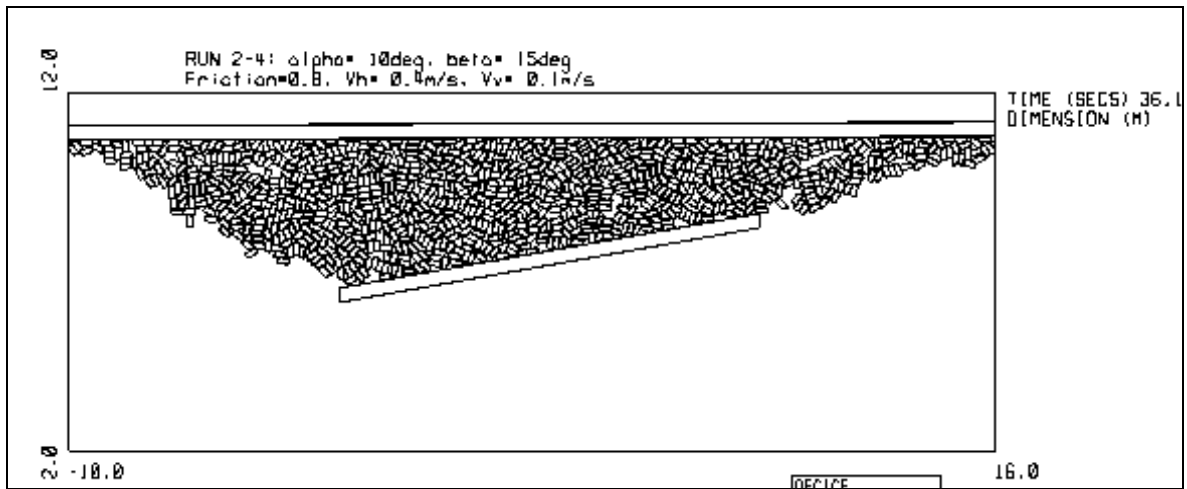


Figure B-41: Snapshot of Run 2-4 at t = 36.19 s

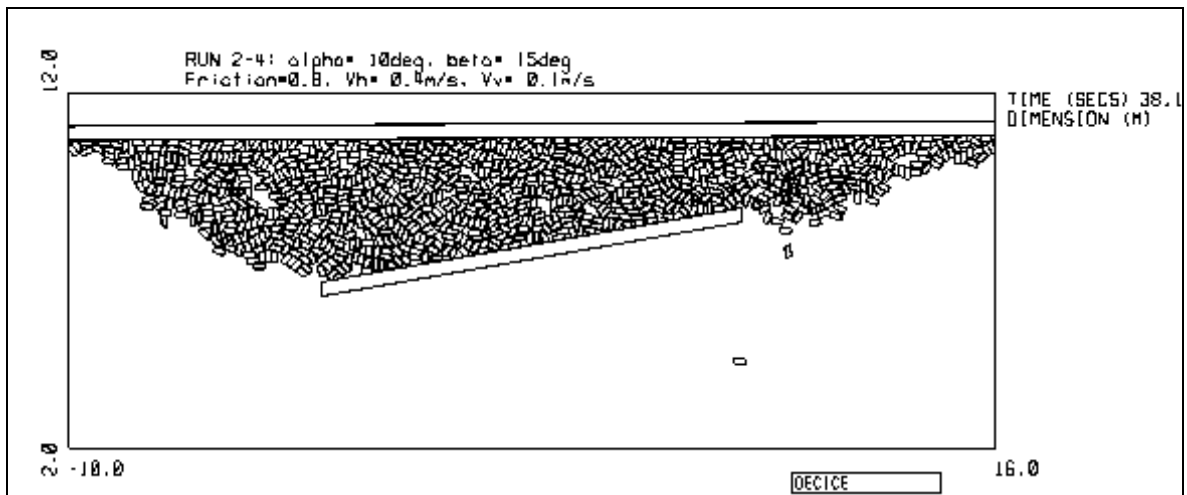


Figure B-42: Snapshot of Run 2-4 at t = 38.19 s

DECICE SIMULATION OF ICE GOUGING

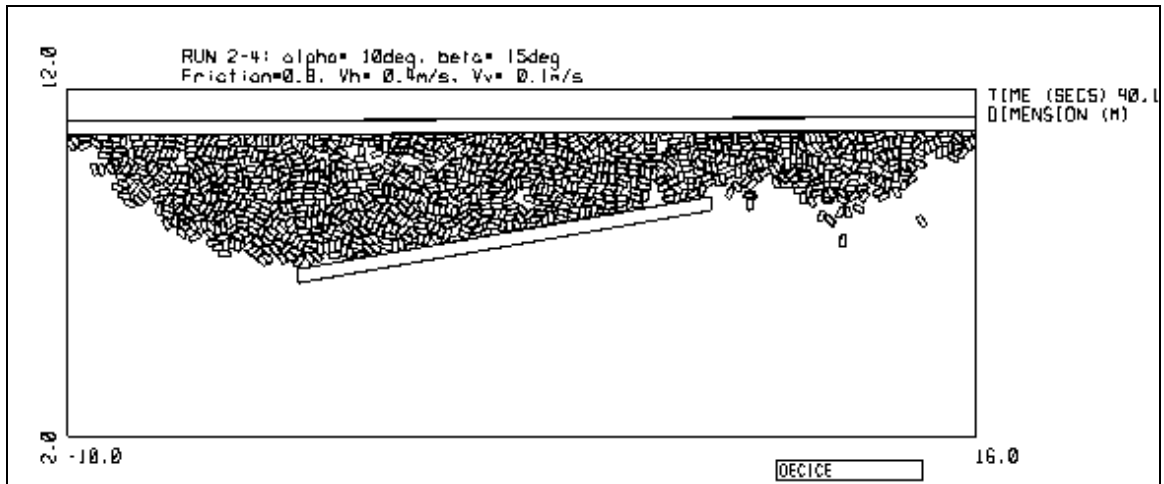


Figure B-43: Snapshot of Run 2-4 at t= 40.19 s

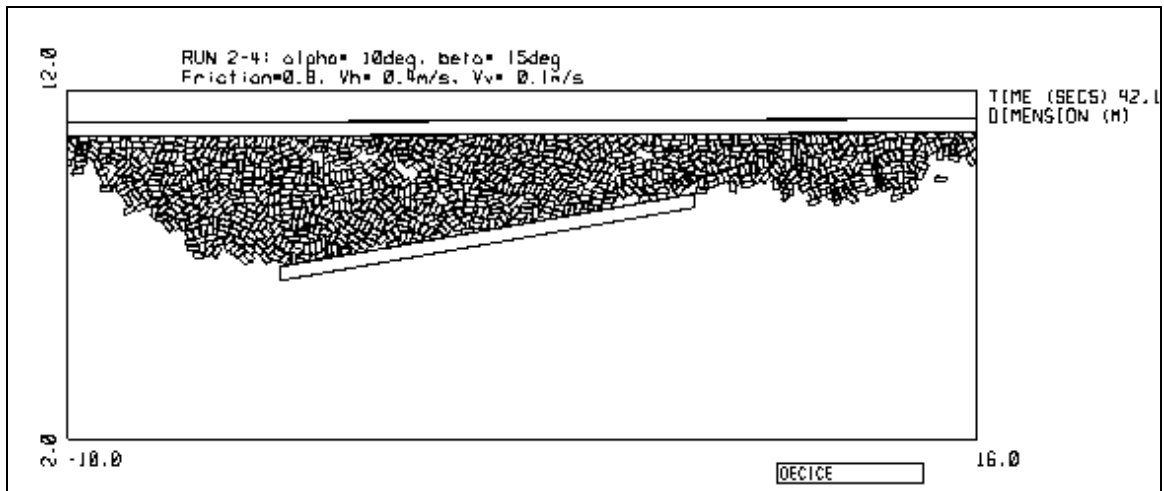


Figure B-44: Snapshot of Run 2-4 at t= 42.19 s

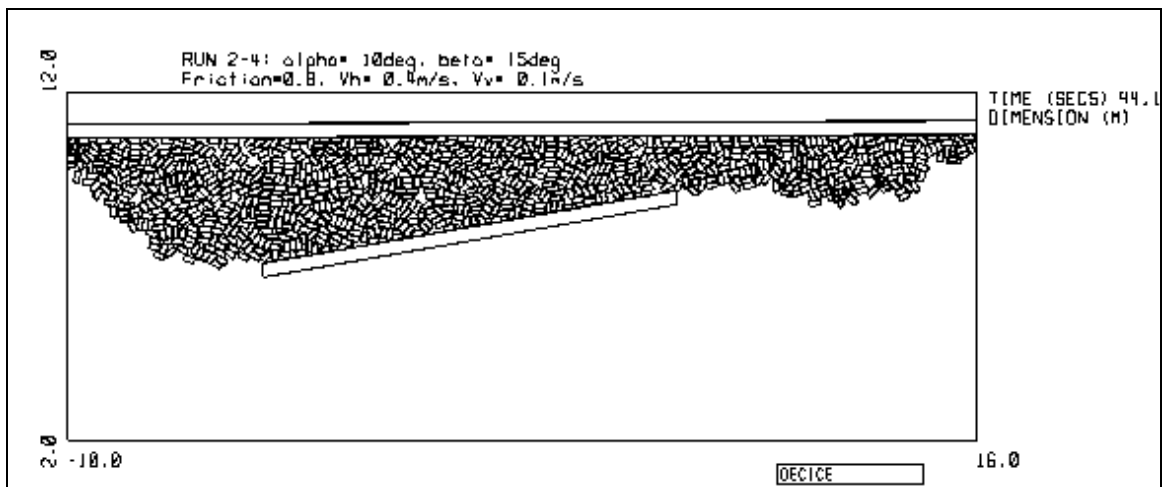


Figure B-45: Snapshot of Run 2-4 at t= 44.19 s

DECICE SIMULATION OF ICE GOUGING

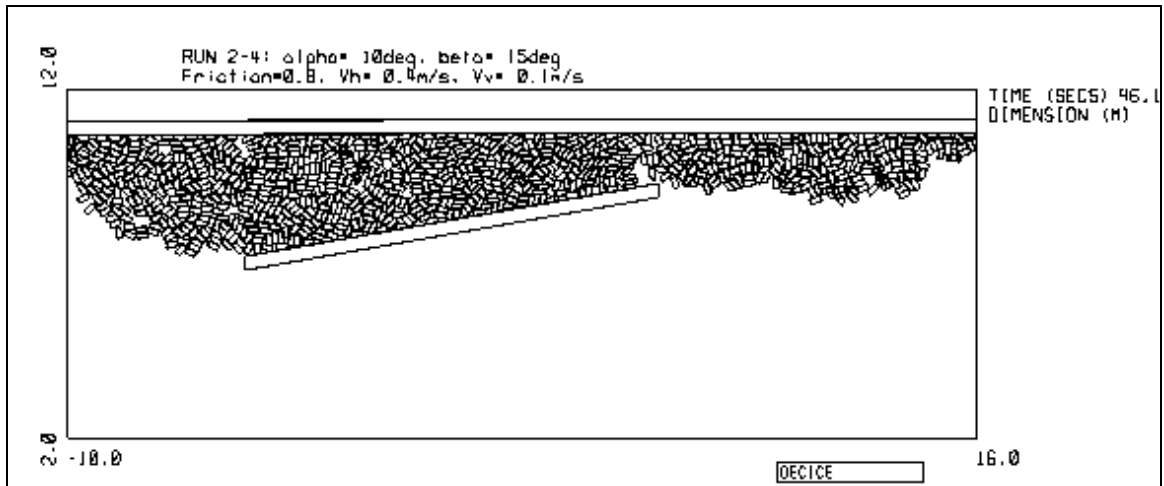


Figure B-46: Snapshot of Run 2-4 at t= 46.19 s

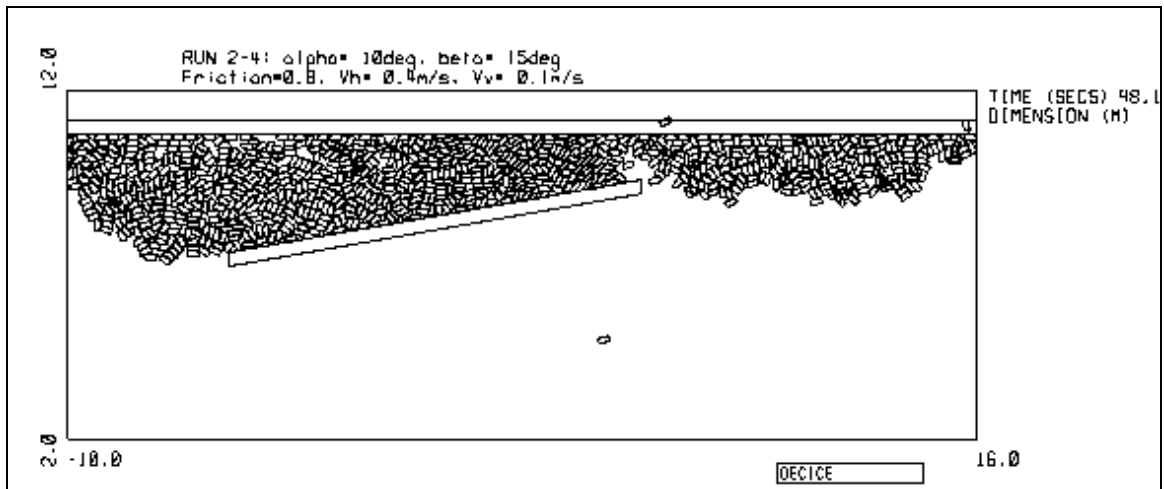


Figure B-47: Snapshot of Run 2-4 at t= 48.19 s

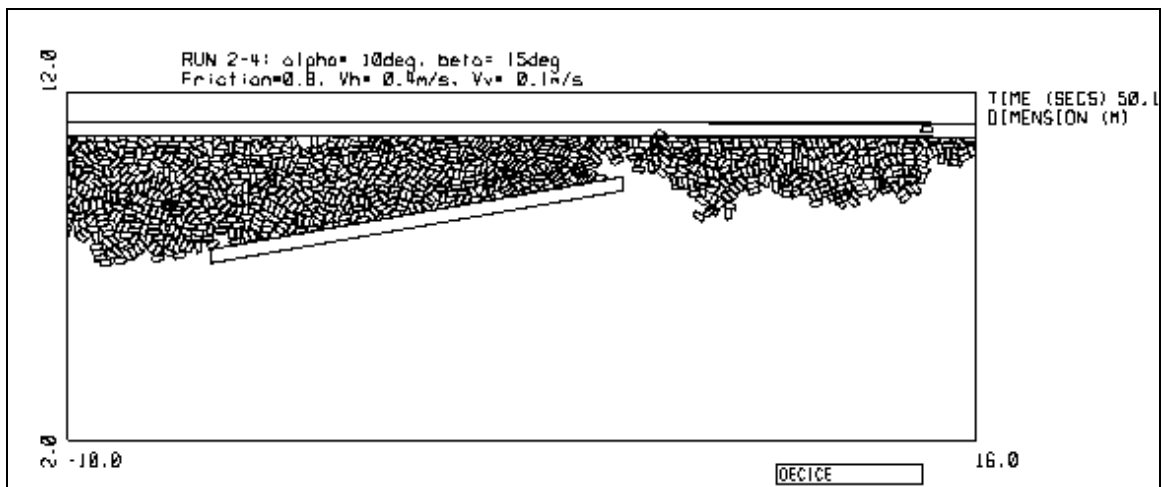


Figure B-48: Snapshot of Run 2-4 at t= 50.19 s

DECICE SIMULATION OF ICE GOUGING

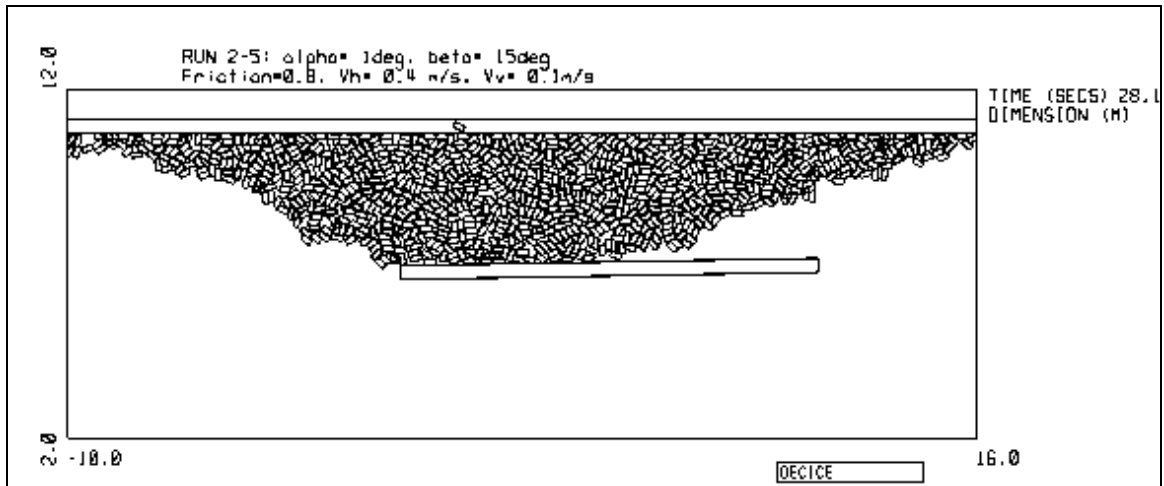


Figure B-49: Snapshot of Run 2-5 at t= 28.19 s

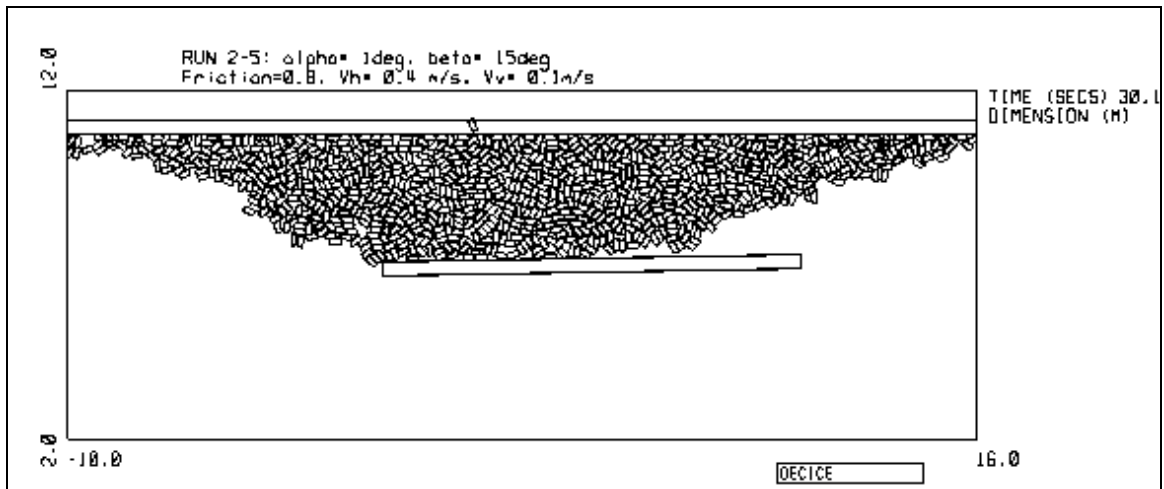


Figure B-50: Snapshot of Run 2-5 at t= 30.19 s

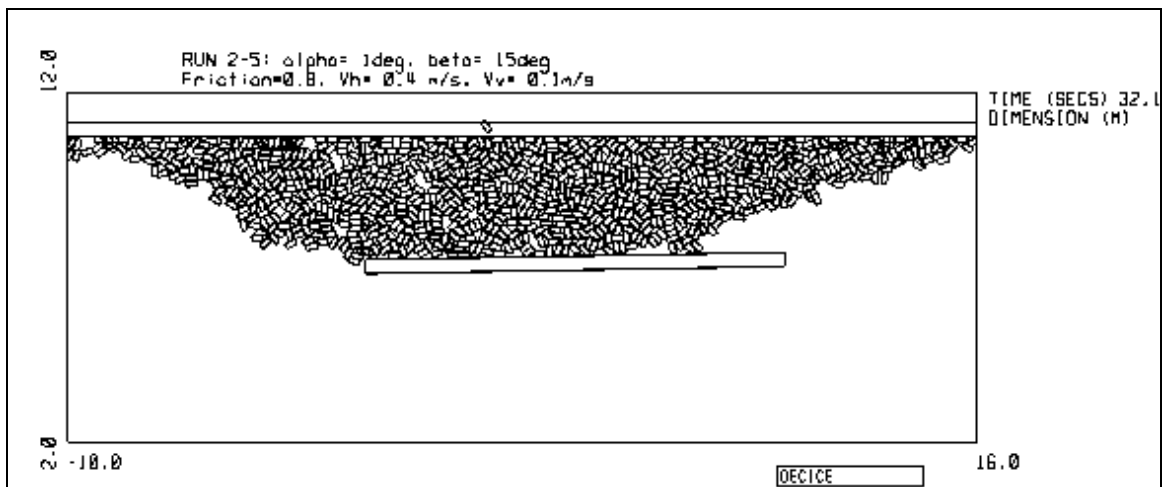


Figure B-51: Snapshot of Run 2-5 at t= 32.19 s

DECICE SIMULATION OF ICE GOUGING

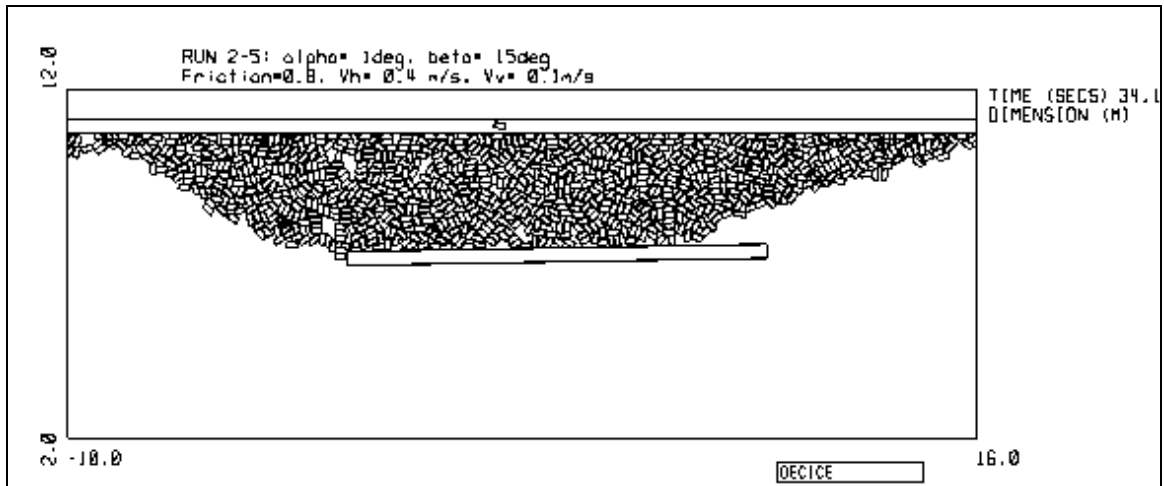


Figure B-52: Snapshot of Run 2-5 at t= 34.19 s

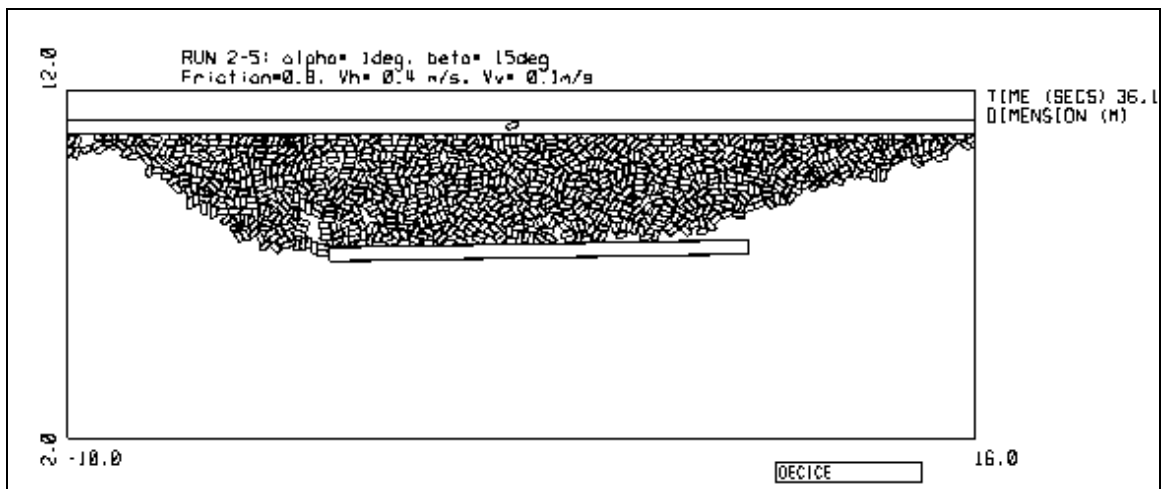


Figure B-53: Snapshot of Run 2-5 at t= 36.19 s

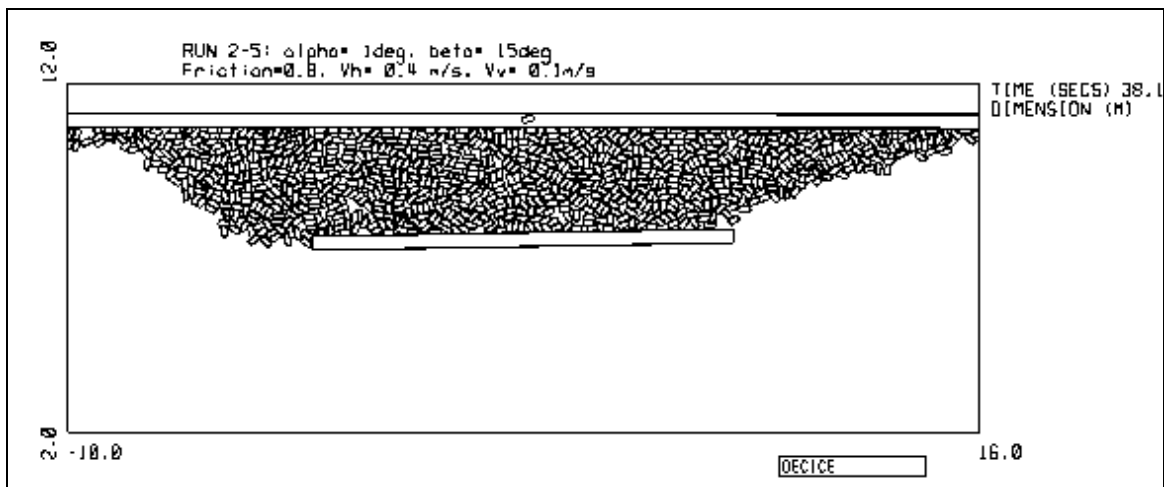


Figure B-54: Snapshot of Run 2-5 at t= 38.19 s

DECICE SIMULATION OF ICE GOUGING

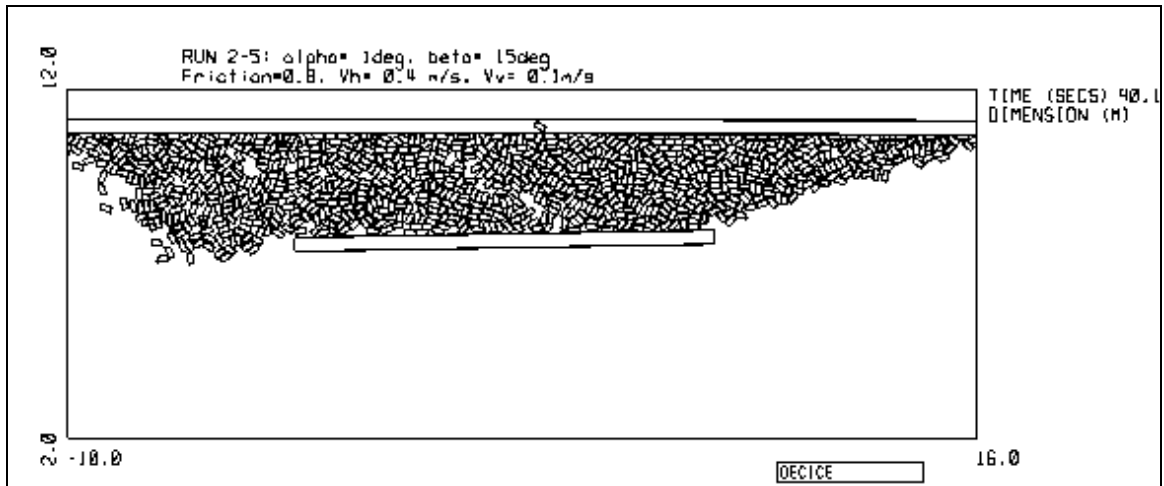


Figure B-55: Snapshot of Run 2-5 at $t= 40.19 \text{ s}$

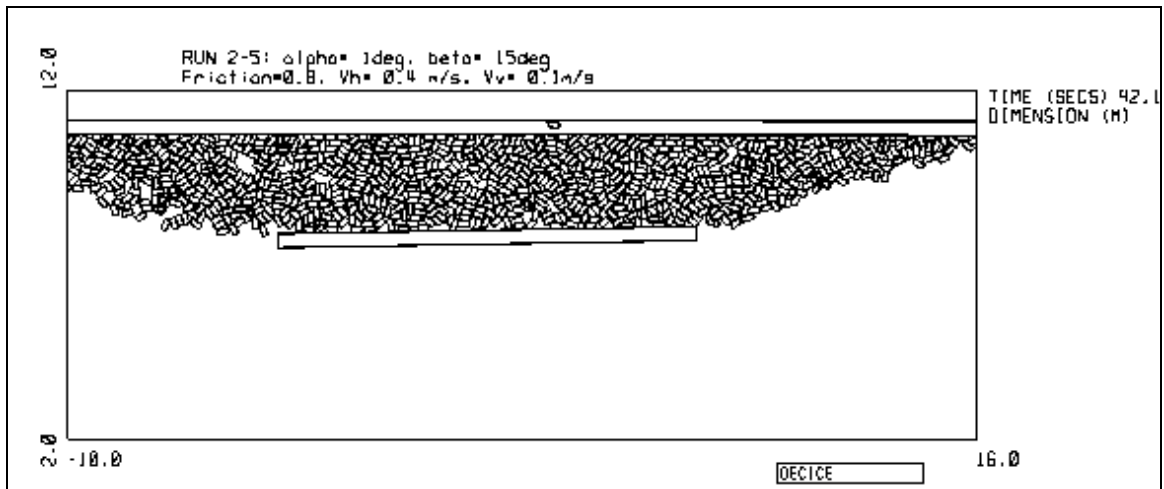


Figure B-56: Snapshot of Run 2-5 at $t= 42.19 \text{ s}$

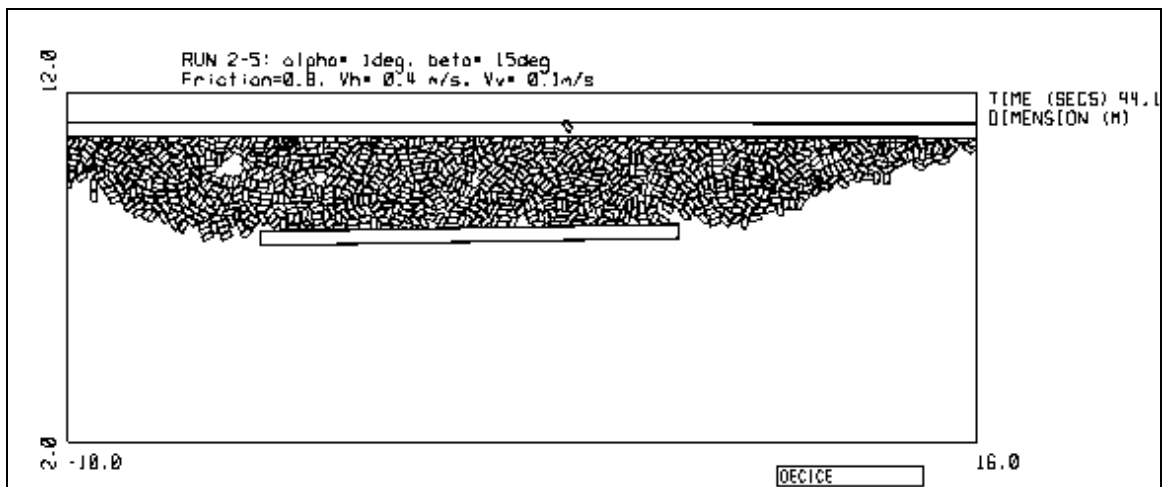


Figure B-57: Snapshot of Run 2-5 at $t= 44.19 \text{ s}$

DECICE SIMULATION OF ICE GOUGING

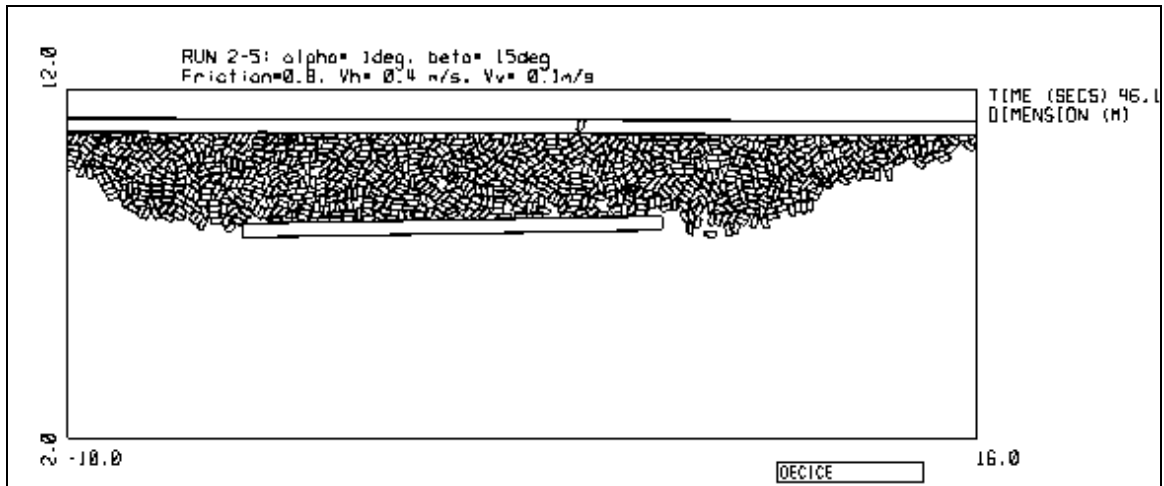


Figure B-58: Snapshot of Run 2-5 at t= 46.19 s

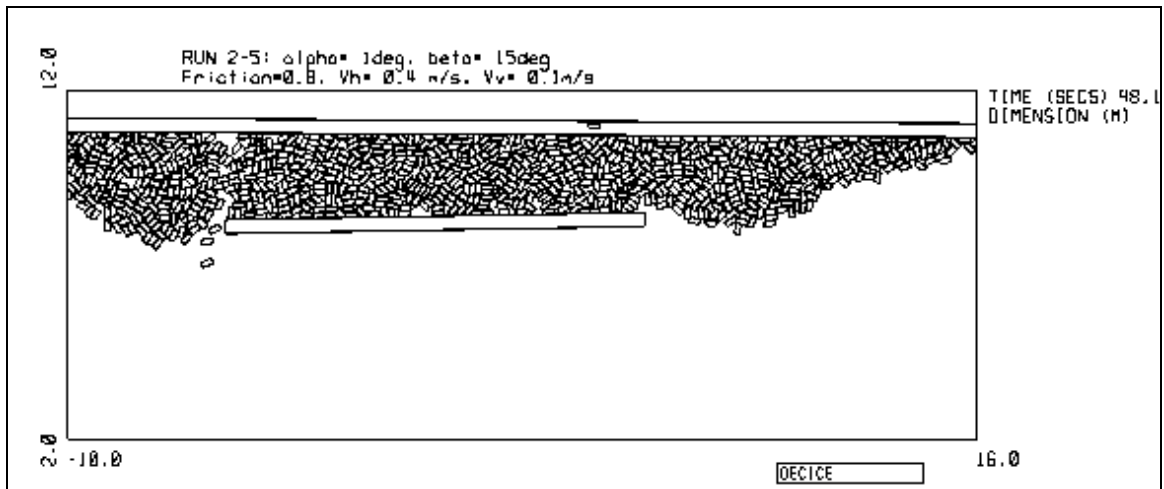


Figure B-59: Snapshot of Run 2-5 at t= 48.19 s

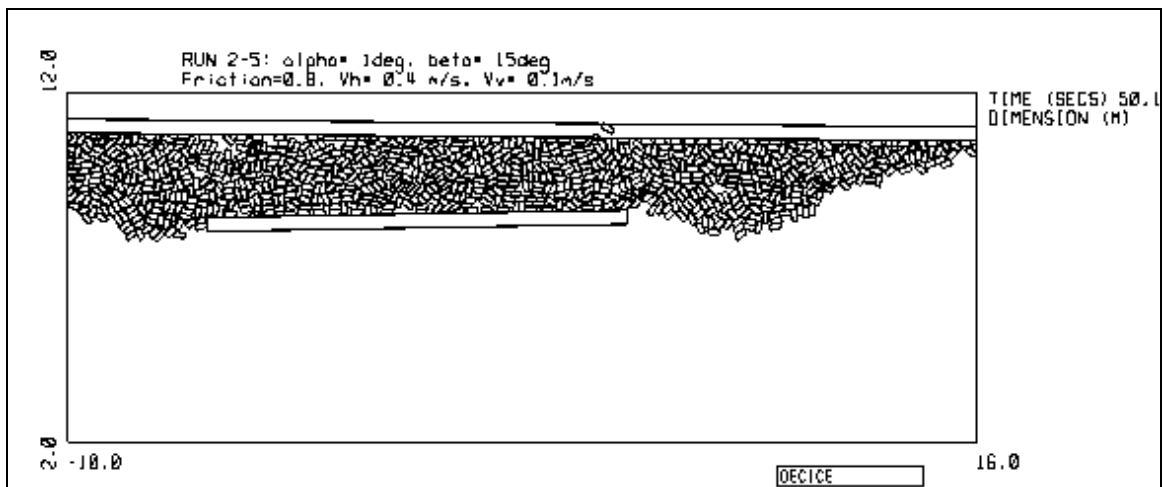


Figure B-60: Snapshot of Run 2-5 at t= 50.19 s

DECICE SIMULATION OF ICE GOUGING

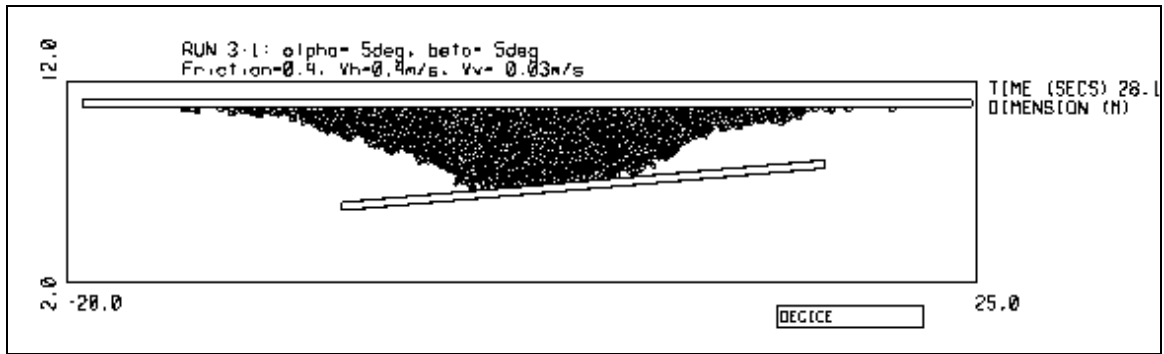


Figure B-61: Snapshot of Run 3-1 at t= 28.2 s

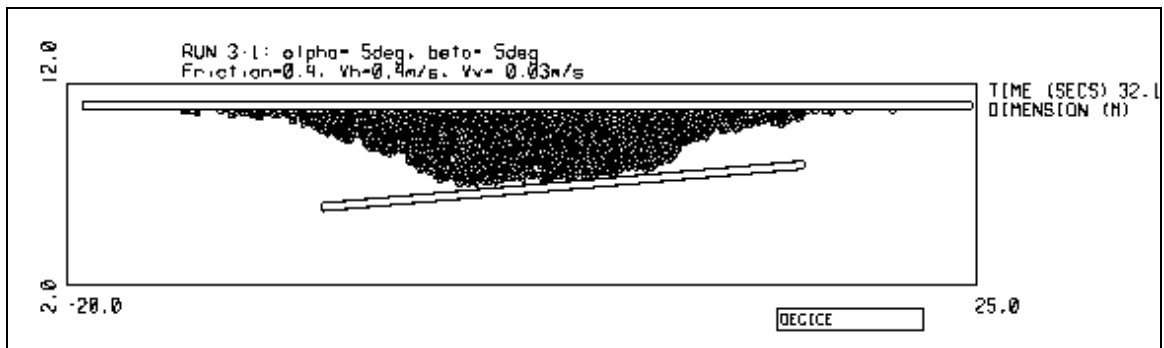


Figure B-62: Snapshot of Run 3-1 at t= 32.2 s

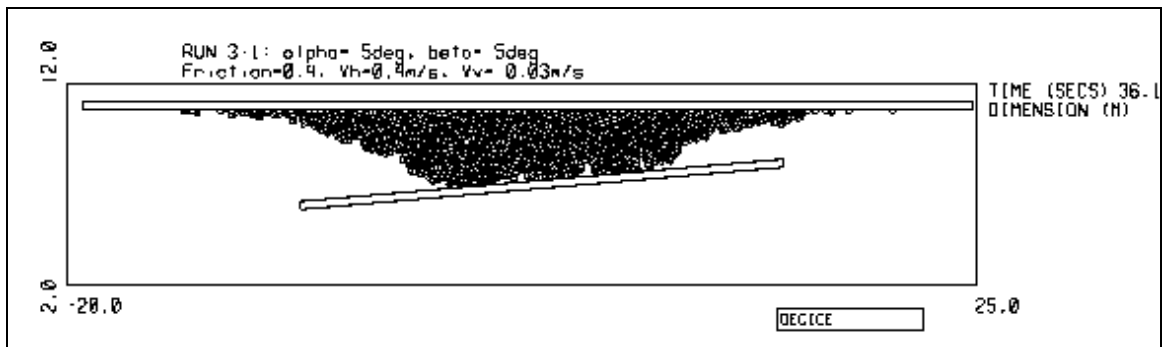


Figure B-63: Snapshot of Run 3-1 at t= 36.2 s

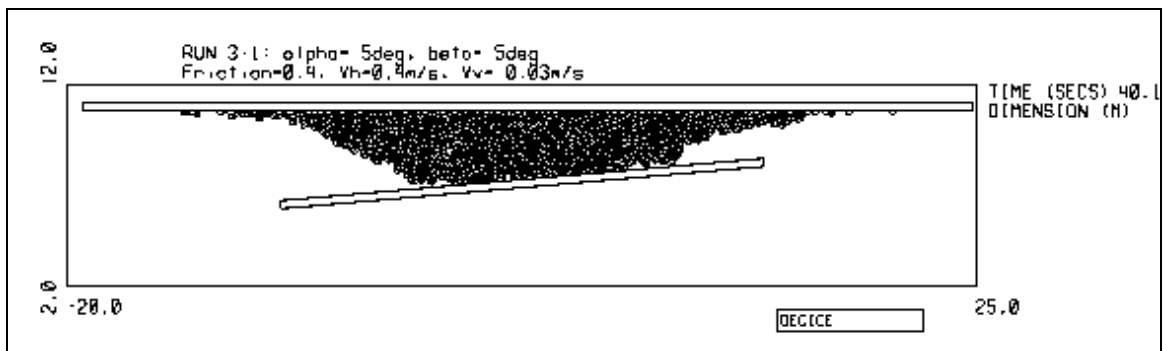


Figure B-64: Snapshot of Run 3-1 at t= 40.2 s

DECICE SIMULATION OF ICE GOUGING

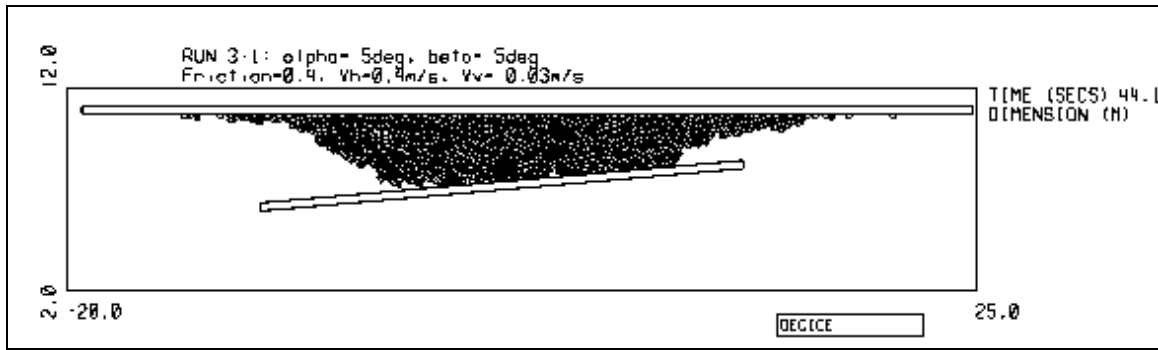


Figure B-65: Snapshot of Run 3-1 at t= 44.2 s

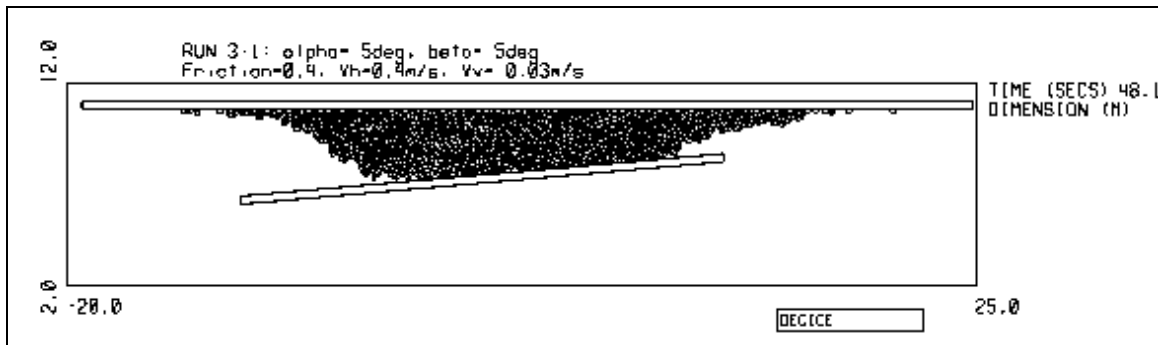


Figure B-66: Snapshot of Run 3-1 at t= 48.2 s

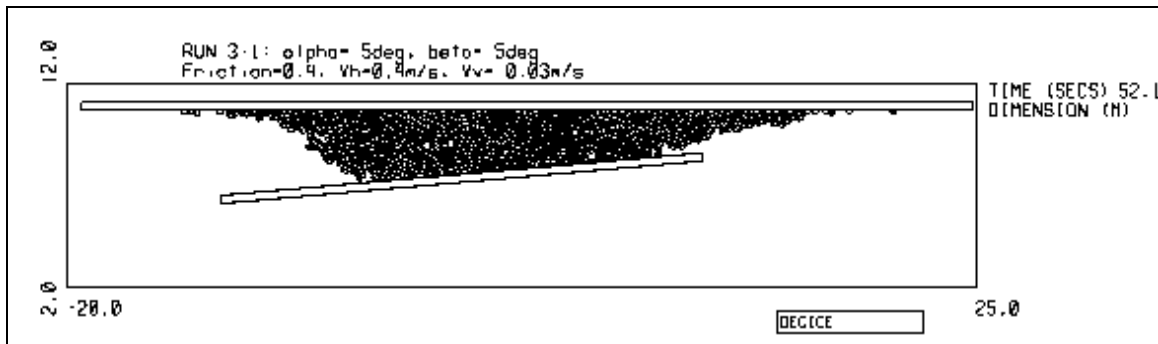


Figure B-67: Snapshot of Run 3-1 at t= 52.2 s

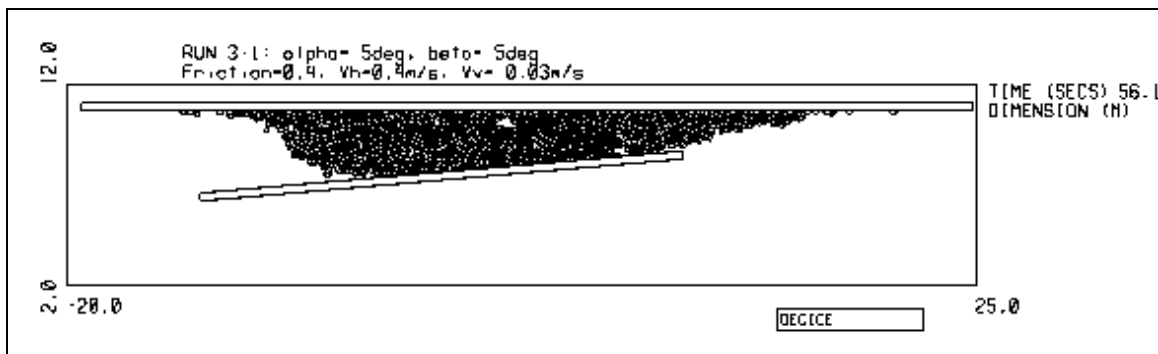


Figure B-68: Snapshot of Run 3-1 at t= 56.2 s

DECICE SIMULATION OF ICE GOUGING

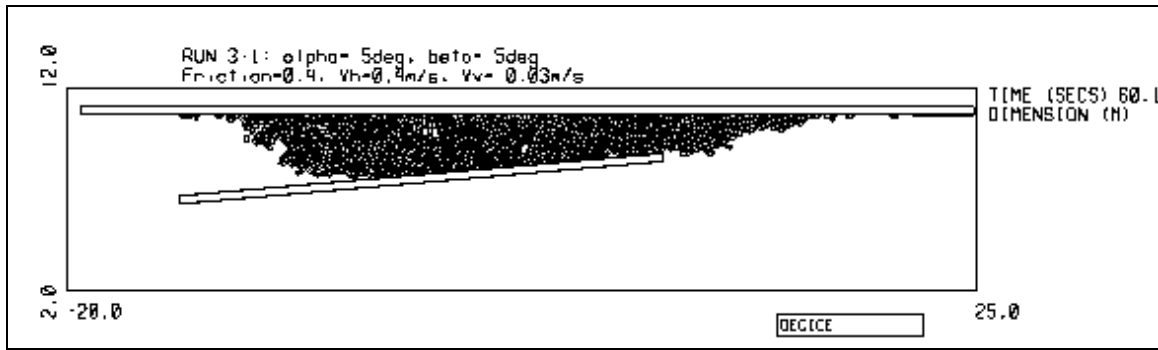


Figure B-69: Snapshot of Run 3-1 at t= 60.2 s

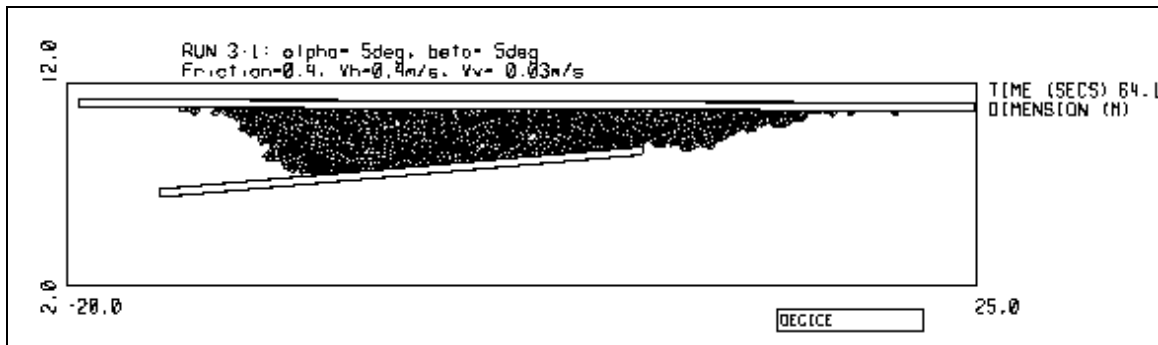


Figure B-70: Snapshot of Run 3-1 at t= 64.2 s

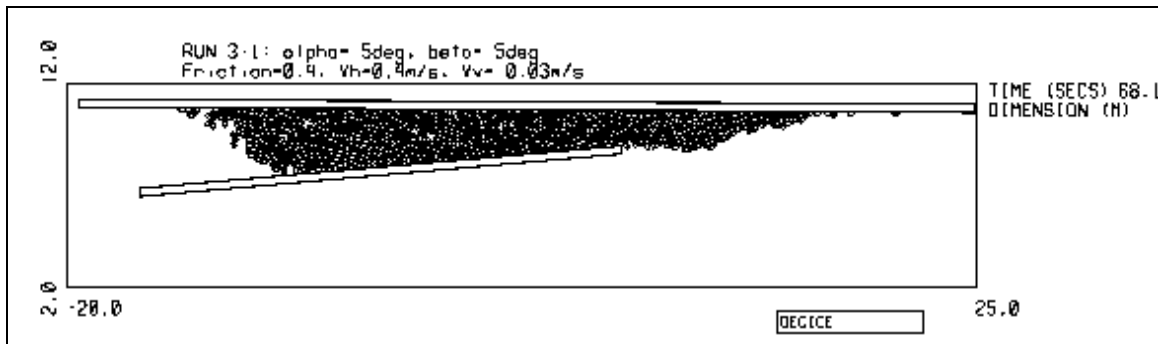


Figure B-71: Snapshot of Run 3-1 at t= 68.2 s

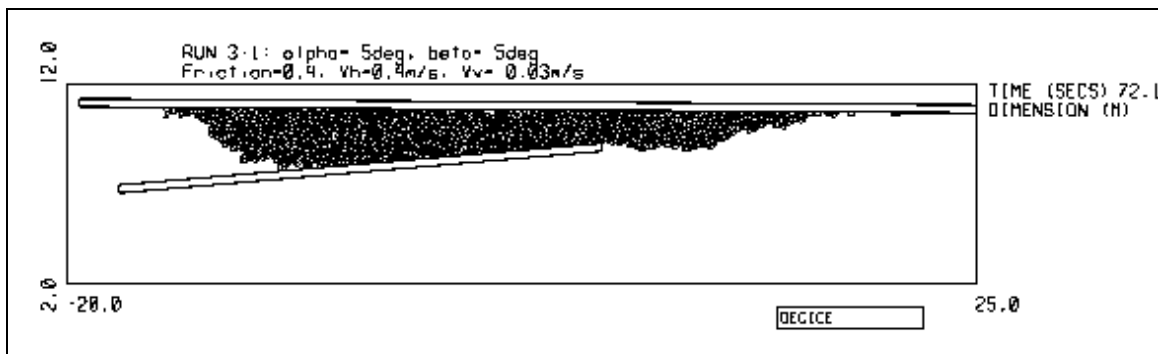


Figure B-72: Snapshot of Run 3-1 at t= 72.2 s

DECICE SIMULATION OF ICE GOUGING

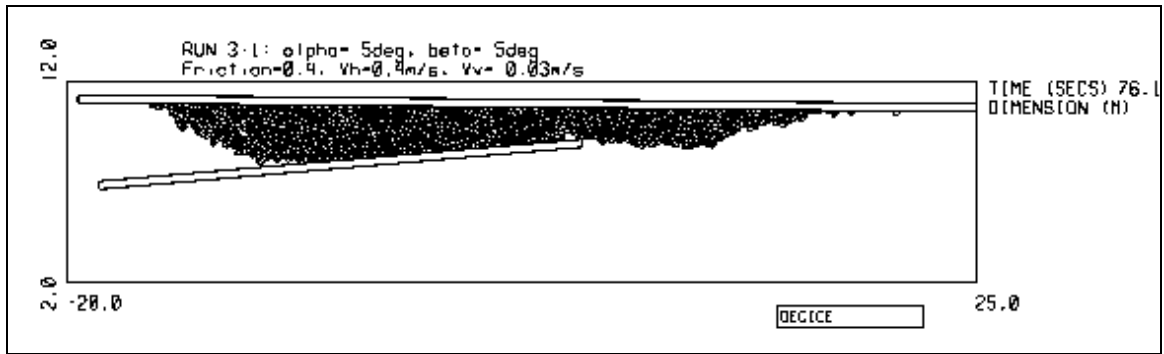


Figure B-73: Snapshot of Run 3-1 at t= 76.2 s

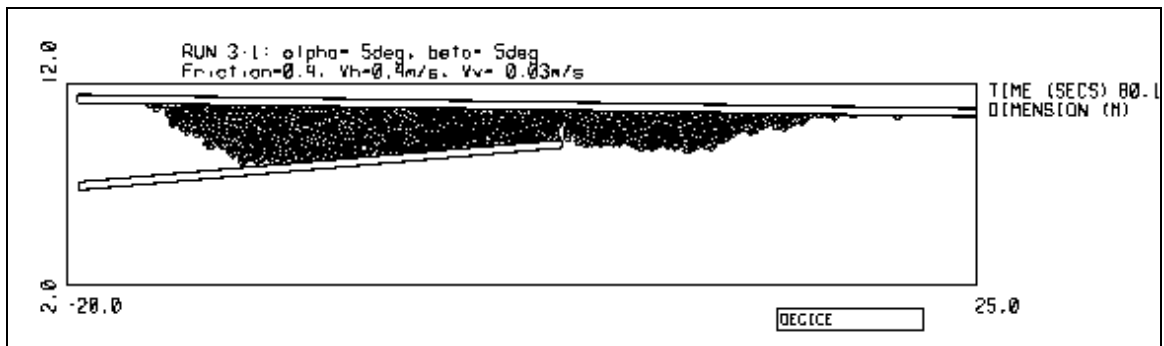


Figure B-74: Snapshot of Run 3-1 at t= 80.2 s

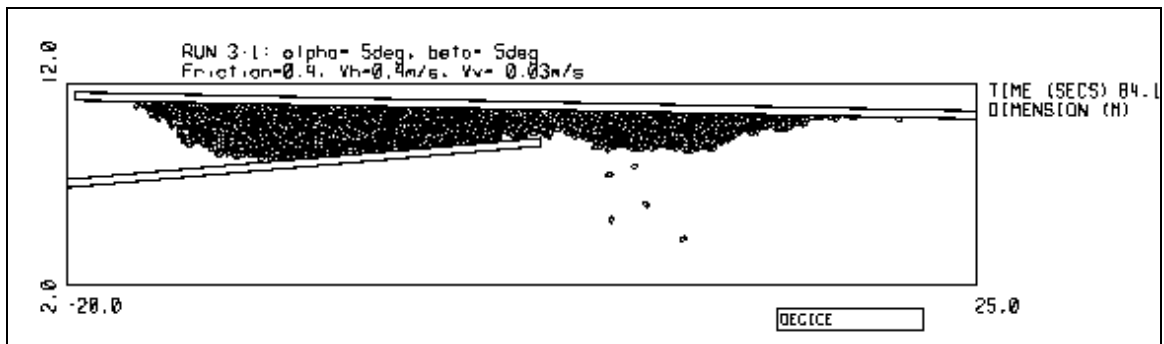


Figure B-75: Snapshot of Run 3-1 at t= 84.2 s

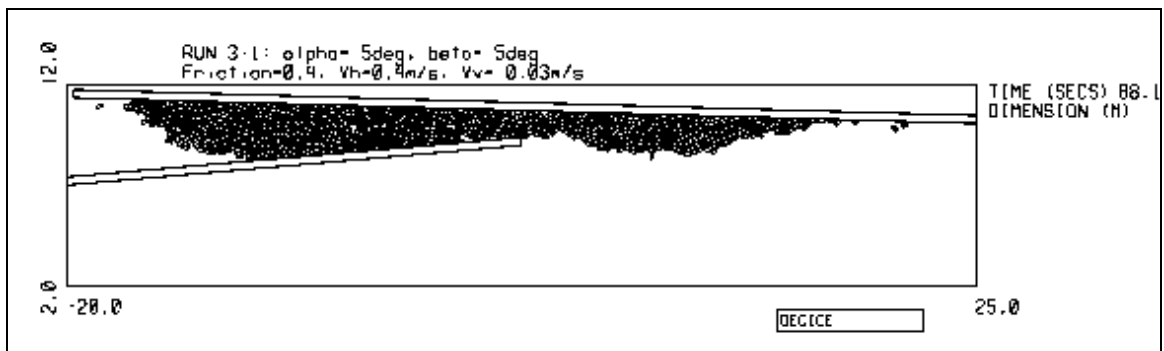


Figure B-76: Snapshot of Run 3-1 at t= 88.2 s

DECICE SIMULATION OF ICE GOUGING

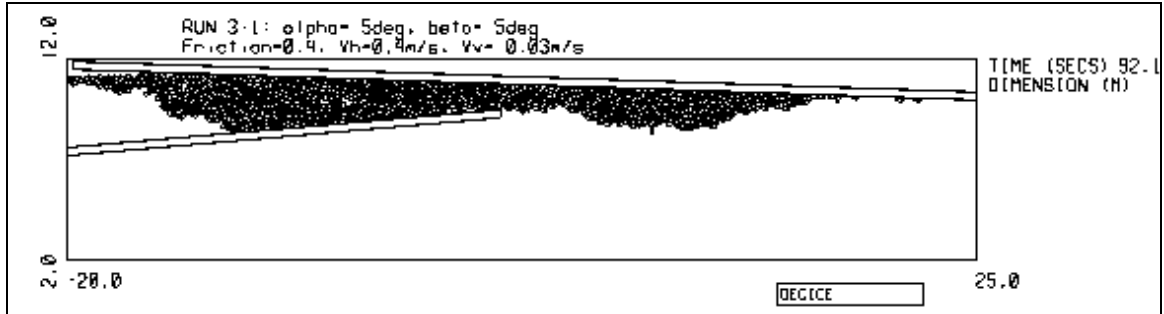


Figure B-77: Snapshot of Run 3-1 at t= 92.2 s

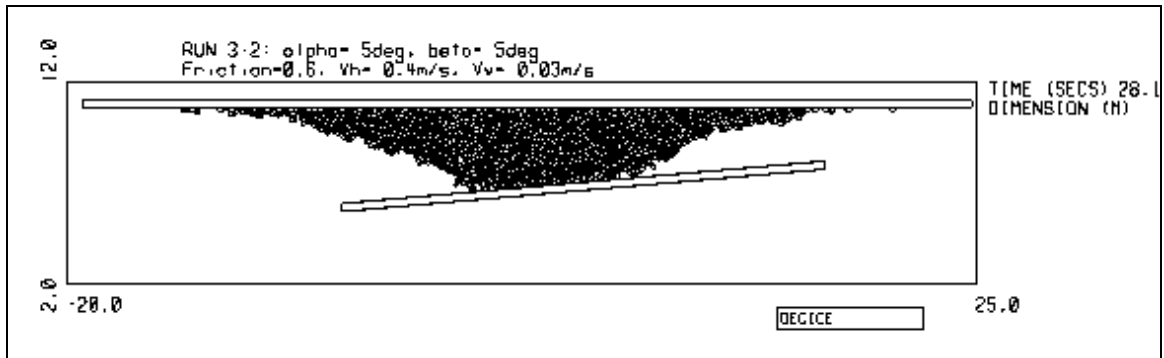


Figure B-78: Snapshot of Run 3-2 at t= 28.2 s

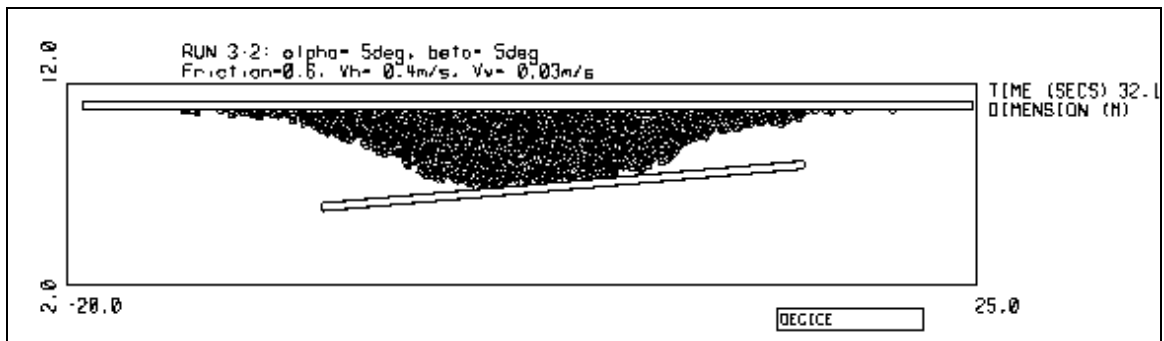


Figure B-79: Snapshot of Run 3-2 at t= 32.2 s

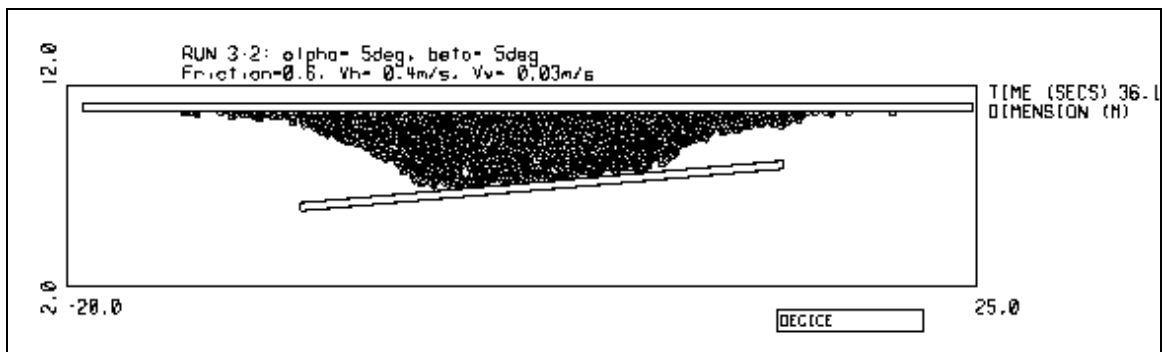


Figure B-80: Snapshot of Run 3-2 at t= 36.2 s

DECICE SIMULATION OF ICE GOUGING

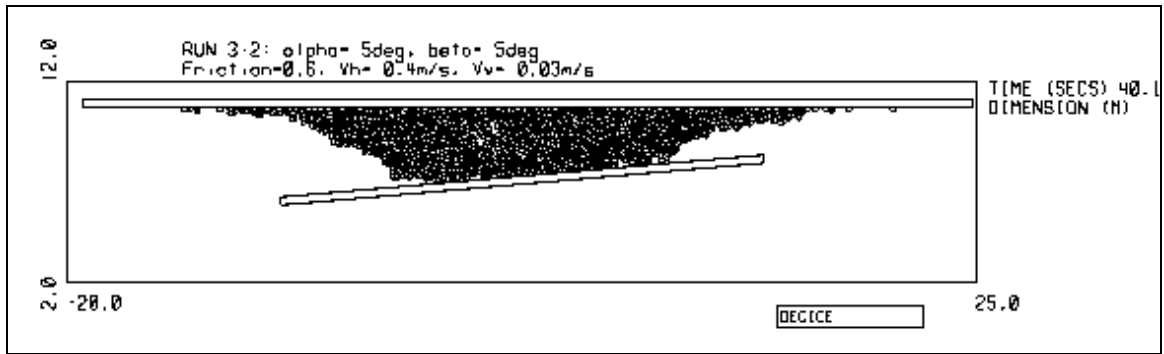


Figure B-81: Snapshot of Run 3-2 at t= 40.2 s

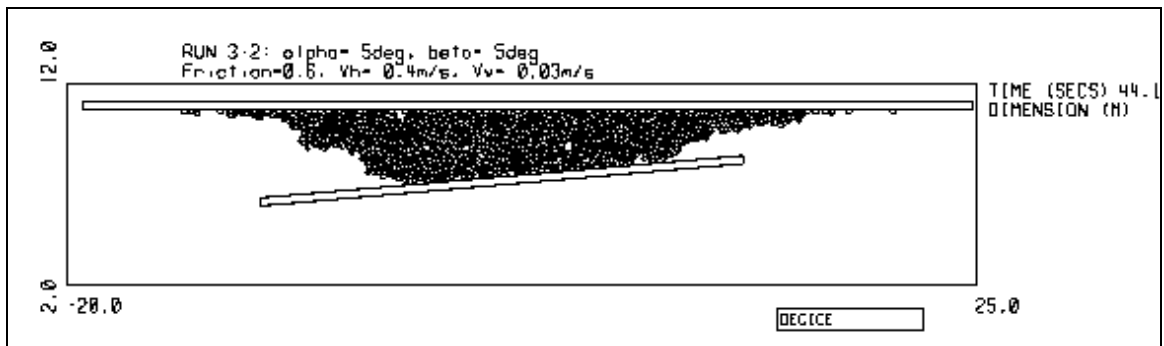


Figure B-82: Snapshot of Run 3-2 at t= 44.2 s

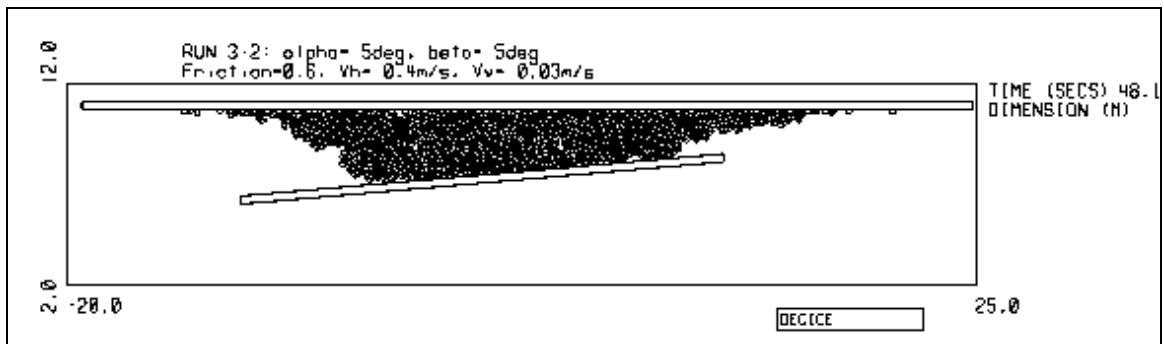


Figure B-83: Snapshot of Run 3-2 at t= 48.2 s

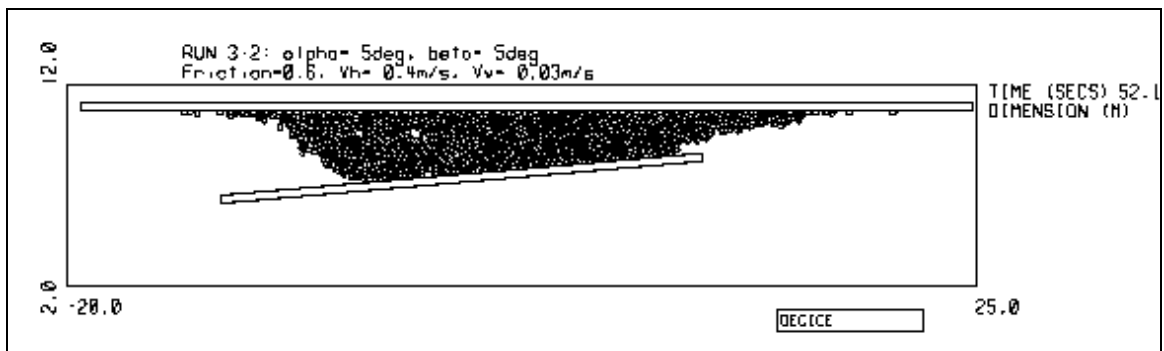


Figure B-84: Snapshot of Run 3-2 at t= 52.2 s

DECICE SIMULATION OF ICE GOUGING

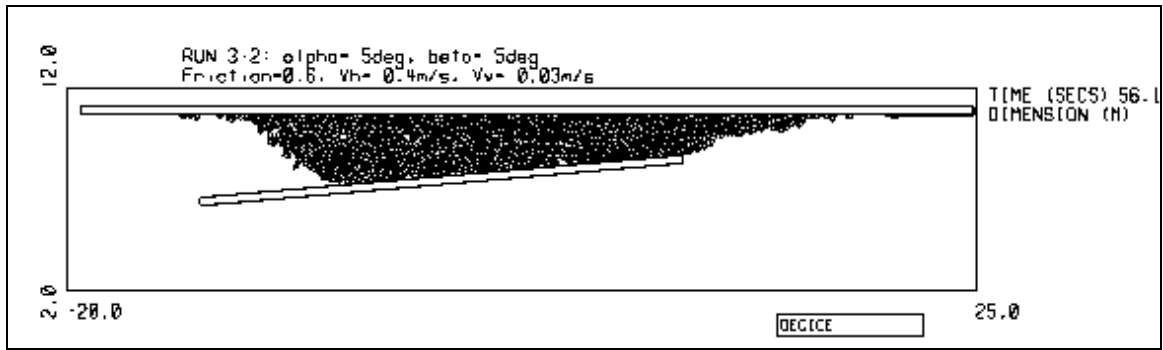


Figure B-85: Snapshot of Run 3-2 at t= 56.2 s

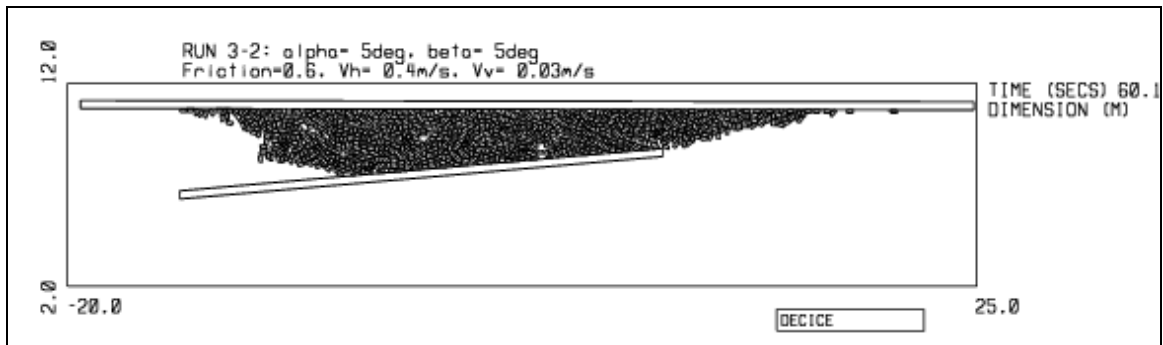


Figure B-86: Snapshot of Run 3-2 at t= 60.2 s

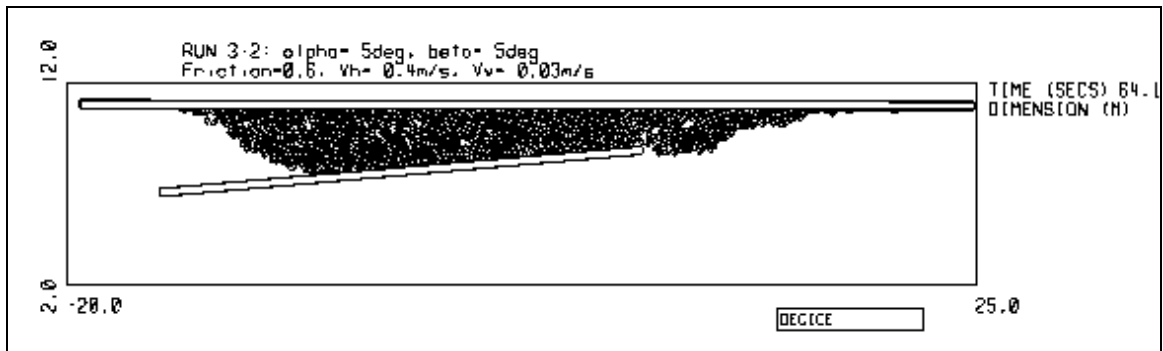


Figure B-87: Snapshot of Run 3-2 at t= 64.2 s

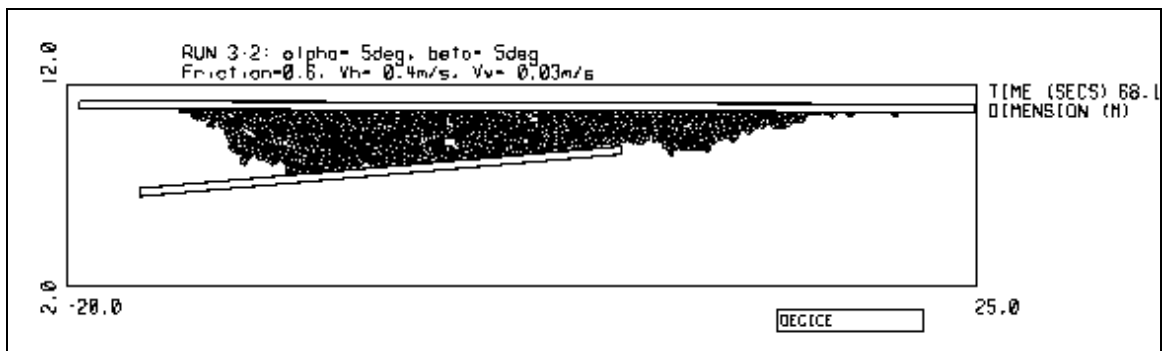


Figure B-88: Snapshot of Run 3-2 at t= 68.2 s

DECICE SIMULATION OF ICE GOUGING

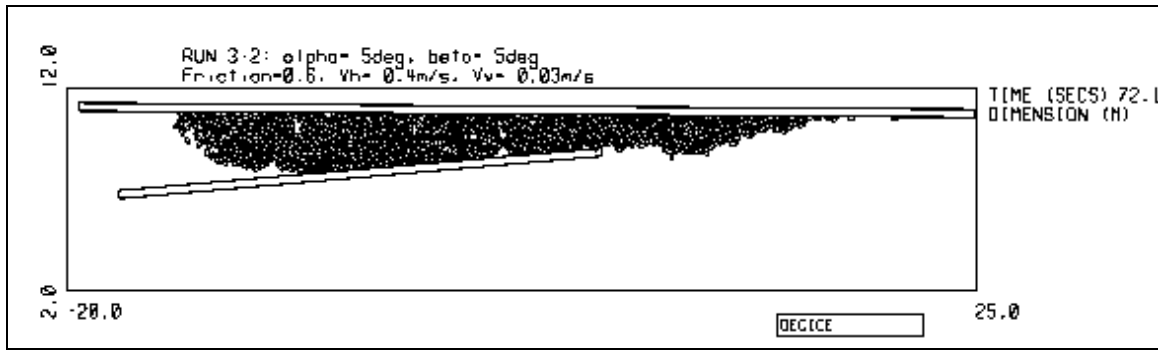


Figure B-89: Snapshot of Run 3-2 at t= 72.2 s

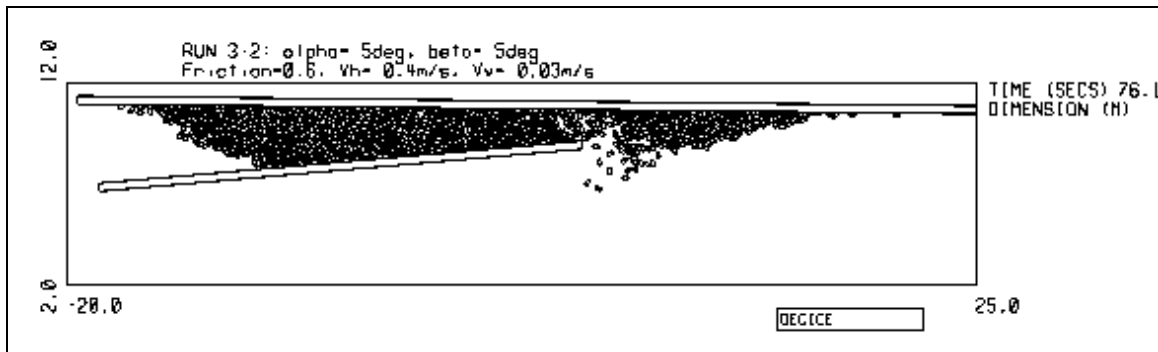


Figure B-90: Snapshot of Run 3-2 at t= 76.2 s

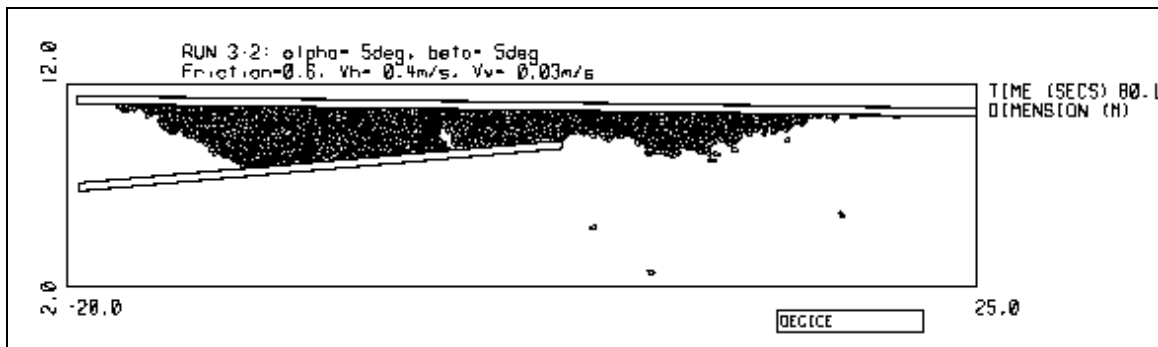


Figure B-91: Snapshot of Run 3-2 at t= 80.2 s

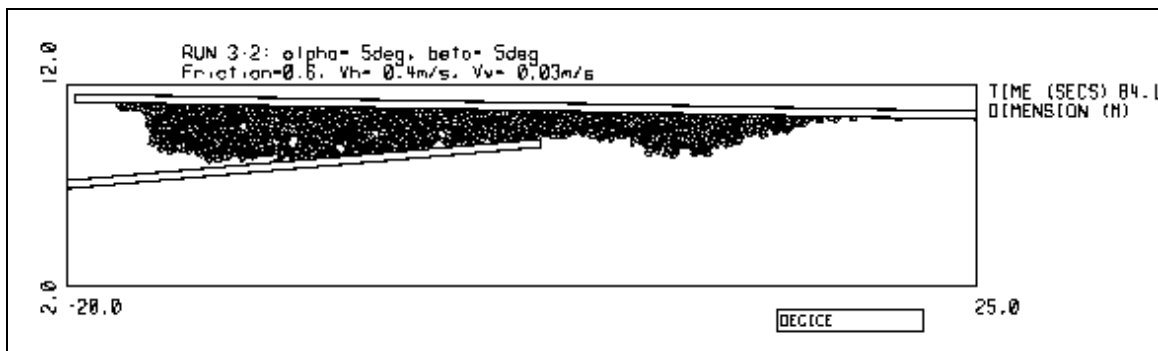


Figure B-92: Snapshot of Run 3-2 at t= 84.2 s

DECICE SIMULATION OF ICE GOUGING

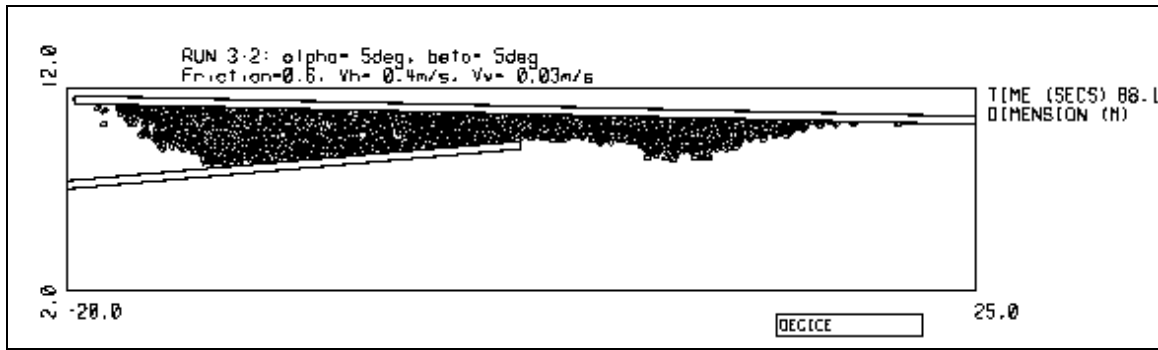


Figure B-93: Snapshot of Run 3-2 at t= 88.2 s

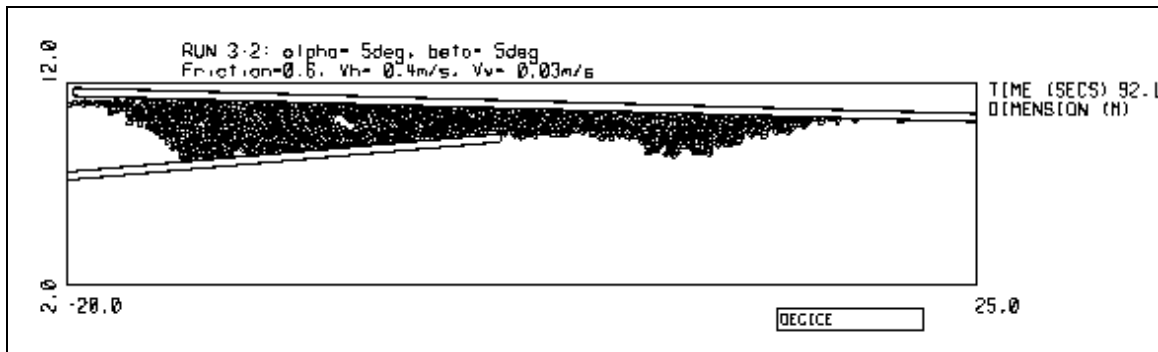


Figure B-94: Snapshot of Run 3-2 at t= 92.2 s

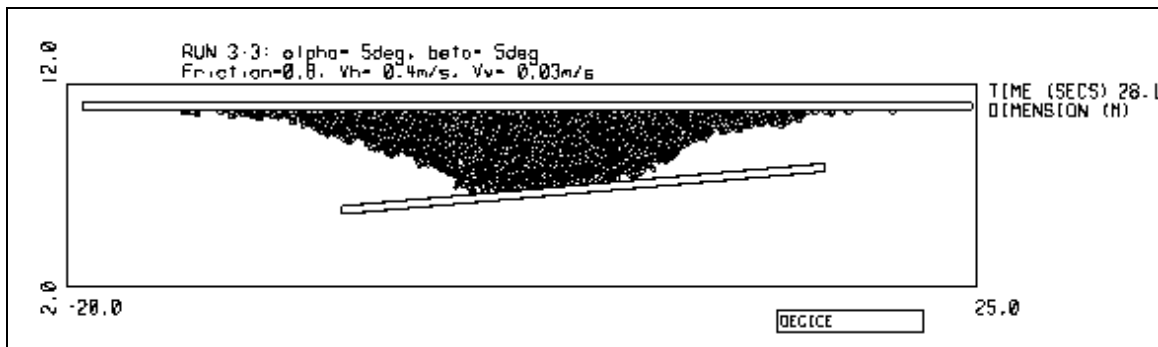


Figure B-95: Snapshot of Run 3-3 at t= 28.2 s

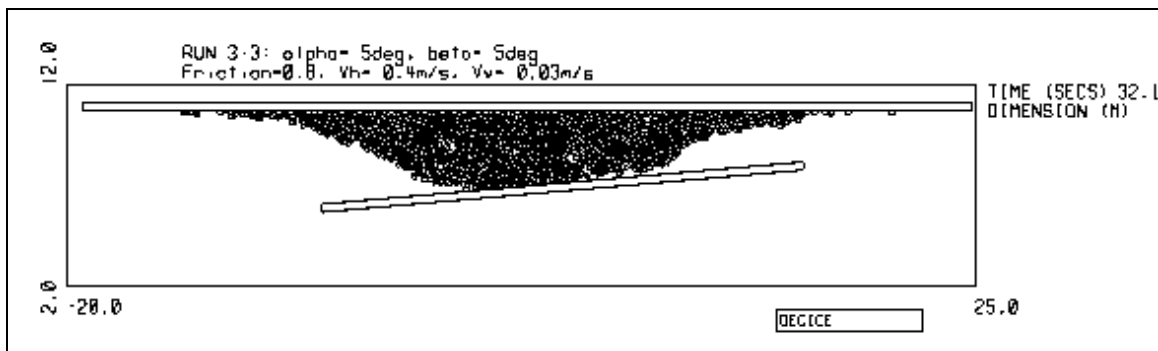


Figure B-96: Snapshot of Run 3-3 at t= 32.2 s

DECICE SIMULATION OF ICE GOUGING

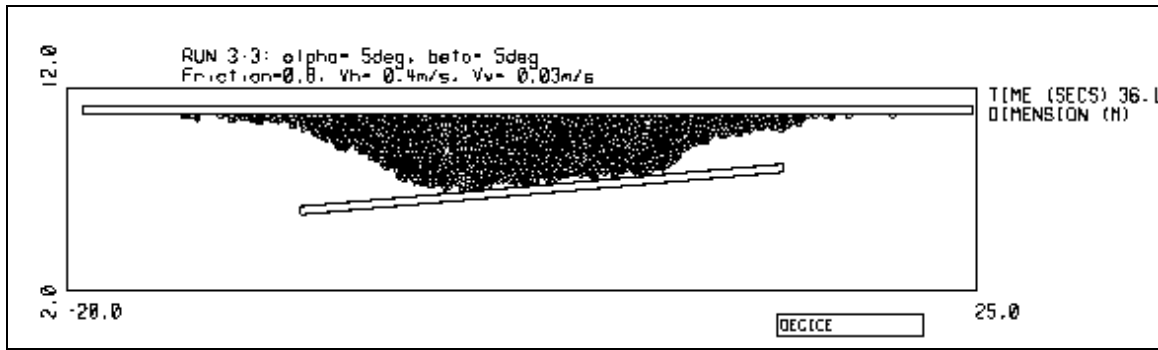


Figure B-97: Snapshot of Run 3-3 at t= 36.2 s

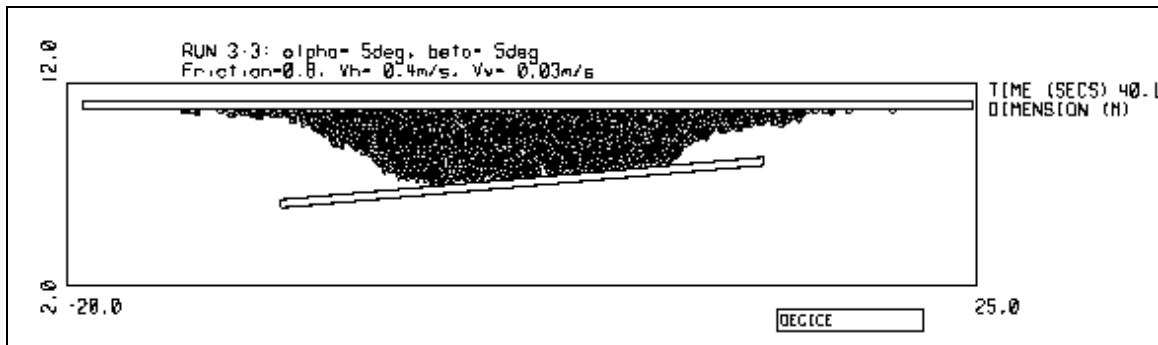


Figure B-98: Snapshot of Run 3-3 at t= 40.2 s

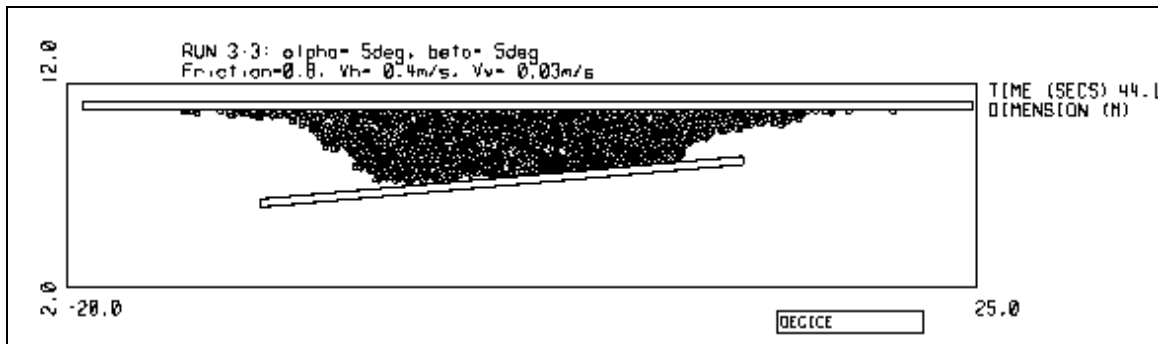


Figure B-99: Snapshot of Run 3-3 at t= 44.2 s

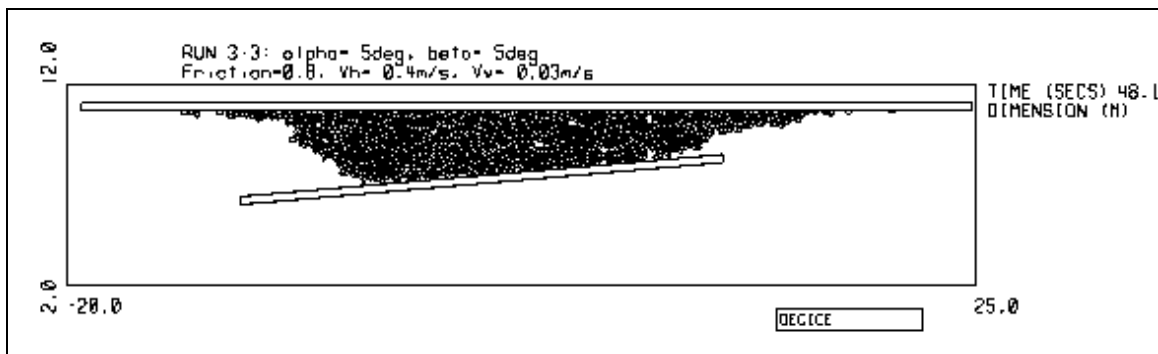


Figure B-100: Snapshot of Run 3-3 at t= 48.2 s

DECICE SIMULATION OF ICE GOUGING

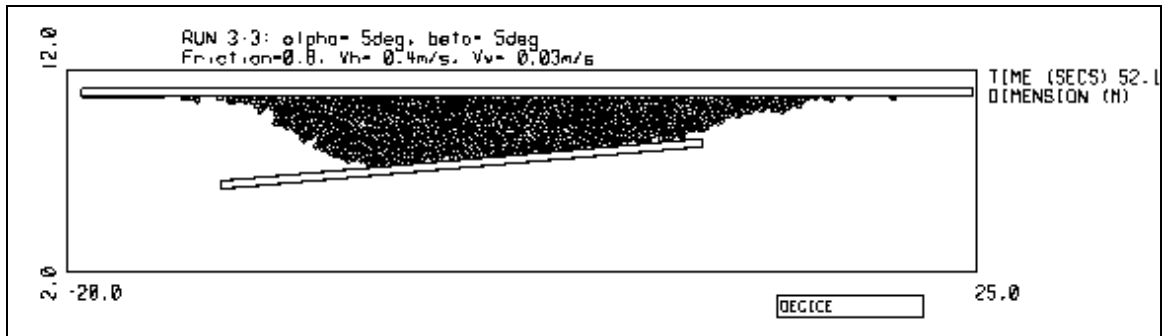


Figure B-101: Snapshot of Run 3-3 at t= 52.2 s

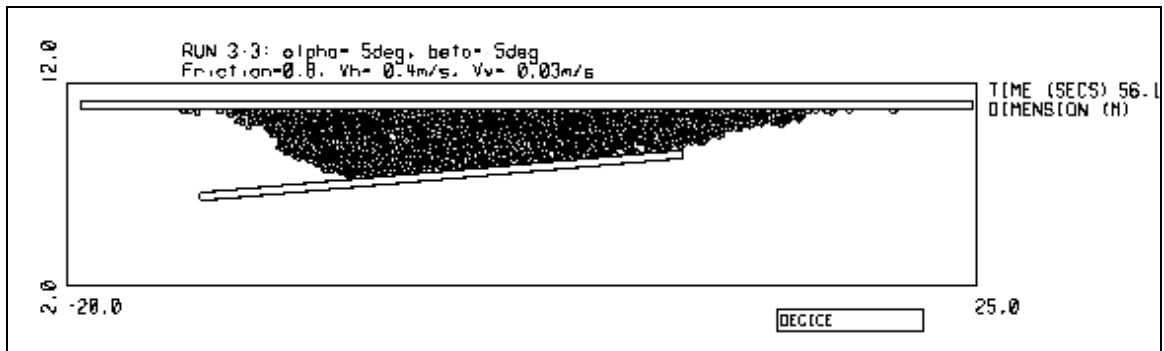


Figure B-102: Snapshot of Run 3-3 at t= 56.2 s

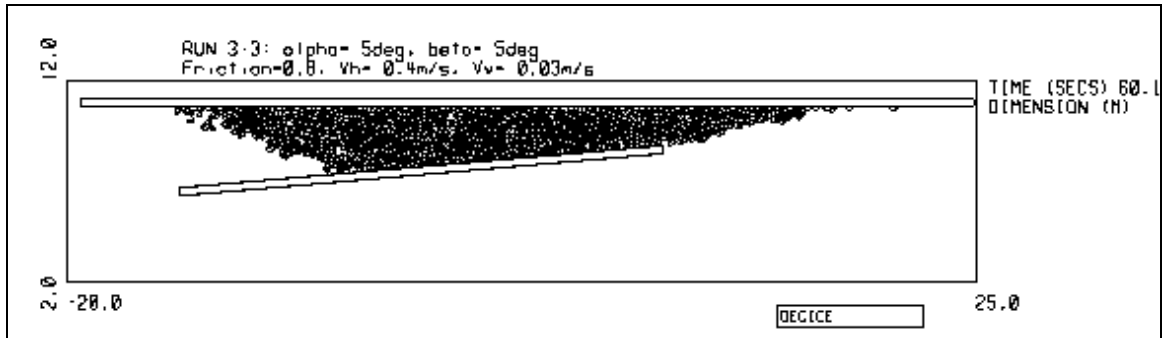


Figure B-103: Snapshot of Run 3-3 at t= 60.2 s

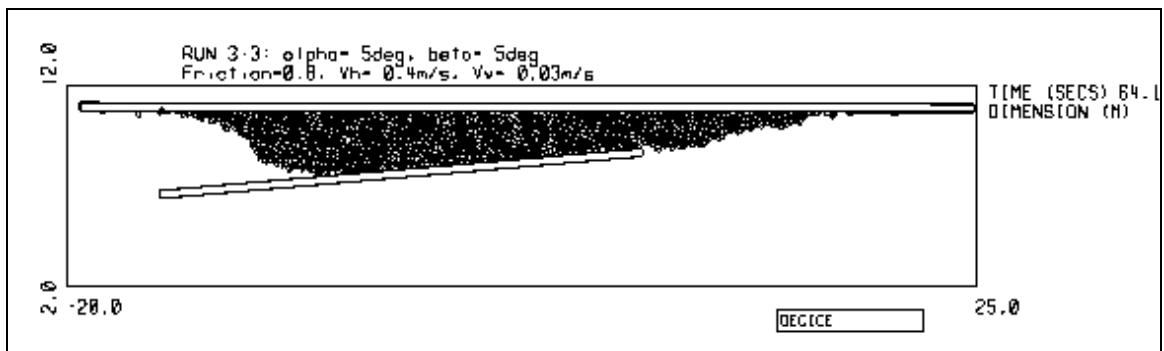


Figure B-104: Snapshot of Run 3-3 at t= 64.2 s

DECICE SIMULATION OF ICE GOUGING

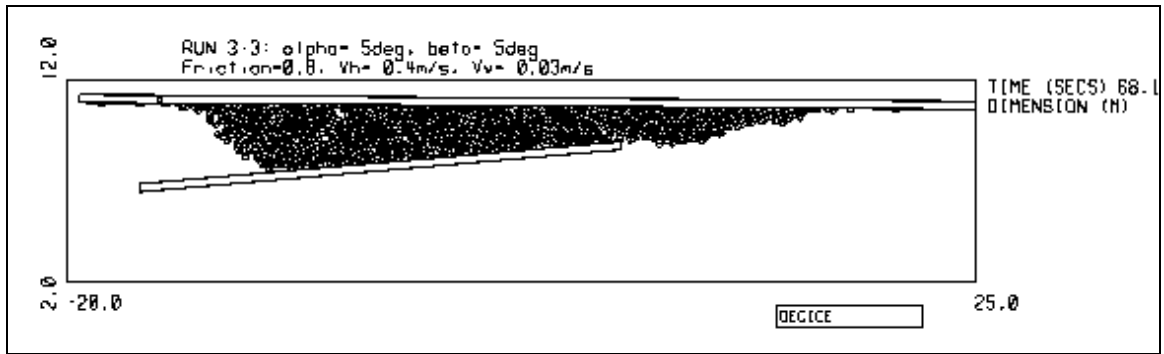


Figure B-105: Snapshot of Run 3-3 at t= 68.2 s

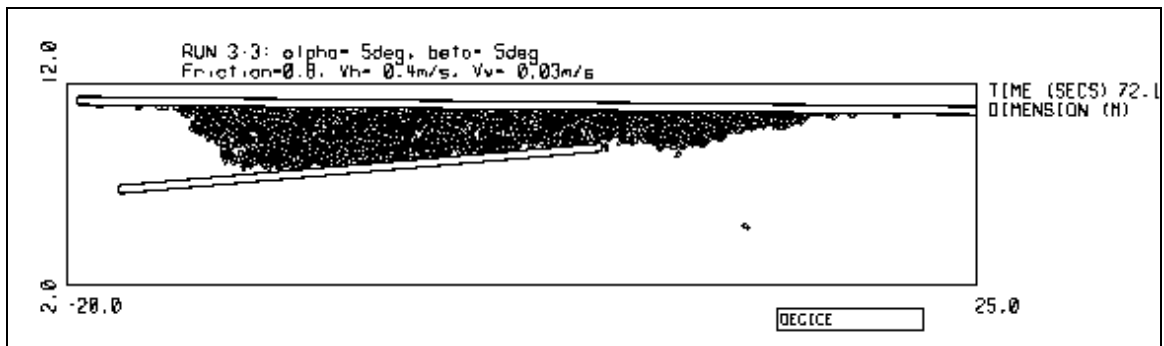


Figure B-106: Snapshot of Run 3-3 at t= 72.2 s

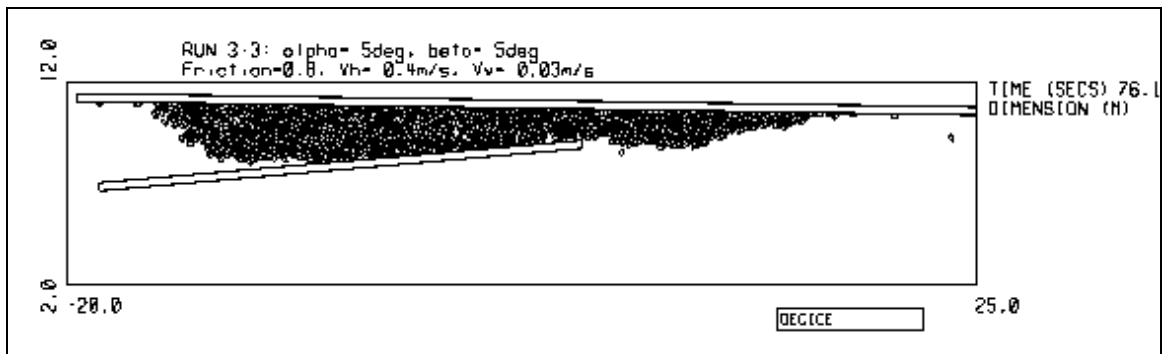


Figure B-107: Snapshot of Run 3-3 at t= 76.2 s

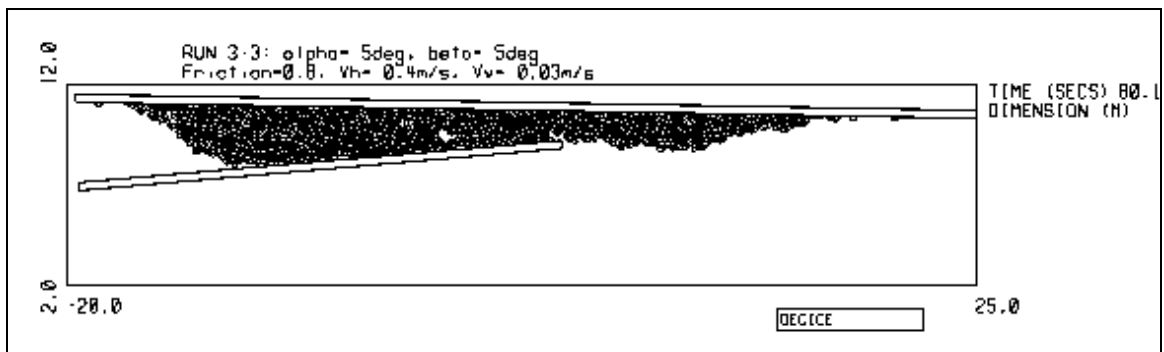


Figure B-108: Snapshot of Run 3-3 at t= 80.2 s

DECICE SIMULATION OF ICE GOUGING

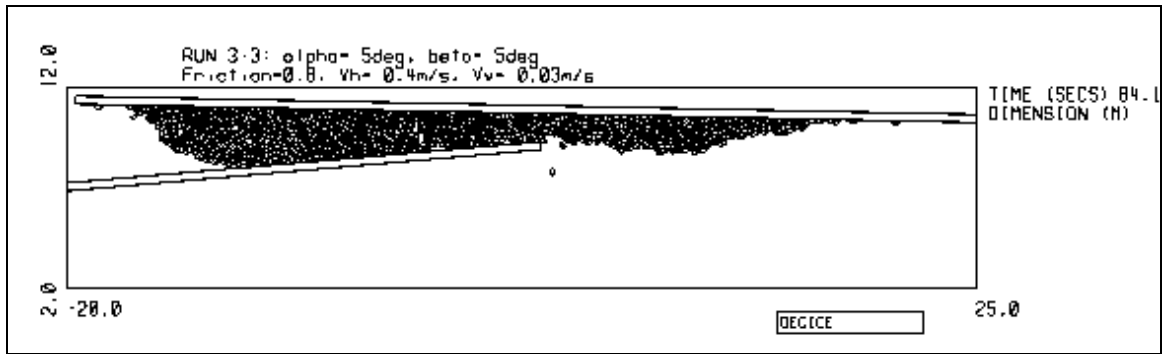


Figure B-109: Snapshot of Run 3-3 at t= 84.2 s

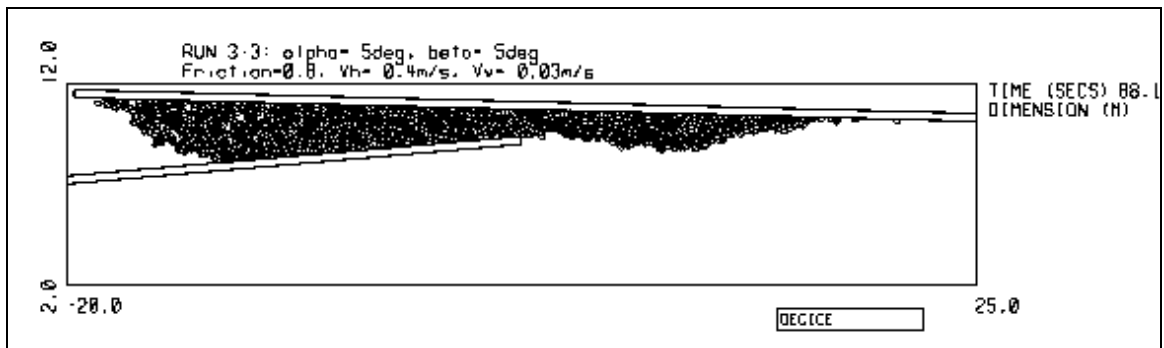


Figure B-110: Snapshot of Run 3-3 at t= 88.2 s

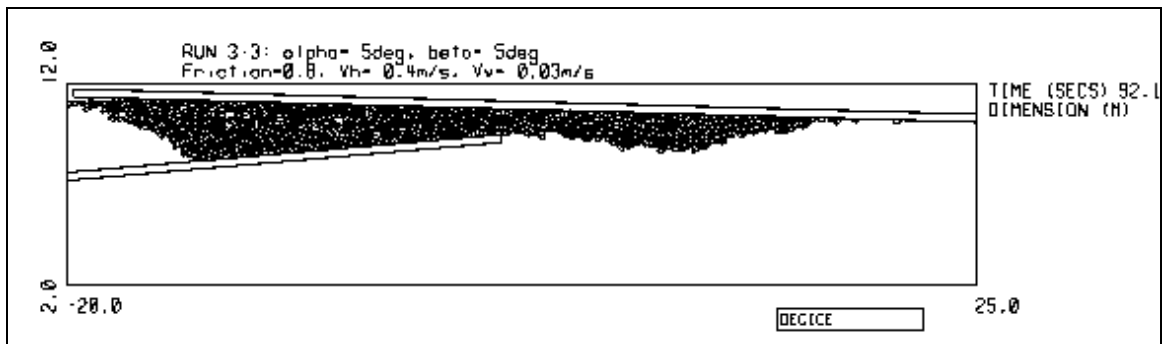


Figure B-111: Snapshot of Run 3-3 at t= 92.2 s

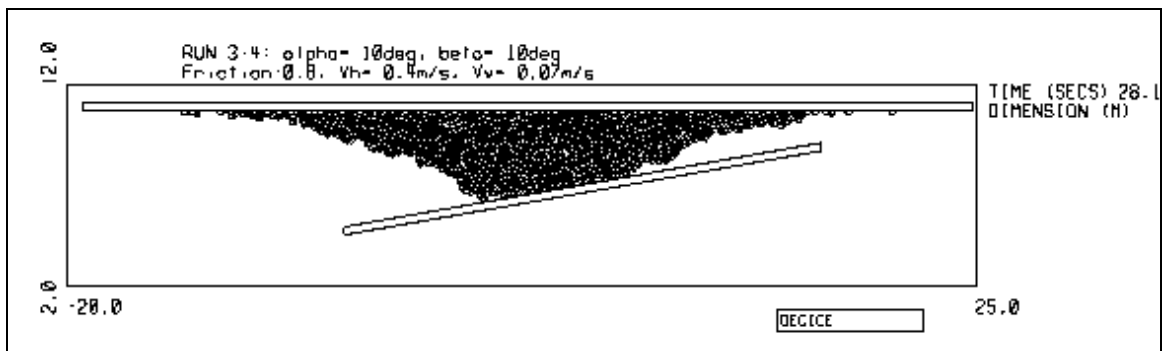


Figure B-112: Snapshot of Run 3-4 at t= 28.2 s

DECICE SIMULATION OF ICE GOUGING

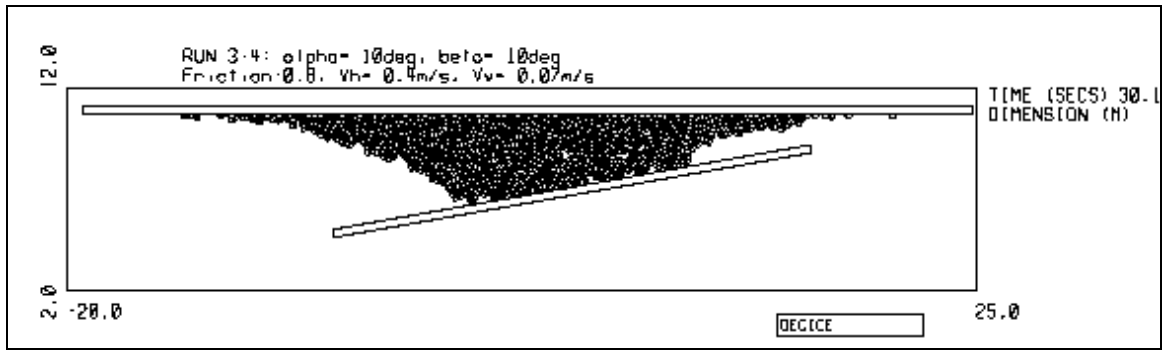


Figure B-113: Snapshot of Run 3-4 at t= 30.2 s

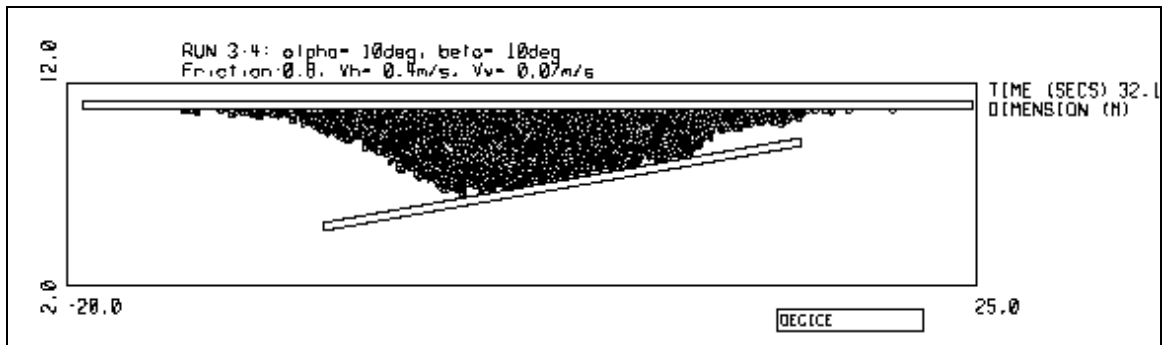


Figure B-114: Snapshot of Run 3-4 at t= 32.2 s

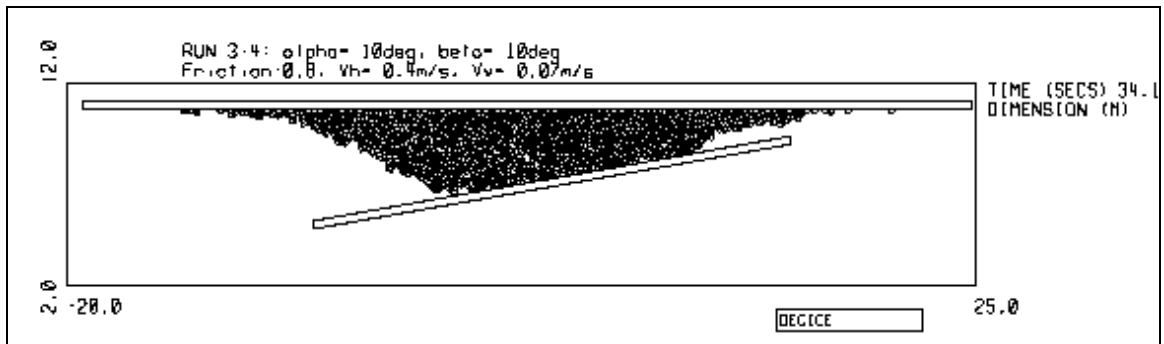


Figure B-115: Snapshot of Run 3-4 at t= 34.2 s

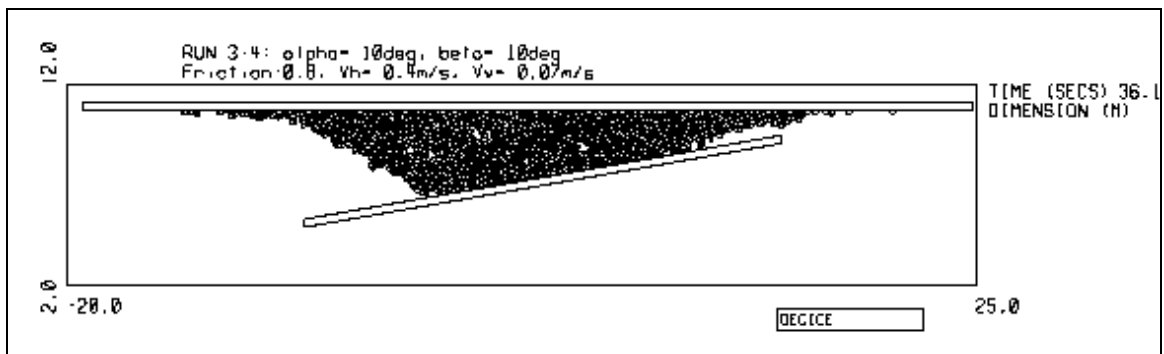


Figure B-116: Snapshot of Run 3-4 at t= 36.2 s

DECICE SIMULATION OF ICE GOUGING

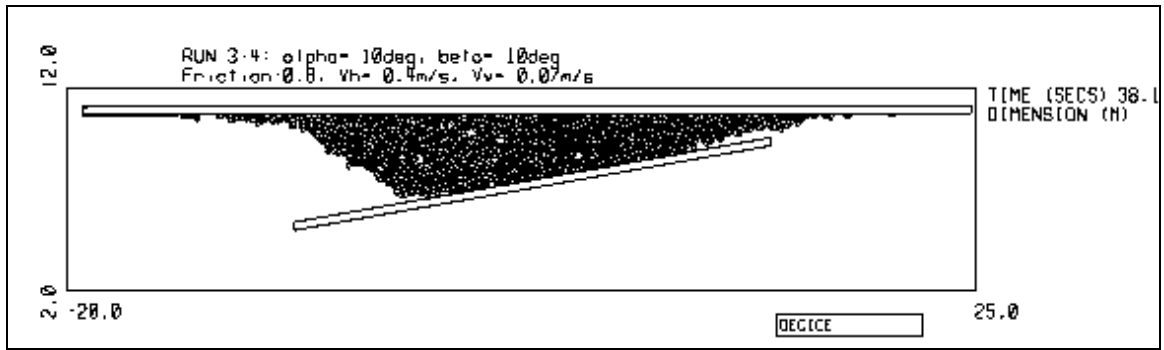


Figure B-117: Snapshot of Run 3-4 at t= 38.2 s

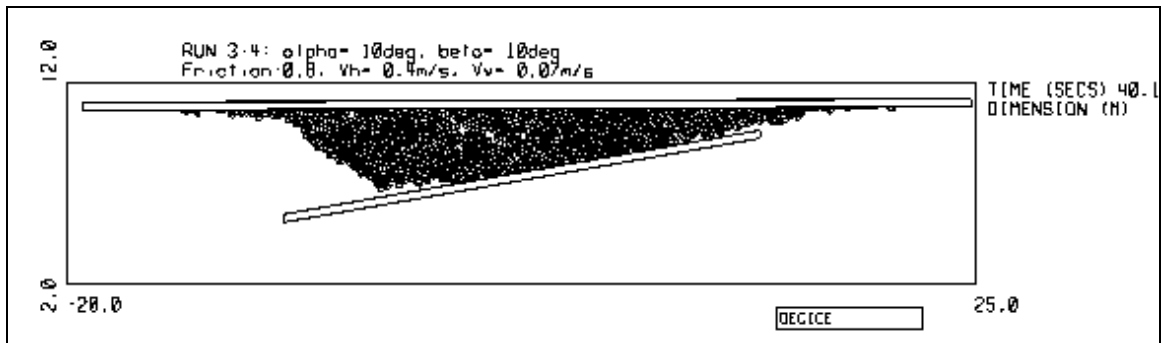


Figure B-118: Snapshot of Run 3-4 at t= 40.2 s

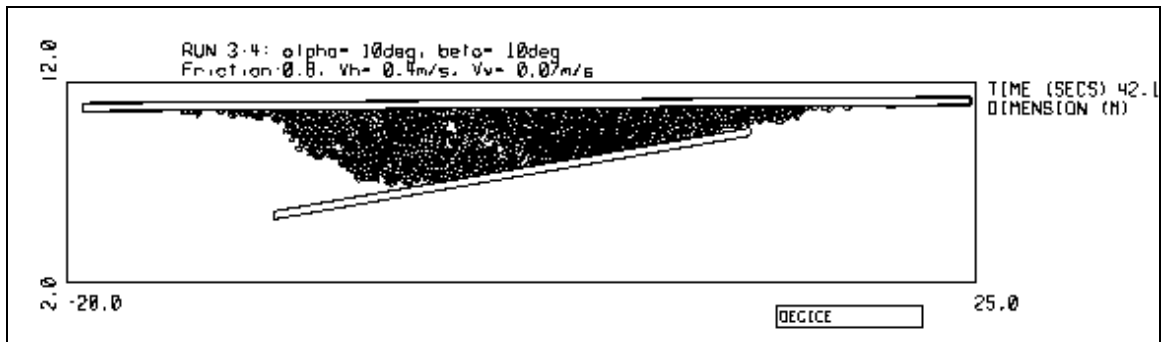


Figure B-119: Snapshot of Run 3-4 at t= 42.2 s

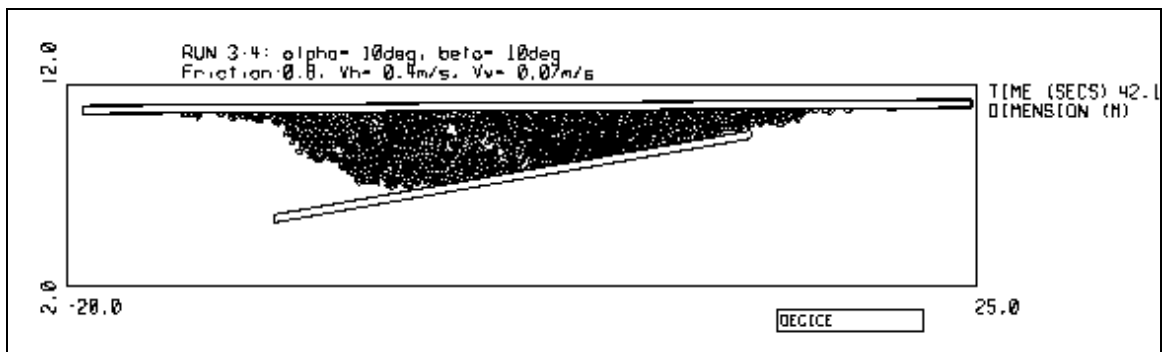


Figure B-120: Snapshot of Run 3-4 at t= 44.2 s

DECICE SIMULATION OF ICE GOUGING

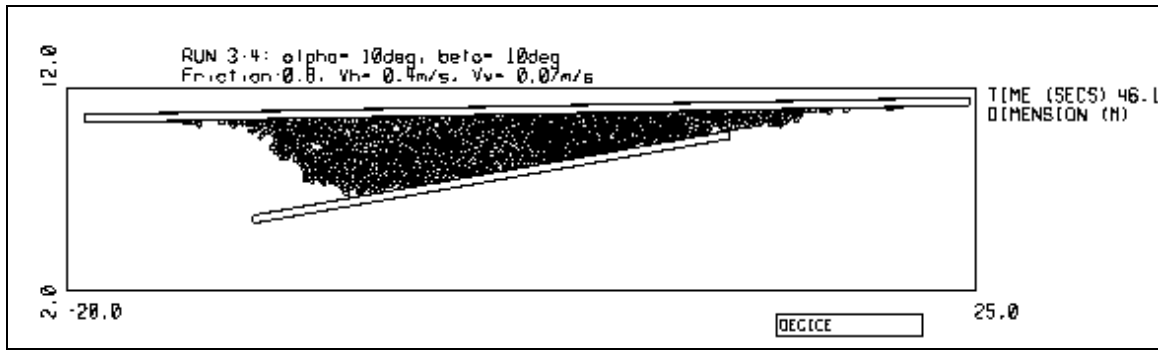


Figure B-121: Snapshot of Run 3-4 at t= 46.2 s

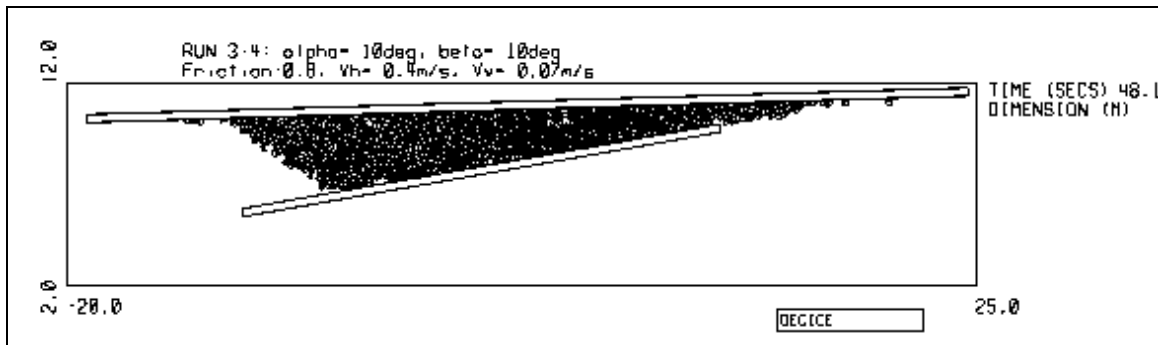


Figure B-122: Snapshot of Run 3-4 at t= 48.2 s

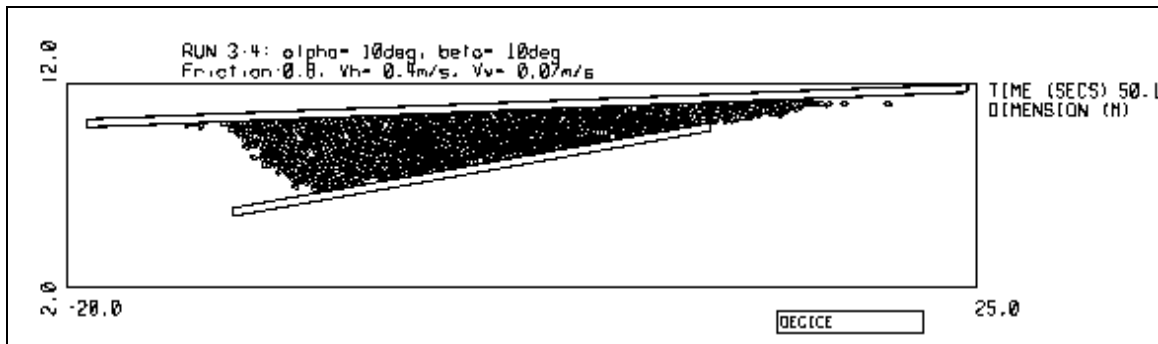


Figure B-123: Snapshot of Run 3-4 at t= 50.2 s

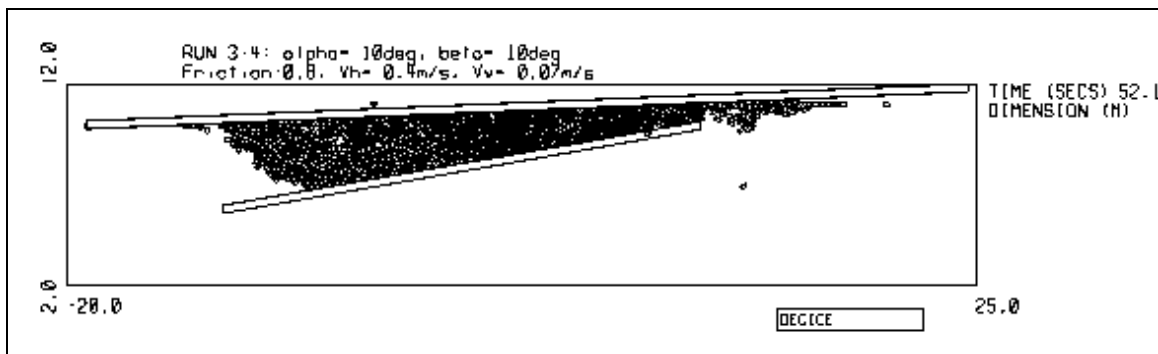


Figure B-124: Snapshot of Run 3-4 at t= 52.2 s

DECICE SIMULATION OF ICE GOUGING

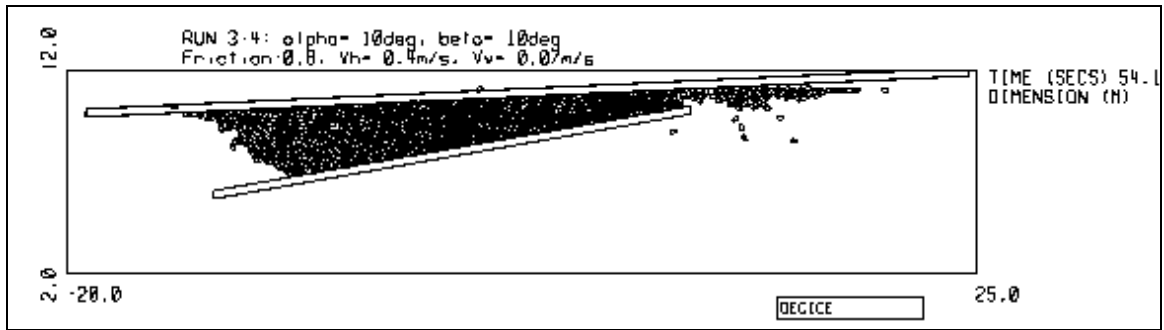


Figure B-125: Snapshot of Run 3-4 at t= 54.2 s

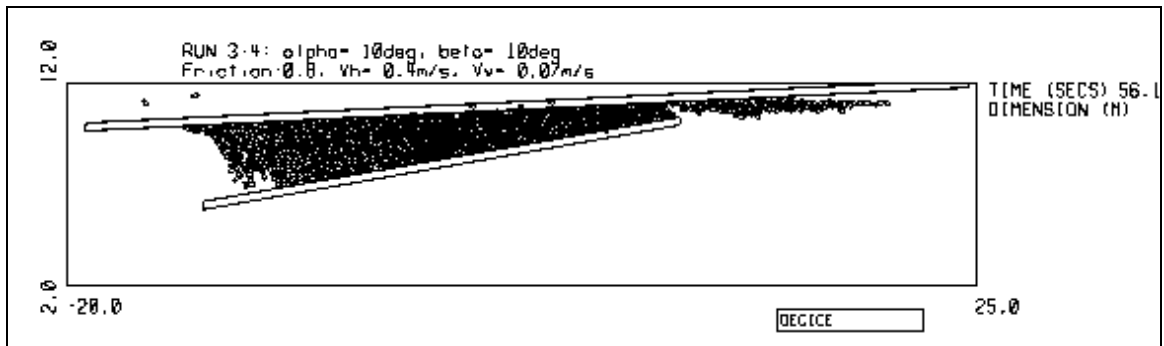


Figure B-126: Snapshot of Run 3-4 at t= 56.2 s

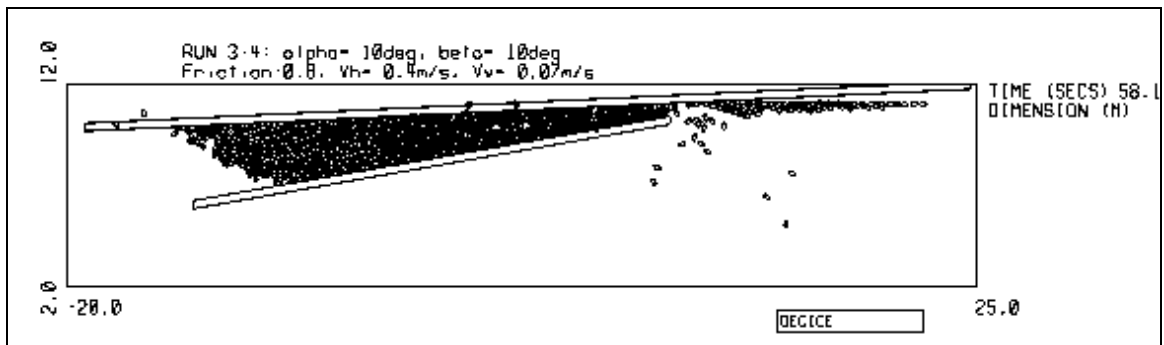


Figure B-127: Snapshot of Run 3-4 at t= 58.2 s

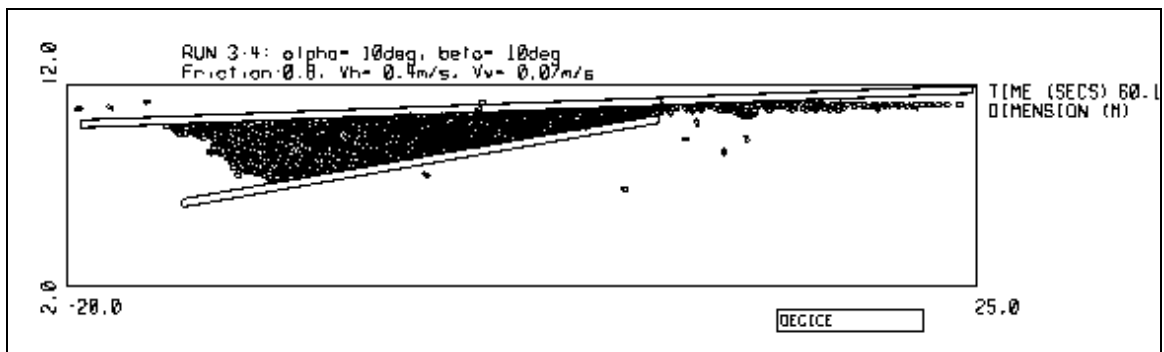


Figure B-128: Snapshot of Run 3-4 at t= 60.2 s

DECICE SIMULATION OF ICE GOUGING

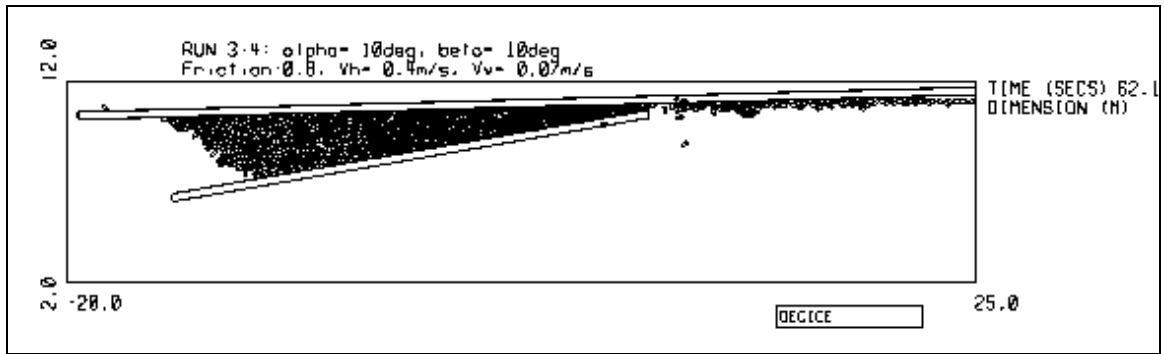


Figure B-129: Snapshot of Run 3-4 at t= 62.2 s

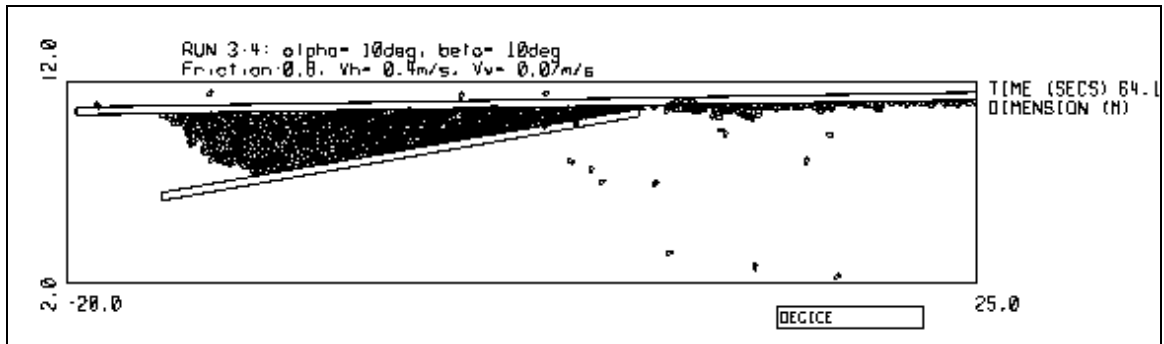


Figure B-130: Snapshot of Run 3-4 at t= 64.2 s

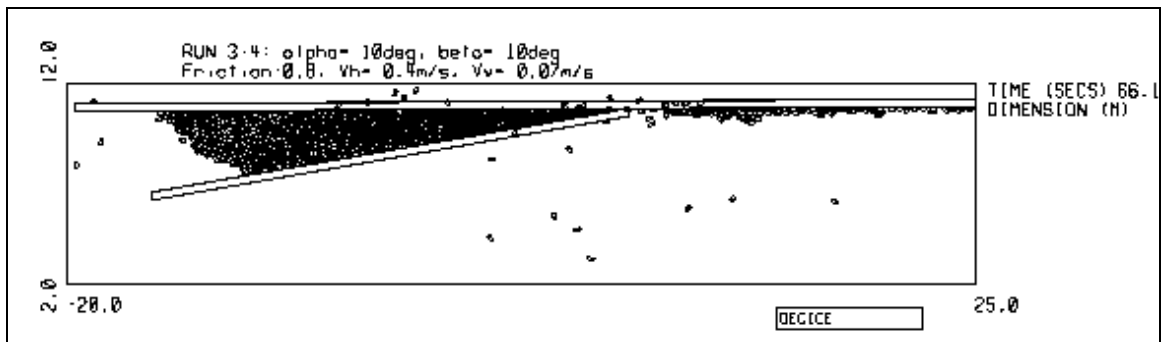


Figure B-131: Snapshot of Run 3-4 at t= 66.2 s

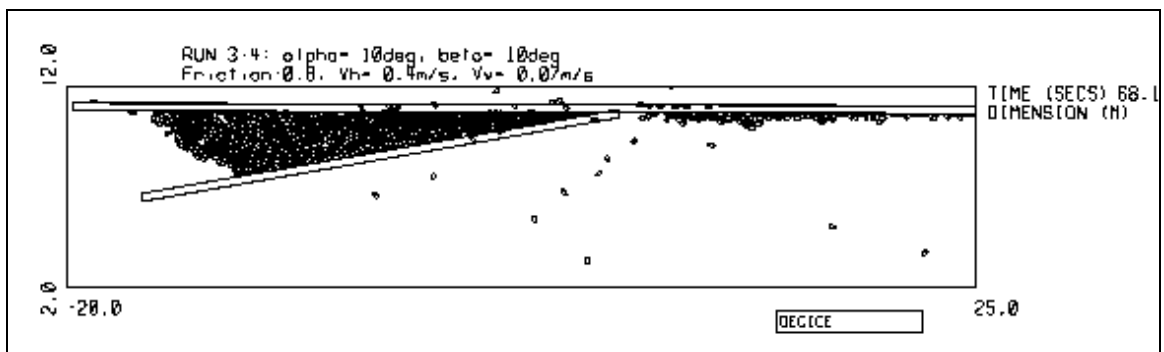


Figure B-132: Snapshot of Run 3-4 at t= 68.2 s

DECICE SIMULATION OF ICE GOUGING

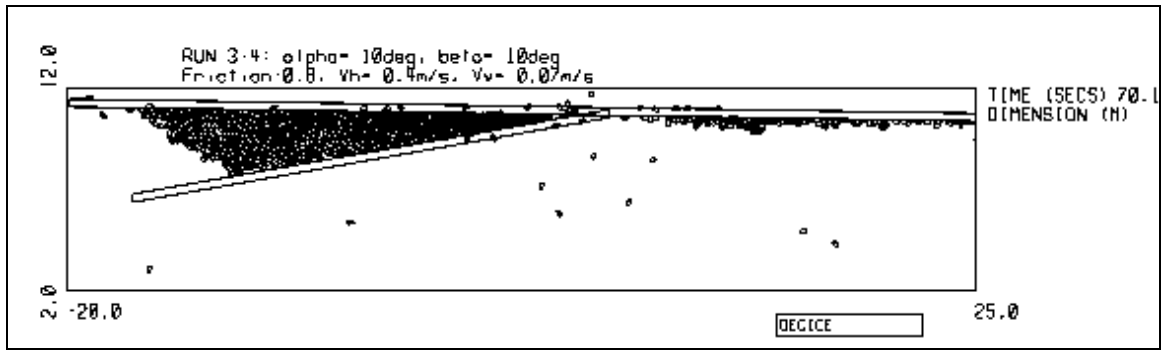


Figure B-133: Snapshot of Run 3-4 at t= 70.2 s

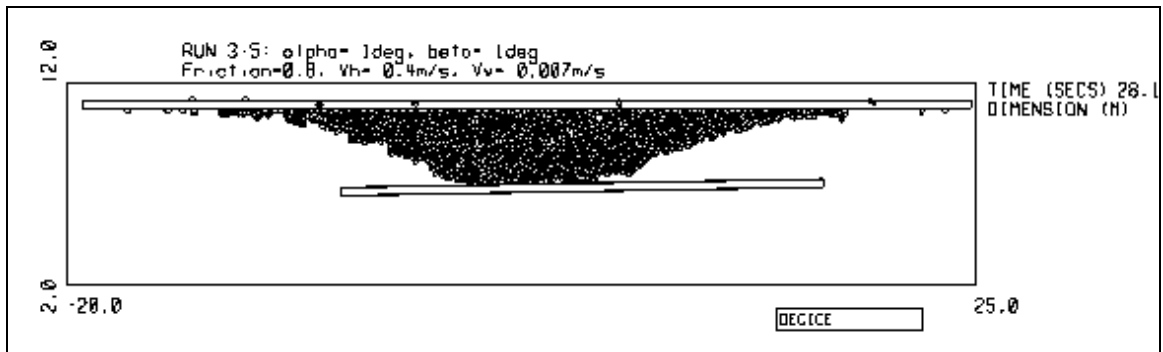


Figure B-134: Snapshot of Run 3-5 at t= 28.2 s

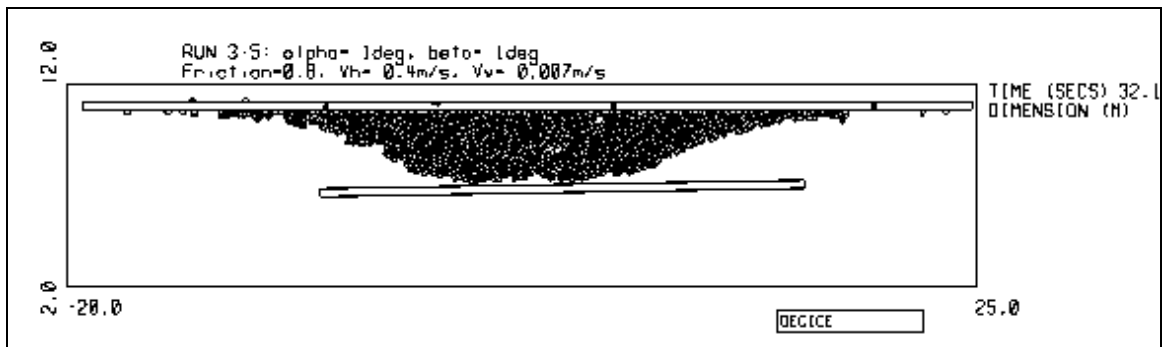


Figure B-135: Snapshot of Run 3-5 at t= 32.2 s

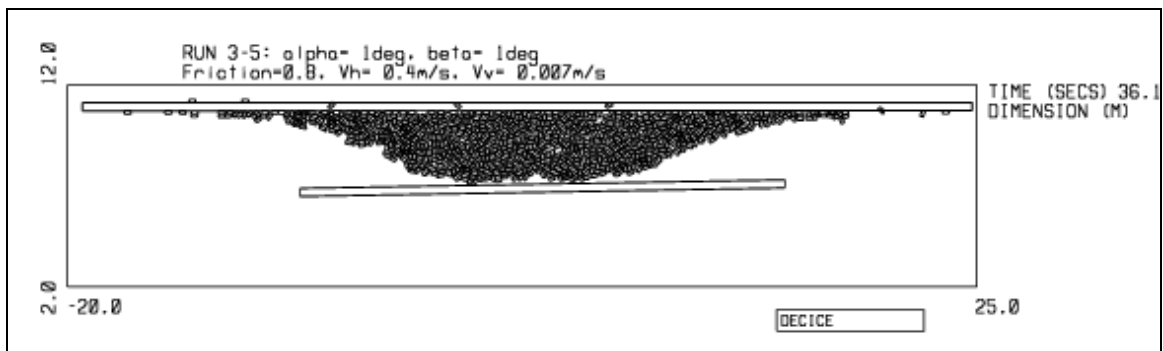


Figure B-136: Snapshot of Run 3-5 at t= 36.2 s

DECICE SIMULATION OF ICE GOUGING

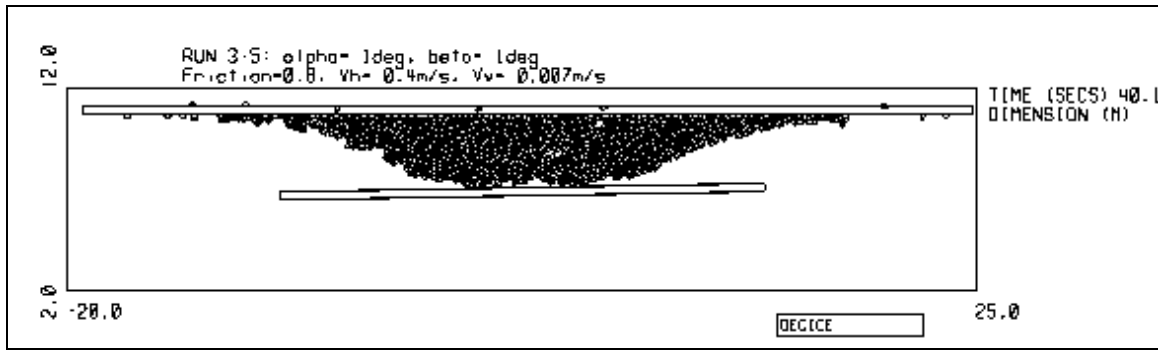


Figure B-137: Snapshot of Run 3-5 at t= 40.2 s

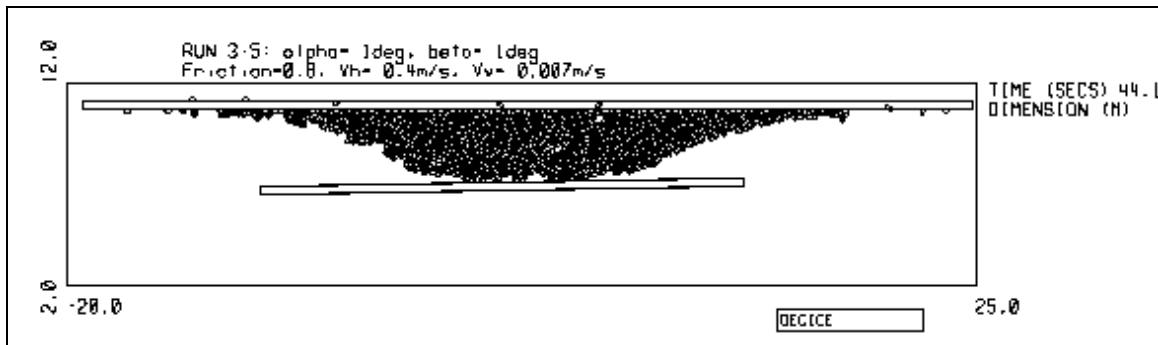


Figure B-138: Snapshot of Run 3-5 at t= 44.2 s

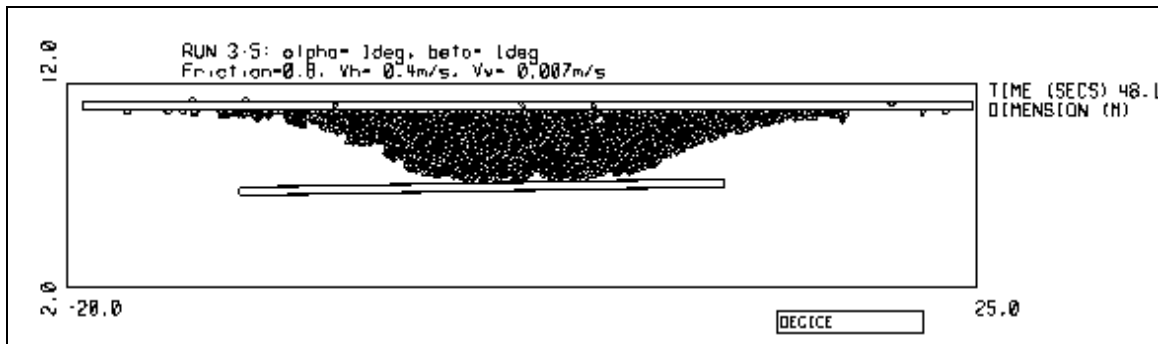


Figure B-139: Snapshot of Run 3-5 at t= 48.2 s

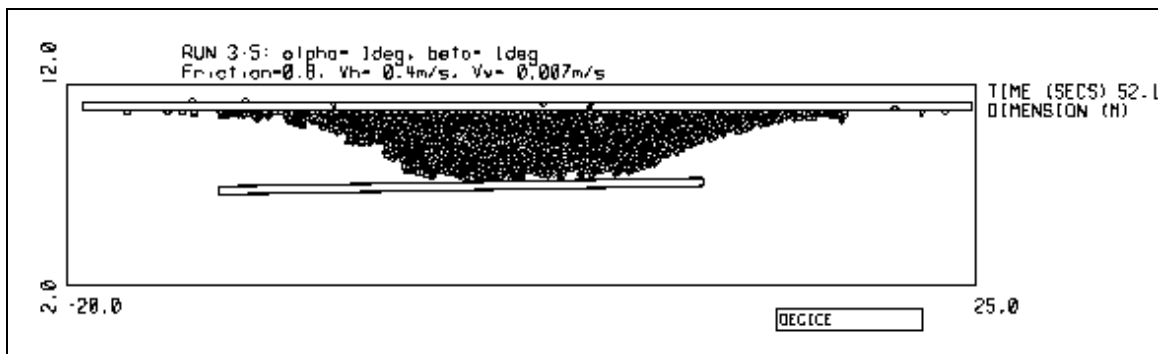


Figure B-140: Snapshot of Run 3-5 at t= 52.2 s

DECICE SIMULATION OF ICE GOUGING

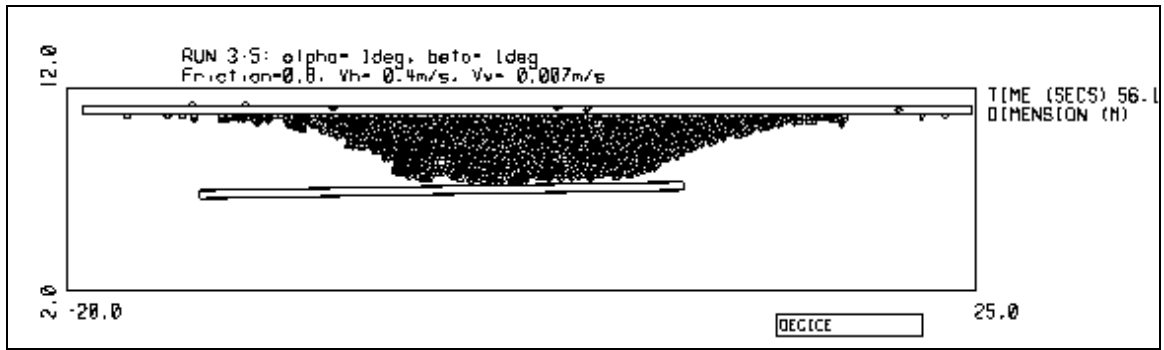


Figure B-141: Snapshot of Run 3-5 at t= 56.2 s

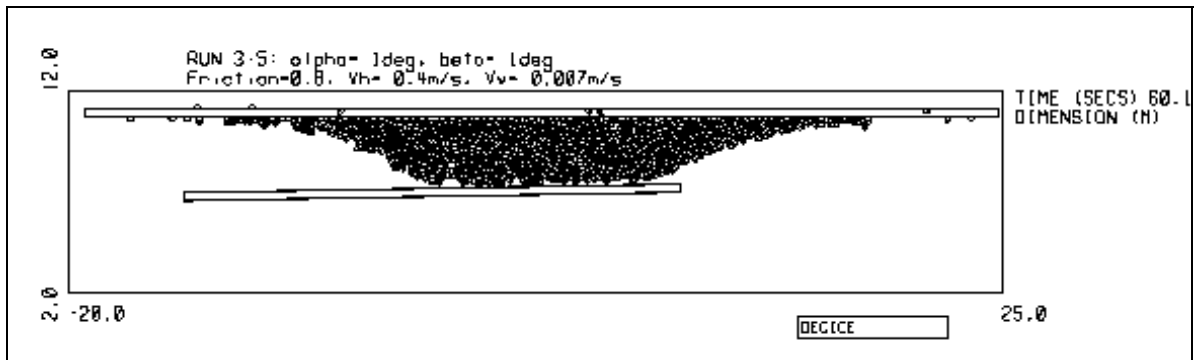


Figure B-142: Snapshot of Run 3-5 at t= 60.2 s

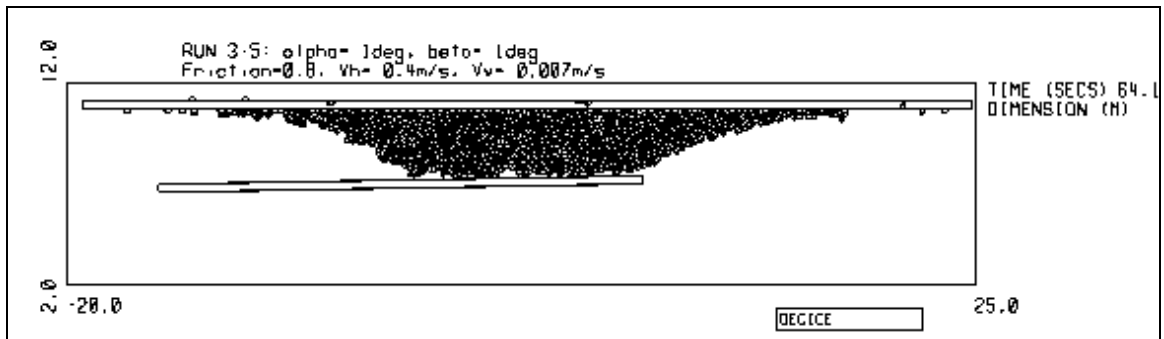


Figure B-143: Snapshot of Run 3-5 at t= 64.2 s

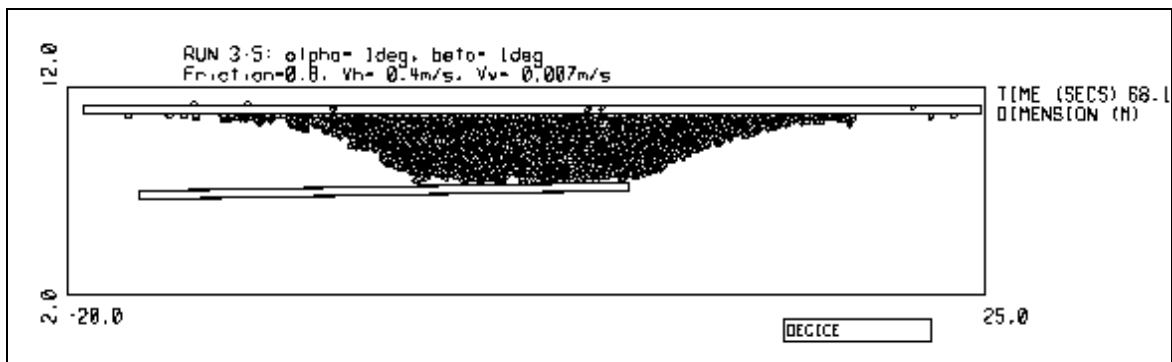


Figure B-144: Snapshot of Run 3-5 at t= 68.2 s

DECICE SIMULATION OF ICE GOUGING

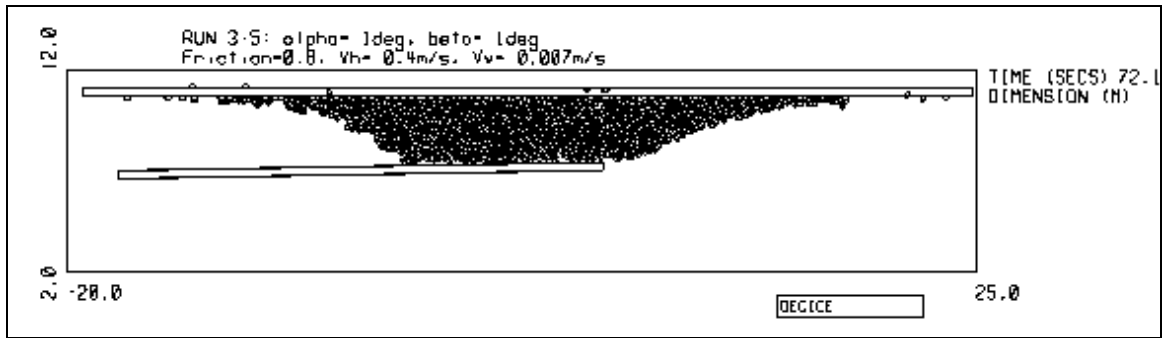


Figure B-145: Snapshot of Run 3-5 at t= 72.2 s

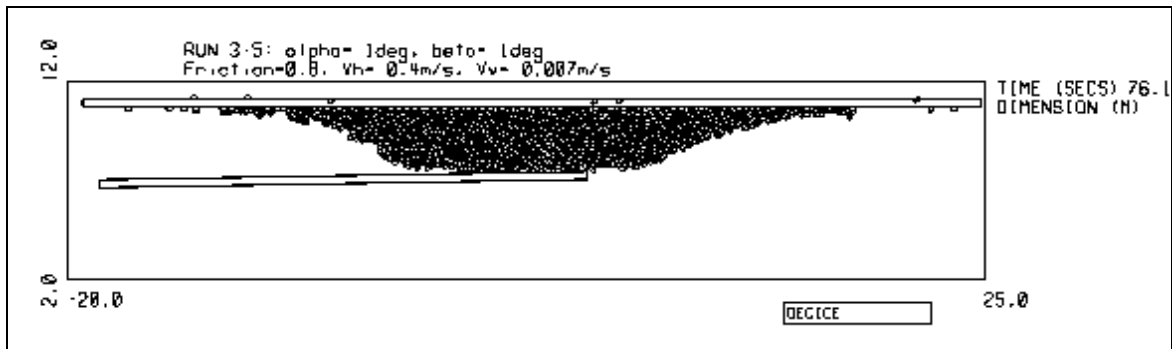


Figure B-146: Snapshot of Run 3-5 at t= 76.2 s

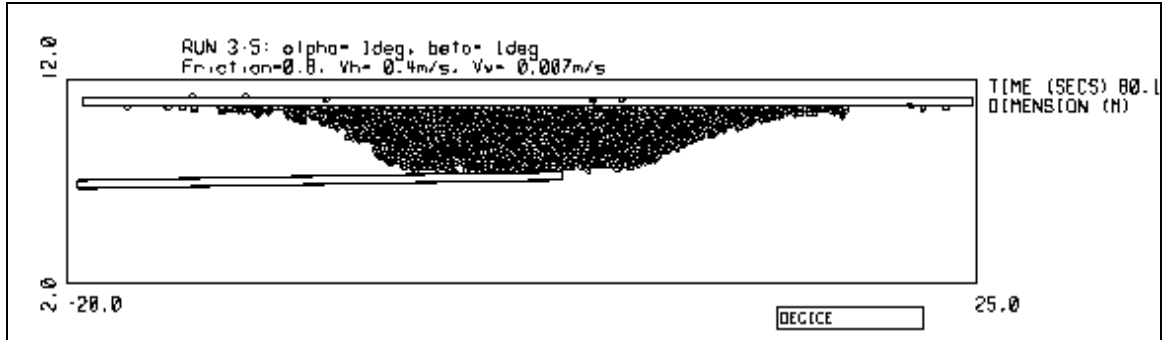


Figure B-147: Snapshot of Run 3-5 at t= 80.2 s

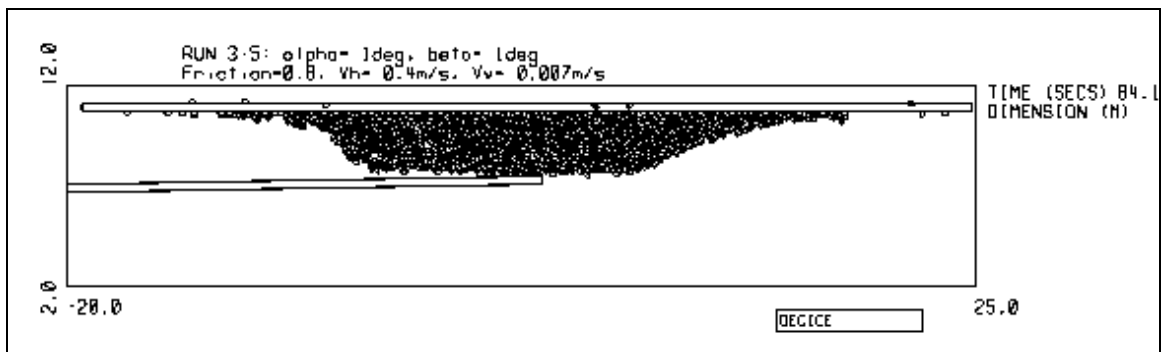


Figure B-148: Snapshot of Run 3-5 at t= 84.2 s

DECICE SIMULATION OF ICE GOUGING

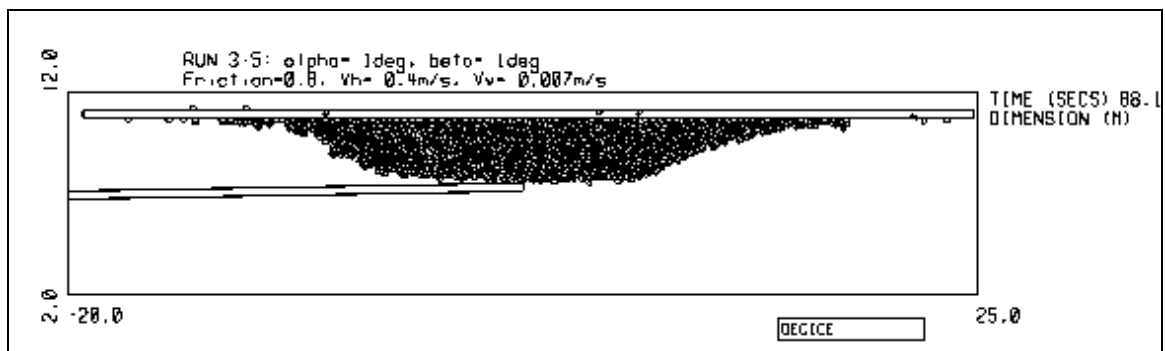


Figure B-149: Snapshot of Run 3-5 at t= 88.2 s