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Validation of Tsunami and Dambreak Hazard Models

- Modelling SIG has adopted idea of using reference tests to establish the validity of modelling techniques
- Reference tests should preferably be based on field or laboratory measurements
- Where field data is sparse and of poor quality (as with tsunamis) need to include analytical models
- These generally apply only in simplified situations, but these can often be matched in numerical models
- Where field and/or laboratory data available, what about experimental errors?
- Experiments need *authentication* to identify possible measurement errors
- Authentication can be established by eliminating obvious outliers, and by checks for mass conservation (e.g. masses under flow curves should balance)
- A quick way of authentication is to fit a good numerical model: if there is agreement, then authentication and validation both happen together
- If there is no agreement, then back to square 1!
- Illustrate by two examples: An analytical tsunami validation and a laboratory dambreak validation
- Propose for adoption by national standards authority for compliance testing

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Tsunami Model Validation

- Solitary wave analysis is known to describe the propagation of gravity waves (such as tsunamis) without a change of shape.
- Can therefore run a model wave over some distance and check for change in shape
- Can also check that wave speed is modelled correctly
- This applies only in water of constant depth and negligible friction
- These conditions are easy to arrange numerically by ensuring the constant wave depth is much larger than the wave height
- The downstream boundary needs to be far enough away that no reflected waves interfere with the test.
- Then only need a boundary condition describing the solitary wave
- A 6m wave was chosen as this will reach about 10m against a fully reflecting (steep) coastline
- This is a typical height for design investigations
- 1000m depth chosen as this gives a wave speed of approximately 100m/s

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Solitary Wave

$$\eta = H\left[\operatorname{sech}\sqrt{\frac{3H}{4h^3}}\,(x - Ct)\right]^2$$

See Ippen "Estuary and Coastline Hydrodynamics" p.122

η = wave height

H = peak height at $x=Ct$

h = normal water depth

C = wave speed ≈ $[g(H+h)]^{1/2}$

Table at right shows $\eta(t)$ for $x=0$, $H=6$m, $h=1000$m

Note: Wave tapered off from 0.133m at 60s to 0.0m at 0s to avoid an infinite wave length at infinitesimal heights.

Time (s)	Height (m)	Time (s)	Height (m)	Time (s)	Height (m)
0	0.000				
5	0.011	155	0.458	305	2.663
10	0.022	160	0.488	310	2.797
15	0.033	165	0.520	315	2.934
20	0.044	170	0.554	320	3.075
25	0.055	175	0.590	325	3.219
30	0.067	180	0.629	330	3.366
35	0.078	185	0.669	335	3.516
40	0.089	190	0.712	340	3.667
45	0.100	195	0.758	345	3.819
50	0.111	200	0.807	350	3.973
55	0.122	205	0.858	355	4.126
60	0.133	210	0.912	360	4.279
65	0.142	215	0.970	365	4.430
70	0.152	220	1.030	370	4.580
75	0.162	225	1.094	375	4.726
80	0.173	230	1.162	380	4.869
85	0.185	235	1.233	385	5.007
90	0.197	240	1.308	390	5.139
95	0.211	245	1.387	395	5.265
100	0.225	250	1.469	400	5.384
105	0.240	255	1.556	405	5.494
110	0.256	260	1.647	410	5.595
115	0.273	265	1.743	415	5.687
120	0.292	270	1.843	420	5.768
125	0.311	275	1.947	425	5.837
130	0.332	280	2.055	430	5.895
135	0.354	285	2.168	435	5.941
140	0.378	290	2.285	440	5.974
145	0.403	295	2.407	445	5.993
150	0.429	300	2.533	450	6.000

And symmetrical from 5.993m at 455s back to 0.000m at 900s

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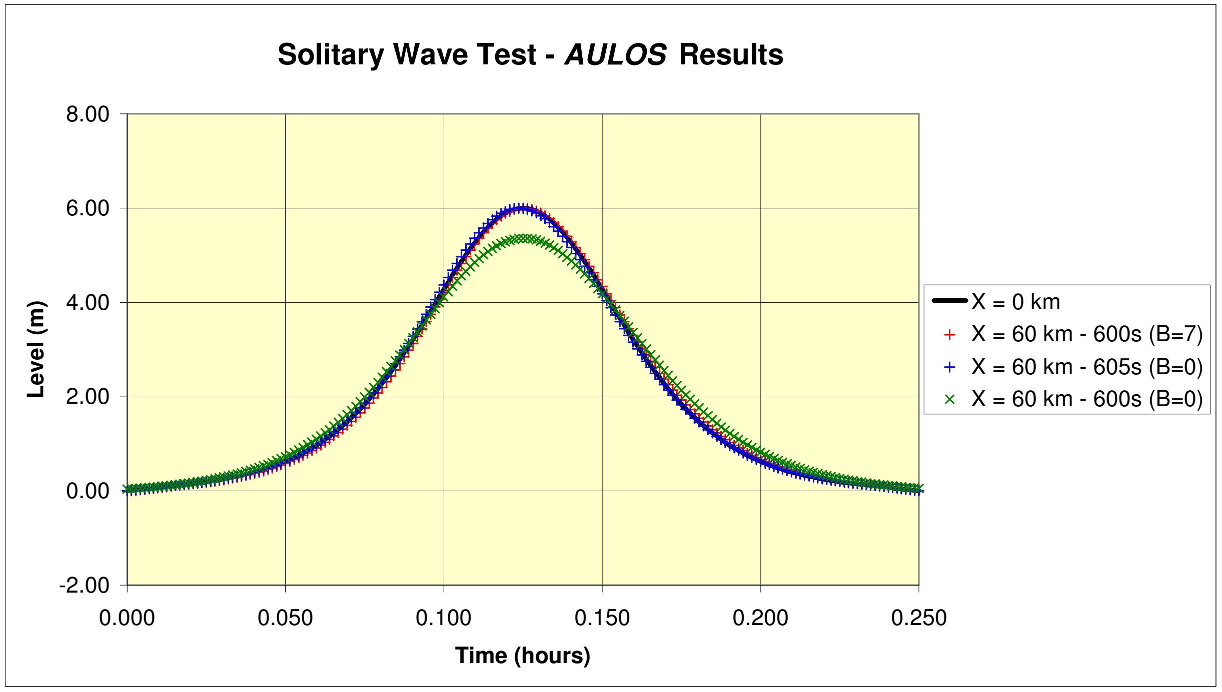
Example: AULOS Results

- For Accuracy Bias B = 7 (highest setting) the wave propagates over 60km without change in shape in a time between 600s (depth=1019m) and 605s (depth=1003m)
- For Accuracy Bias B = 0 (default setting) the wave propagates at the same speed but with some numerical diffusion. This reduces the wave height.



- Development of other standard tests for validation of modelling waves on sloping beaches now proposed for NZWERF research funding

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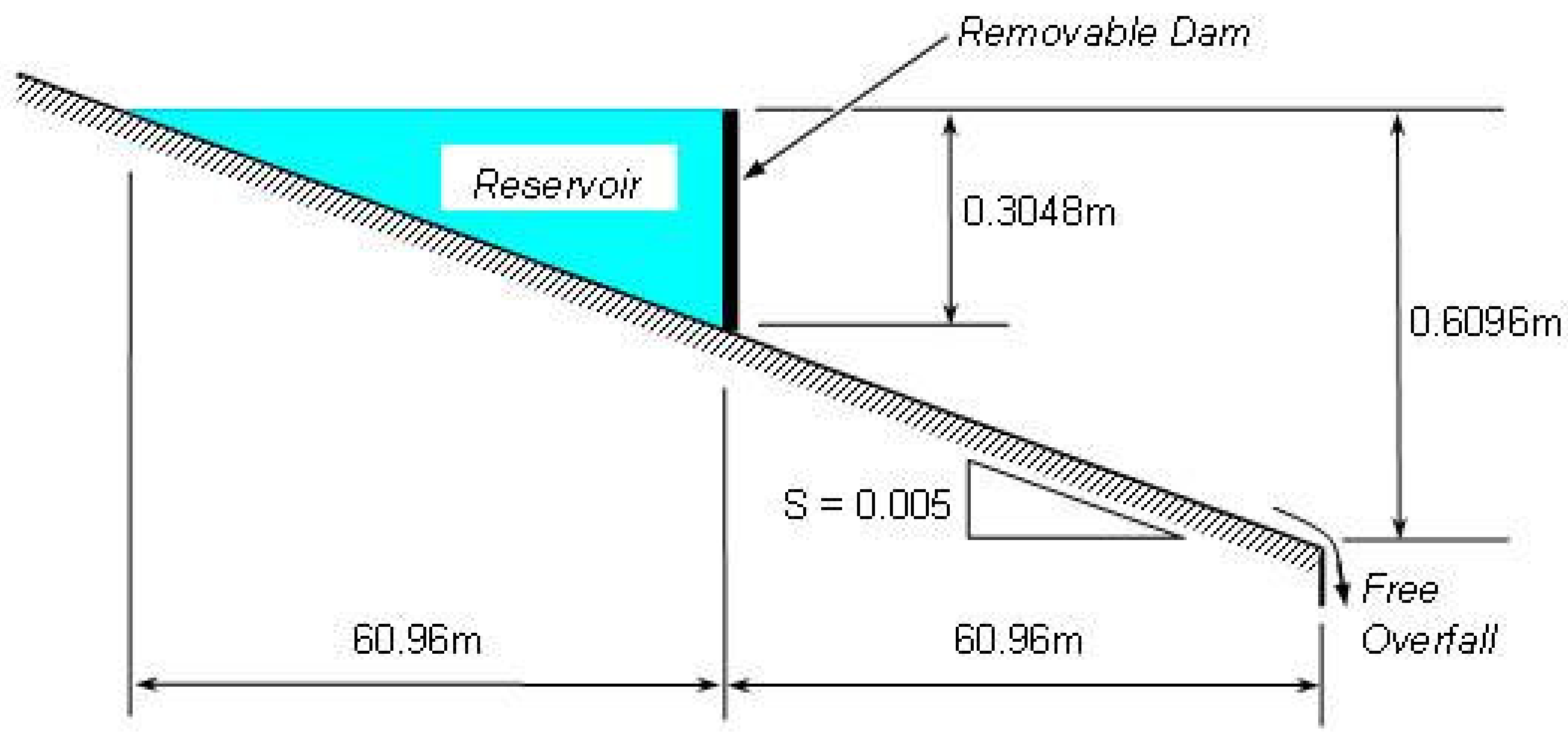
Dambreak Model Validation: Experimental Layout



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WES Test Flume (1960)

- US Army Engineer WES (Waterways Experimental Station), Vicksburg, Mississippi
- Rectangular Flume 400ft (122m) long, 4ft (1.22m) wide
- Slope = 0.005
- Manning n = 0.009
- Dam removal took 0.01-0.03s
- Surface velocities measured by time lapse photography of floating confetti
- Depths measured by timed photographs

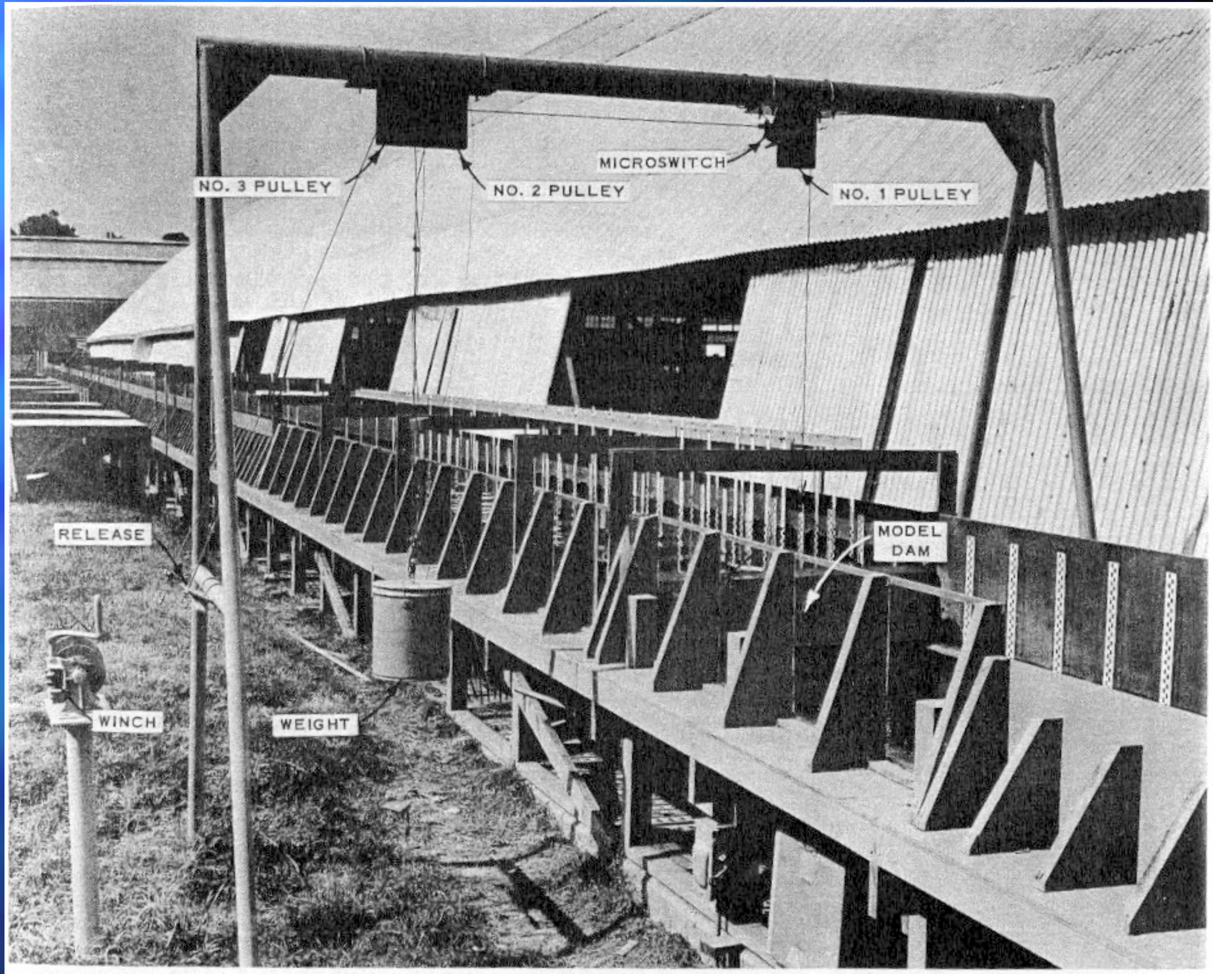

Fig. 6. Dam-ejection mechanism

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Selection of Test Data

- WES tested various combinations of dam breach openings and initial downstream base flows
- Test 5.1 was chosen by Sanders (2001) for validation testing of his solution. This involved a full depth (0.3048m) rectangular breach of width 0.4 ft (0.122m).

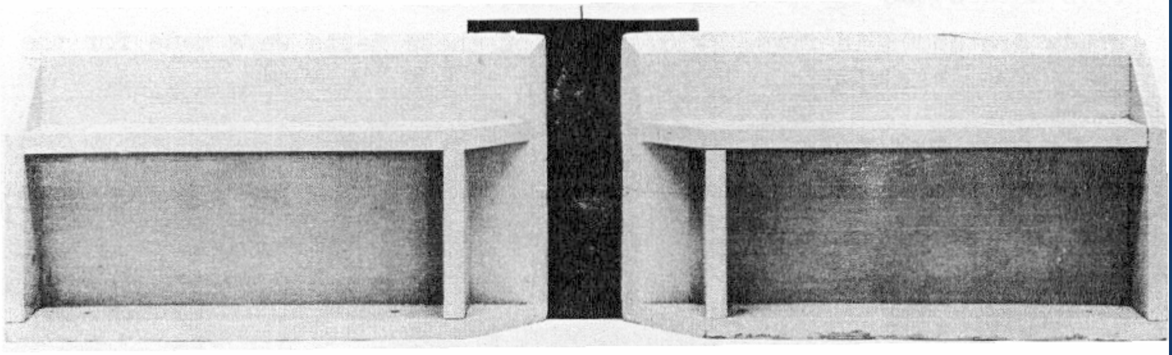

Fig. 8. Model dam for test condition 6.1

- The WES report does not picture the model dam for Test 5.1, but it was presumably similar to that for Test 6.1 (above), which differed only in having a narrower breach of width 0.24 ft (0.073m).
- This shows the slot sides were defined by sharp edges, not rounded

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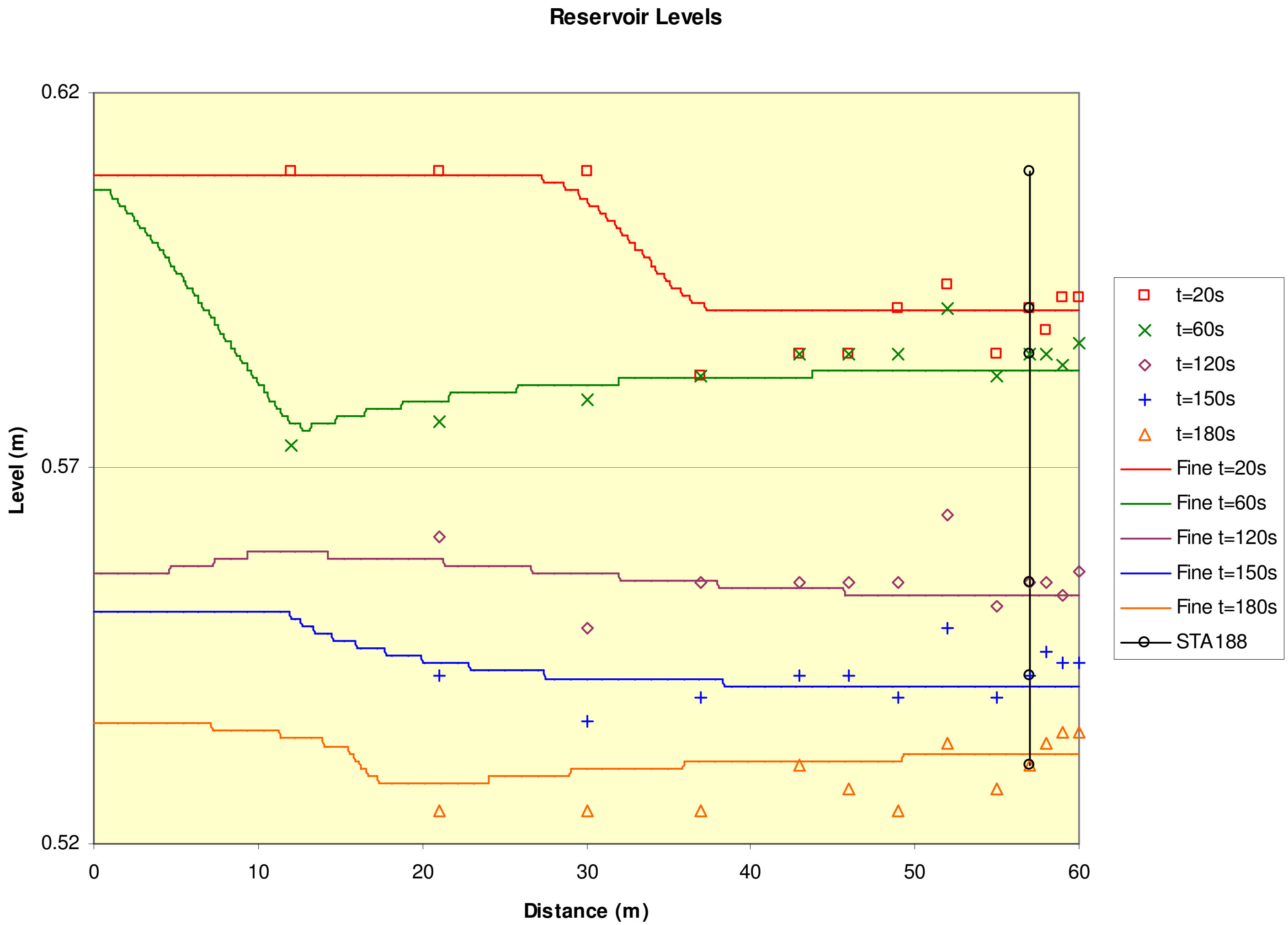
Upstream Reservoir Levels



Levels at STA188 (57.3m from upstream end)

Time(s)	Level(m)
0	0.6096
2	0.6066
3	0.5944
4	0.5971
5	0.5944
7	0.5913
10	0.5913
20	0.5913
30	0.5913
60	0.5852
120	0.5547
150	0.5425
180	0.5304

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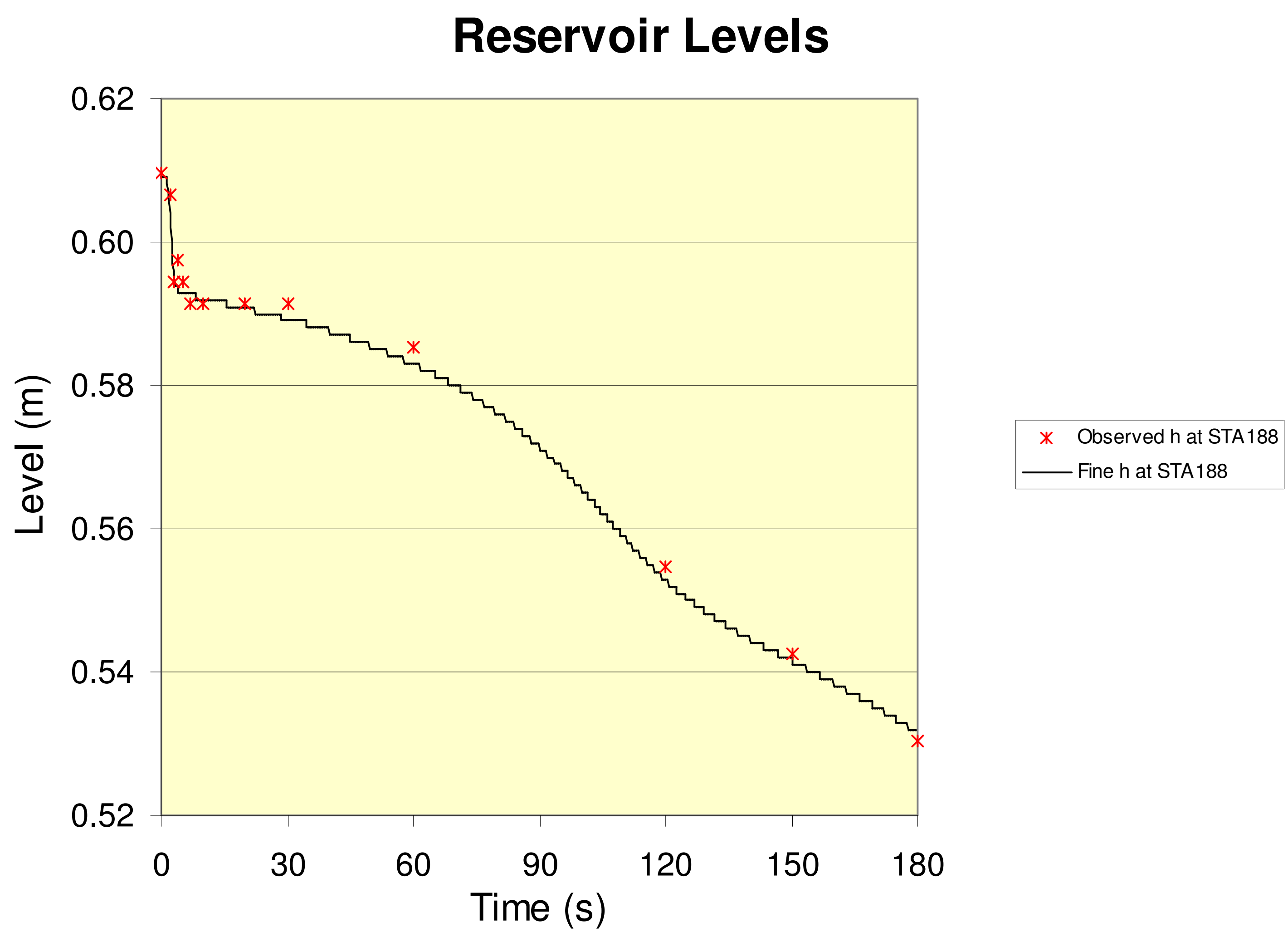
Example: AULOS Results at STA188

Plotted STA188 results as per previous table.

This suggests that outflows are accurately matched.

The model used the energy equation at the breach, with a textbook discharge coefficient C_B=0.9 for sharp edges (Henderson, 1966)



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Downstream Observations

These were made at three points:
STA225, STA280, STA350
respectively 225, 280 and 350 ft
(68.6m, 85.3m and 106.7m) from
upstream end of flume.

Flow values calculated from
mean velocity x depth,
but only surface velocities available

Mean velocity V assumed = kV_s
Where V_s is surface velocity

k was assumed to be 0.80 by WES,
but this is too low except at STA225.
Analytically, k=0.88 a better estimate for
smooth channels.

Time sec	Observed depth at STA225 m	Observed depth at STA280 m	Observed depth at STA350 m	Observed flow at STA225 litre/s	Observed Q (k=0.88) at STA280 litre/s	Observed Q (k=0.88) at STA350 litre/s
0	0	0	0	0	0	0
5	0					
7	0.0183			9.51		
9	0.0274					
10	0.0305			26.05		
11	0.0305					
13	0.0335					
15	0.0335			32.40		
17	0.0335			33.64		
19	0.0335					
20	0.0335			33.64		
21	0.0335	0				
25	0.0335	0.0213		33.64	11.34	
27	0.0335	0.0274			22.43	
30	0.0335	0.0305		33.64	26.17	
35	0.0335	0.0335		33.64	28.78	
40	0.0335	0.0335		33.64	28.78	
45	0.0335	0.0335	0	33.64	28.78	
50	0.0335	0.0335	0.0213	33.64	28.78	12.21
55	0.0335	0.0335	0.0244	33.64	28.78	19.94
60	0.0305	0.0335	0.0305	30.58	28.78	26.17
65		0.0335	0.0305		28.78	26.17
70	0.0305	0.0335	0.0335	30.58	28.78	28.78
75			0.0335			28.78
80	0.0305	0.0305	0.0335	29.45	26.17	28.78
85			0.0335			28.78
90	0.0305	0.0305	0.0335	29.45	26.17	28.78
100	0.0305	0.0305	0.0335	29.45	24.92	28.78
110	0.0274	0.0305	0.0335	25.49	24.92	28.78
120	0.0274	0.0305	0.0335	25.49	24.92	28.78
130	0.0274	0.0305	0.0335	24.47	23.67	28.78
140	0.0274	0.0274	0.0305	23.45	21.31	26.17
150	0.0274	0.0274	0.0305	22.43	21.31	26.17
160	0.0274	0.0274	0.0274	22.43	21.31	22.43
170	0.0274	0.0274	0.0274	22.43	21.31	21.31
180	0.0244	0.0274	0.0274	19.94	20.18	20.18

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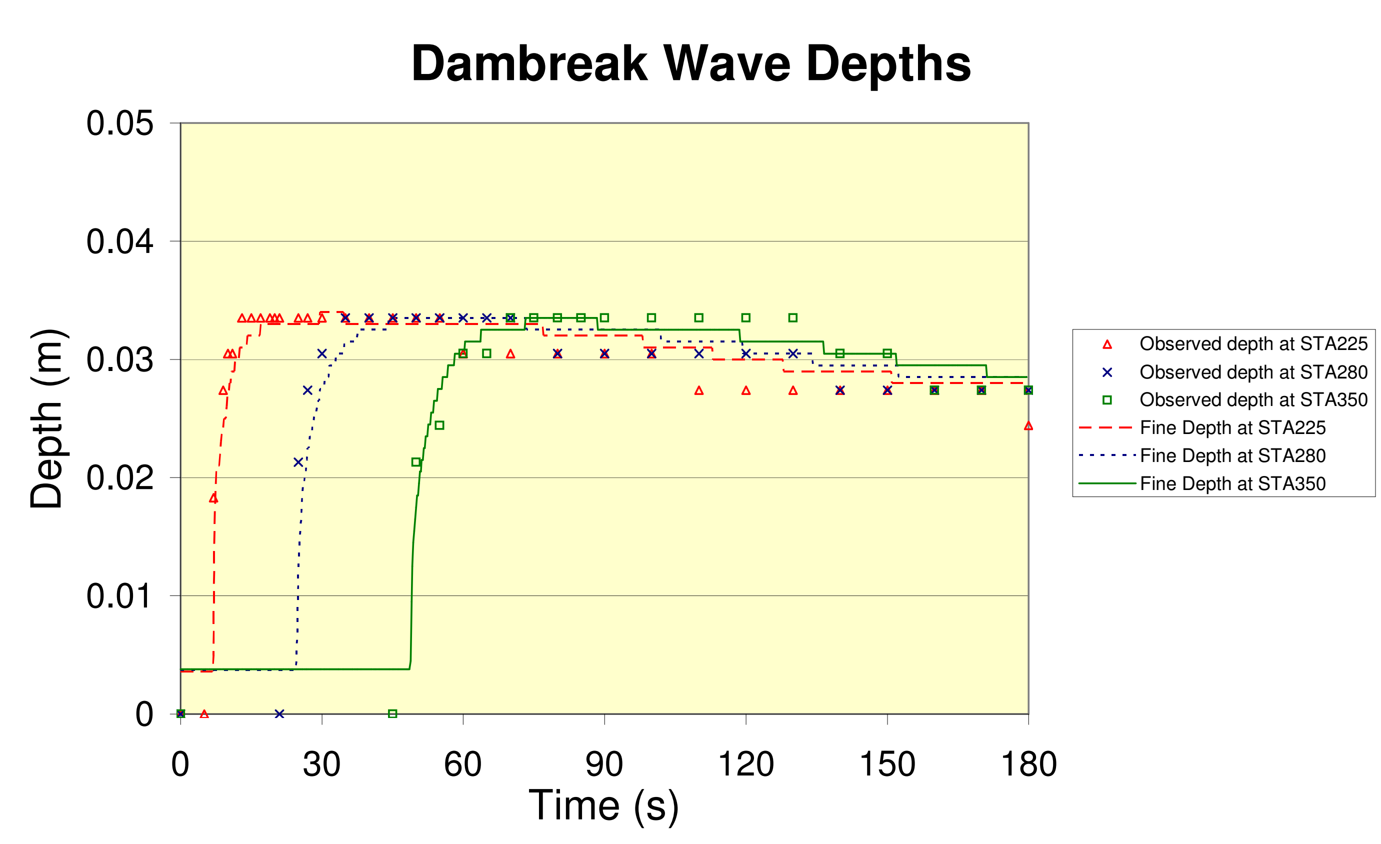
Example: AULOS Depth Results

The depth validation is generally good, with excellent matching of wave front arrival times



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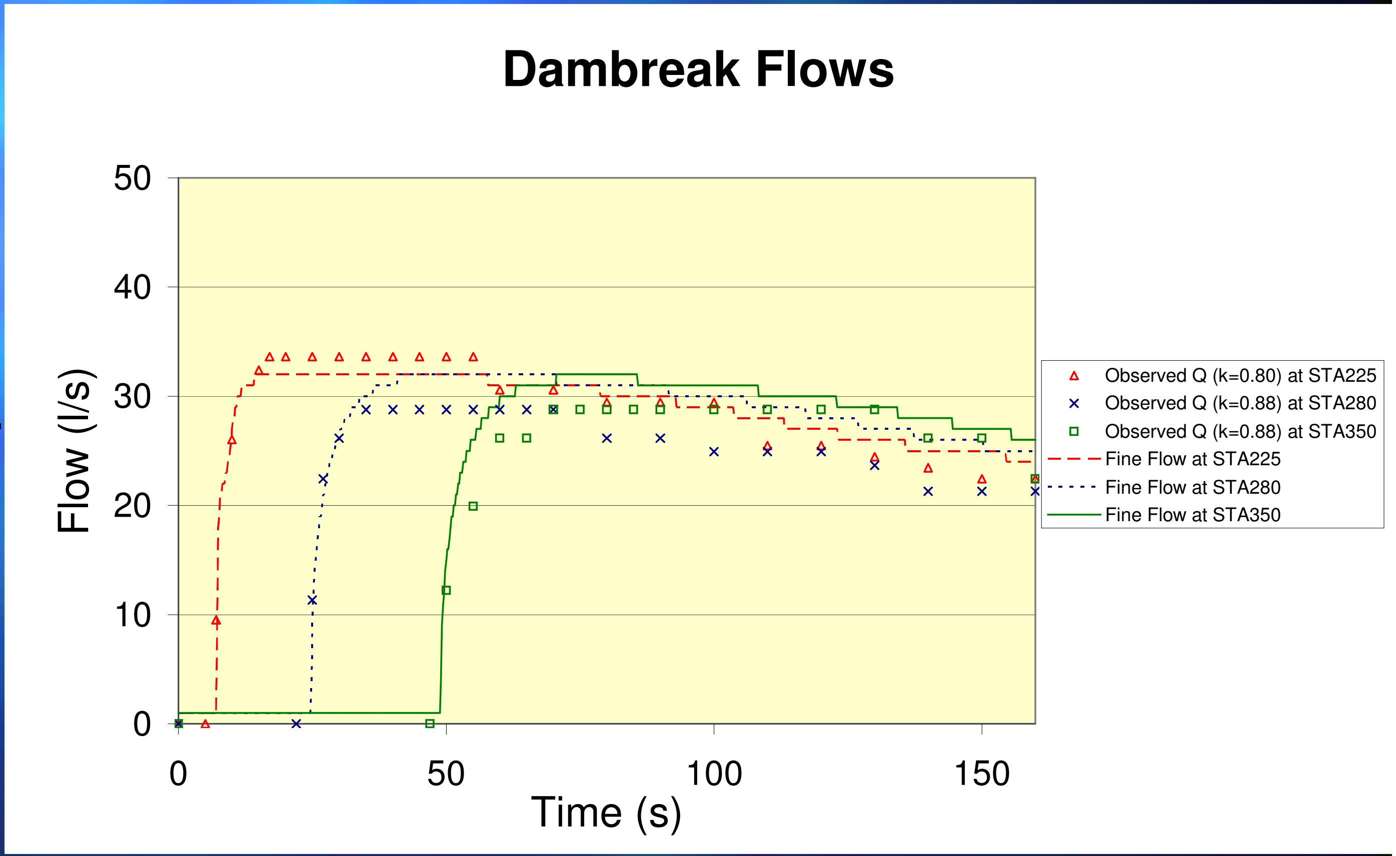
Example: AULOS Flow Results

The validation again gives an excellent match with dambreak wave arrival times, but the flow match is only within about 10% at STA 225 (k too high) and STA280 (k too low).

The close match at STA350 and with reservoir drawdown upstream (STA188) suggests main problem with evaluating k.



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Conclusions

1. Reference tests are an excellent way to establish the validity of modelling techniques
2. They also indicate the effect of using various model tuning parameters
3. Where possible, reference tests should be based on field or laboratory measurements
4. Analytical models can partly fill the gap where field data is sparse or of poor quality (as with tsunamis)
5. For tsunamis, a solitary wave forms a good analytical test for the ability of a model to reproduce wave behaviour in deep water.
6. Further work on runup on sloping beaches will (hopefully) follow soon.
7. For dambreak waves, the 1960 WES laboratory experiments are a useful source of wave behaviour under a range of conditions.
8. Experimental scatter in level measurements can be averaged out
9. The evaluation of mean velocity from the measured surface velocity required appeal to mass conservation plus an analytical shear model
10. The result adjustments have been authenticated partly by successful fitting with a model which conserves mass, momentum and energy
11. All input data required for sample validation of numerical tsunami and dambreak models is documented in this presentation
12. These tests are therefore recommended as suitable for adoption by a national standards authority for compliance testing.