TSUNAMI FREQUENCY AT TOFINO AND PORT ALBERNI

by
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March 1979

Mr. G.E. Simmons,
Assistant Deputy Minister,
Ministry of the Environment,
Parliament Buildings,
Victoria, B.C.

Your file Votre référence

Our file Notre référence 6850-9

Dear Sir,

In recognition of the need for improved forecasting of tsunami frequencies and magnitudes, work was begun two years ago on the development of a data base and procedures for conducting a Historical Study of Tsunamis. In response to requests from your Department, these methods have been applied to a detailed study of Tofino and Port Alberni.

Herewith we are pleased to present the results in the report, Tsunami Frequency at Tofino and Port Alberni. I hope to be available, if required for meetings relating to this report or its implications.

Principal finding of the study is that the destructive tsunami of March 28, 1964 was not a unique event, but that it will probably be equalled or exceeded in a 100-year period. Tsunamis therefore need to be recognized as a significant factor in planning for land use in low lying areas, both at Port Alberni and other vulnerable portions of the British Columbia coast. There is need also to plan for educational programs and emergency preparedness measures in order that losses when a tsunami occurs will be minimal.

We acknowledge with appreciation the help your Department has provided, both in direct consultation, and in making available the services of Mr. Allan M. McCrae, consulting civil engineer, for participation in the analysis and interpretation of results.

Yours truly,

Sydney O. Wigen, P. Eng.,
Tsunami Adviser.

TSUNAMI FREQUENCY AT TOFINO AND PORT ALBERNI

A study of tsunamis registered at the Tofino and Port Alberni tide gauges provided the basis of the report, Tsunami Threat to Port Alberni (Wigen 1977).

This study identified 21 tsunamis on Tofino tide records, associated with major tsunamis in the Pacific. It also showed a correlation, based on 6 of these events, of response to tsunamis at Port Alberni and Tofino. From analysis of the data it was concluded that the destructive tsunami from the 1964 Alaskan earthquake, the largest on record in British Columbia, was an event to be expected to recur or be exceeded at least once in a 200-year design period. However, the investigation had been founded on only a fraction of the possibly tsunamigenic events, and this limited the conclusions that could be drawn regarding the frequencies and magnitudes of tsunamis that could be expected at Tofino and Port Alberni.

Recognizing that a complete study of all possibly tsunamigenic events could provide a strongerdata base for estimating tsunami frequencies, a list of 1500 major earthquakes and known or suspected tsunamis was compiled. This list covered the period 1883 to 1976, and included all oceans. Procedures for a study were set forth in a report, Historical Study of Tsunamis - An Outline (Wigen 1978).

Tide records for Tofino, 1906 to 1976, have now been searched for all events in the list that could have produced a tsunami on the British Columbia coast. Thirty-three tsunamis have been identified, with maximum wave height ranging from a low of 6 cm to a high of 240 cm. These heights have been determined with the tide removed, following the methods used in the previous study. Procedures followed, and accuracy of data, will be described in a future paper, Historical Study of Tsunamis at Tofino.

Following is a tabulation of the tsunamis on which the present analysis is based.

Date & Time of Earthquake U.T.				Position of Epicenter		Richter Magnitude	Max Wave Tofino	Max Wave Alberni
Year	Mo	Day	Hr	Lat	Long			
1915	11	01	0724	38.0N	144.0E	7.8	12	
1917	05	01	1826	29.0S	177.0W	8.6	12	
1917	06	26	0550	15.5S	173.0W	8.7	9	
1918	09	07	1716	45.5N	151.5E	8.3	16	
1918	11	08	0438	44.5N	151.5E	7.9	7	
1919	04	30	0717	19.0S	172.5W	8.4	15	
1921	02	27	1824	18.5S	173.0W	7.2	7	
1922	11	11	0433	28.5S	070.0W	8.4	27	
1923	02	03	1602	54.0N	161.0E	8.4	27	
1923	04	13	1531	56.5N	162.5E	7.2	15	
1923	09	01	0259	35.3N	139.5E	8.3	8	
1923	09	02	0247	35.0N	139.5E	7.7	9	
1929	03	07	0135	51.0N	170.0W	8.6	11	
1931	10	03	1913	10.5S	161.8E	8.1	6	
1933	03	02	1731	39.3N	144.5E	8.9	23	
1934	11	30	0205	18.5N	105.5W	7.0	22	
1938	11	10	2019	55.5N	158.0W	8.7	27	
1944	12	07	0436	33.8N	136.0E	8.3	12	
1944	12	27	1526	06.5S	152.0E	7.0	12	
1946	04	01	1229	52.8N	163.5W	7.4	58	
1951	10	22	0543	24.0N	121.3E	7.1	7	
1952	03	04	0123	42.5N	143.0E	8.6	12	
1952	11	04	1658	52.8N	159.5E	8.4	58	
1957	03	09	1422	51.3N	175.8W	8.2	52	
1957	03	11	1455	51.5N	178.5W	7.2	18	
1958	11	06	2258	44.5N	148.5E	8.7	10	
1960	05	22	1911	39.5S	074.5W	8.3	126	200 est
1963	10	13	0518	44.8N	149.5E	8.2	16	27
1964	03	28	0336	61.1N	147.6W	8.5	240	800 est
1968	05	16	0049	40.8N	143.2E	6.1	13	24
1971	07	26	0123	04.9S	153.2E	6.6	7	?
1973	06	17	0355	43.2N	145.8E	6.5	6	16
1975	11	29	1448	19.4N	155.1W	7.2	9	10

The 33 events are plotted on Figure 1, sequentially in order of maximum wave height, using logarithmic scales for both the number of event and the wave height. The plot shows a linear relation for the tsunamis registered in the 71-year period. Applying normal linear regression analysis, the projection gives a maximum wave of 309 cm as a 100-year eventat Tofino, and 622 cm as a 200-year event.

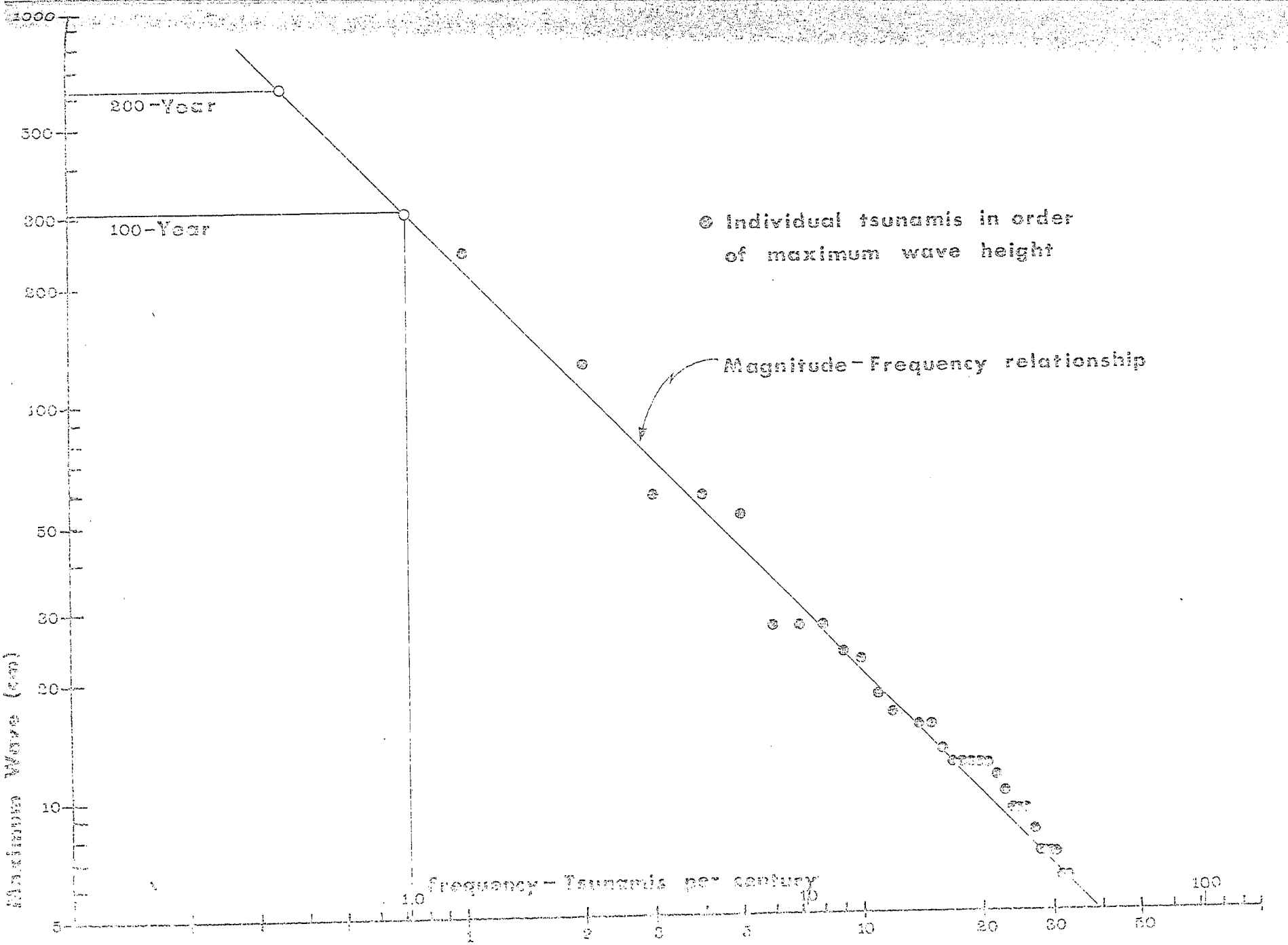
Since the size of the 200-year event is greatly influenced by the 1964 tsunami of 240 cm, and the 1960 tsunami of 126 cm, analyses have been made using only the events occurring prior to one or both of these tsunamis, to see whether these major destructive waves are in fact normal events. Fortunately the number of tsunamis is large enough to make such projections. Figure 2 shows the 58-year sample, 1906 to 1963, and Figure 3 the 54-year sample, 1906 to 1959. Each has a 100-year and 200-year projection shown. For the 58-year sample, the analysis indicates a 216 cm maximum wave as a 100-year event, and 395 cm as a 200-year event. From the 54-year sample, the projection indicates a 143 cm maximum wave as a 100-year event, and 242 cm as a 200-year event.

In other words it is clear that the tsunamis of 1960 and 1964 were not freak events. Even prior to their occurrence, given present knowledge, it would have been possible to forecast that such tsunamis were a reasonable possibility, though the years of their occurrence could not have been anticipated. Now, using them as part of the sample it is evident that their recurrence must be expected, and that tsunamis larger than the one of 1964 are a probability on the British Columbia coast.

Knowledge of the interrelationship between maximum tsunami waves at Tofino and at Port Alberni has been only slightly increased by this present study. An analysis by Allan M. McCrae, consulting civil engineer, appended to this report, provides the latest available information on this relationship, and also includes an independent statistical analysis of the Tofino data.

It is evident that whatever land use is accepted for low-lying areas of Port Alberni, tsunamis must clearly be accepted as a problem to be anticipated. The types of hazard associated with tsunamis need to be a factor in land use planning, in the inclusion of escape routes from vulnerable areas, and in the maintenance of a civil preparedness organization.

It is evident also from the present study that consideration of the tsunami hazard may be warranted for other coastal communities in British Columbia, together with a more general analysis of the response of inlets to tsunamis.



Individual Tsunamis at Tofino 1906 - 1970

Figure 1

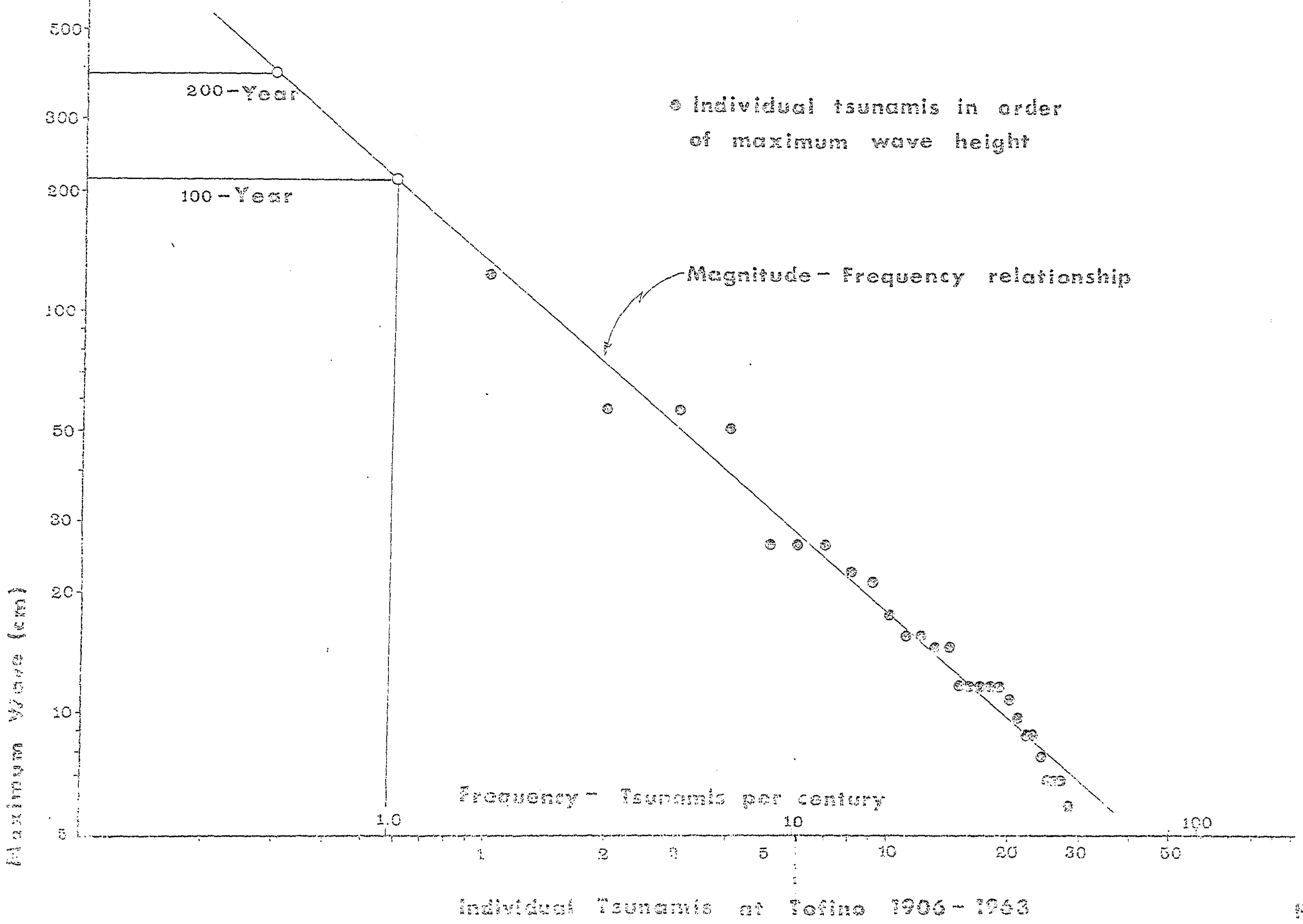

Maximum Wave (cm)
500
300
200
100
50
30
20
10
5
200-Year
100-Year
• Individual tsunamis in order of maximum wave height
Magnitude - Frequency relationship
Frequency - Tsunamis per century
1.0
10
100
1
2
3
5
10
20
30
50
Individual Tsunamis at Tofino 1906 - 1963

Figure 3

Figure 3 Individual tsunamis in order of maximum wave height 1896 - 1950

APPENDIX

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1979 04 06

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Dear Sir:

Following is my report on: PORT ALBERNI TSUNAMI OCCURRENCE.

The report describes analyses by Dr. Walter Muir of the University of Victoria and the author of the historical data provided by you. I shall be pleased to receive your comment on the analyses, findings, and conclusions.

1. INTRODUCTION

In 1978 consultants investigating the development potential of a low lying area of the City of Port Alberni carried out a statistical analysis of tsunami events recorded at Tofino and Port Alberni. The brief study indicated that tsunamis occurred with a frequency and severity to be of significant concern. It was recommended that further studies be carried out to confirm or amend preliminary conclusions.

Mr. S. O. Wigen of the Institute of Ocean Sciences has undertaken to carry out a thorough search of recorded tsunami occurrences at Tofino and Port Alberni and to analyze their significants.

The Provincial Government, in a letter dated March 6, 1979, retained A. M. McCrae to assist Mr. Wigen.

2. RECORDED TSUNAMIS

Mr. Wigen identified a large number of tsunamigenic events and carried out a thorough search of tidal record tracings for resulting tsunamis. A summary of events identified are shown on Table 1.

A vague report of a large tsunami having occurred at Port Alberni in 1896 prompted a search of newspaper reports of that

TABLE 1

Recorded Tsunamis 1906 to 1976[a]

Rank	Year	Maximum Wave, Trough to Crest	
		Tofino 1906 - 1976 cm	Port Alberni 1960 - 1976 cm
1	1964	240	800 est
2	1960	126	200 est
3	1952	58	-
4	1946	58	-
5	1957	52	-
6	1938	27	-
7	1923	27	-
8	1922	27	-
9	1933	23	-
10	1934[b]	22	-
11	1957[b]	18	-
12	1963	16	27
13	1918[b]	16	-
14	1923[b]	15	-
15	1919	15	-
16	1968[b]	13	24
17	1952[b]	12	-
18	1944	12	-
19	1944[b]	12	-
20	1917	12	-
21	1915	12	-
22	1929	11	-
23	1958	10	-
24	1975	9	10
25	1923[b]	9	-
26	1917[b]	9	-
27	1923[b]	8	-
28	1971	7	?
29	1951	7	-
30	1921	7	-
31	1918[b]	7	-
32	1973	6	16
33	1931	6	-

[a]As catalogued by S. O. Wigen.

[b]Lower height of second event occurring in a single year.

period. The Colonist newspaper of Sunday, June 21, 1896, p. 5, reported the following:

> Coincidant with the devestation of the coastal cities of Japan by a tidal wave on Monday last a similar disturbance of the sea created no little alarm along the entire seaborad of Vancouver Island sweeping the length of the west coast but fortunately doing no serious damage to the settlements. . . . For upwards of three hours the waters rushed inland for miles moving strangely to and fro at a velocity of 8 miles per hour. The steamer Maude was at Kyuquot during the few hours of inundation all the sea skirting land was submerged to a depth of four to five feet.

Mr. Wigen reviewed high tide levels at the time the tsunami arrived and noted that only moderately high tides would have been coincident. A thorough analyses of the height of the "sea skirting land" related to probable high tide levels has not been carried out; however, if the report is accurate the runup from tsunami high water would exceed the four feet (120 cm) to five feet (150 cm) flood level reported. The maximum wave it is assumed, would be greater than 300 cm.

The Colonist newspapers published following the large earthquake of 1897 were searched, but no reference was reported of a tsunami.

3. ANALYSIS

The principal concern of this study is with the frequency of tsunami runup levels at Port Alberni. Because the tide gauge at Port Alberni has only operated since 1961, the statistical data from this station is sparse. Good data are available for the Tofino station, these data will be analyzed and a review of the correlation to the Port Alberni data assessed.

3.1 Tofino

The maximum wave height, MWH, reported for the Tofino station was analyzed by Prof. Walter Muir of the University of Victoria for correlation with frequency of occurrence. Dr. Muir reports: "The suggestion of an underlying logarithmic relationship, as seen in the 50 and 70 year sample graphs, appears to be supported. In other words, the correlation between the rank of tsunami intensity

and the natural logarithm of the MWH (0.96) is the highest of those calculated, the others included no transformation of the variable (0.82), and square root transformation (0.89), thus confirming the logarithmic scaling used in the graphs.[2]

The MWH data was statistically analysed according to the Hazen's method (Ref. 3, pp. 57-60) normally used for the statistical projection of peak flood flows in rivers. Only the largest MWH listed for a particular year was used and for those years when no tsunami was identified it was assumed the MWH was less than 6 cm. This is the minimum size wave reliably identifiable on the record tracings. For these years wave heights of 5, 4, 3, 2, 1, and 0 cms were assigned equally.

The MWH data was analyzed in different groupings as shown in Figure 1.

The results of the analyses are shown on Figure 2. Also plotted on this graph is the frequency-wave height projection

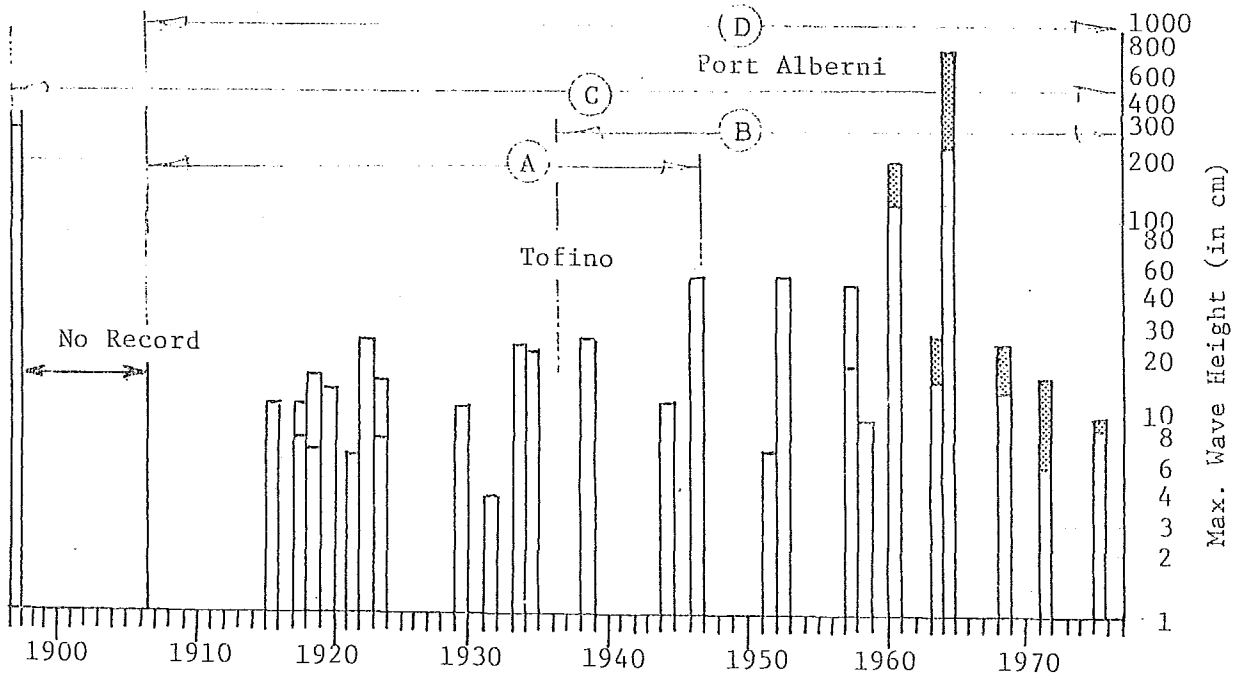

Figure 1. Tsunami Chronology

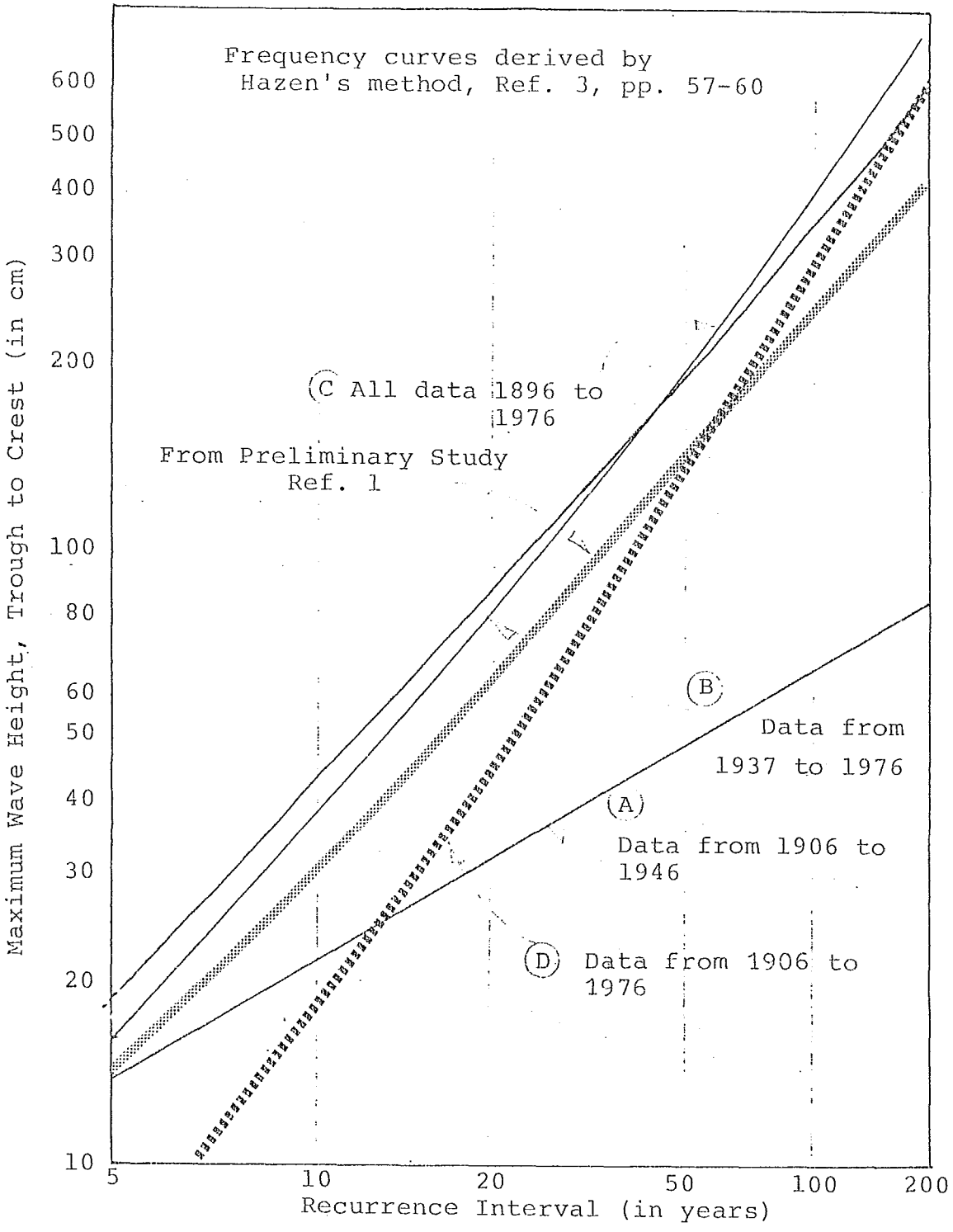

Figure 2. Maximum Wave Height - Tofino Tsunamis

contained in the original preliminary analysis (Ref. 1, Fig. 3.6, pp. 3-12).

It will be seen from Figure 2 that:

3.1.1 Curve A, data 1906 to 1946 - as illustrated in Figure 1, this is a period of low tsunami activity and the curve derived from the data reflects this.

3.1.2 Curve B, data 1936 to 1976 - this period contains all the larger recorded tsunamis and excludes periods when events are small and infrequent. The curve therefore plots higher than data from other groupings investigated.

3.1.3 Curve C, data from 1896 to 1976 - this is an analysis of all the data available. It assumes there were no measurable tsunamis from 1896 to 1906 where records are not available.

3.1.4 Curve D, data from 1906 to 1976 - all the data from tide gauges is incorporated. This curve covers the longest period with reliable data and will therefore be used to estimate tsunami frequencies at Port Alberni.

3.2 Analysis - Port Alberni

The tide gauge at Port Alberni was installed in 1961 following the tsunami generated by the Chile earthquake in 1960. The short term of records make the projections less reliable than for Tofino. It is therefore desirable to establish a relationship between maximum wave heights experienced at Tofino and Port Alberni.

Dr. Walter Muir reviewed coincident data from the two recording stations and reported as follows: "Although there are at most seven corresponding measures, these yielded a high correlation ($r = 0.9659$, $P = .0004$). This offers the possibility of estimating maximum wave height at Alberni based on the more complete set of measures at Tofino." "The linear regression equation for prediction is:

MWH at Alberni = 3.12 x MWH Tofino - 31.0" (cm)

The frequency-wave height projection for Port Alberni using the Tofino curve generated using all recorded data, both including and excluding the 1896 tsunami (Curves C and D, Figure 2) and the above equation is shown in Figure 3.

Although there are only 18 years of data directly available for Port Alberni, this data was analyzed using the Hazen's method of computing frequency curves (Ref. 1, pp. 57-59). The resultant curve is shown on Figure 3. As indicated in Figure 1, more severe tsunamis have been more frequent in recent years. Because of this, the direct projection for Alberni which uses data only from this period is more severe. Also shown in Figure 3 is the MWH - frequency projection derived in the preliminary analysis (Ref. 1, Figure 3.6, pp. 3-12).

The projected maximum wave heights derived from the Tofino records are similar to those contained in the previous study in the critical long range recurrence periods.

4. COMPARISON WITH OTHER LOCATIONS

Similar MWH frequency analyses have been carried out by other authorities for tsunami prone areas. The results of studies done for Crescent City, California; San Francisco, California; Hilo, Hawaii; and for Japan are shown on Figure 3 for comparison with the Port Alberni projections. The projections for these areas are summarized in Ref. 4, Figure 11.38, p. 294.

5. APPLICATION

The projections for Port Alberni indicate the water levels shown in Table 2.

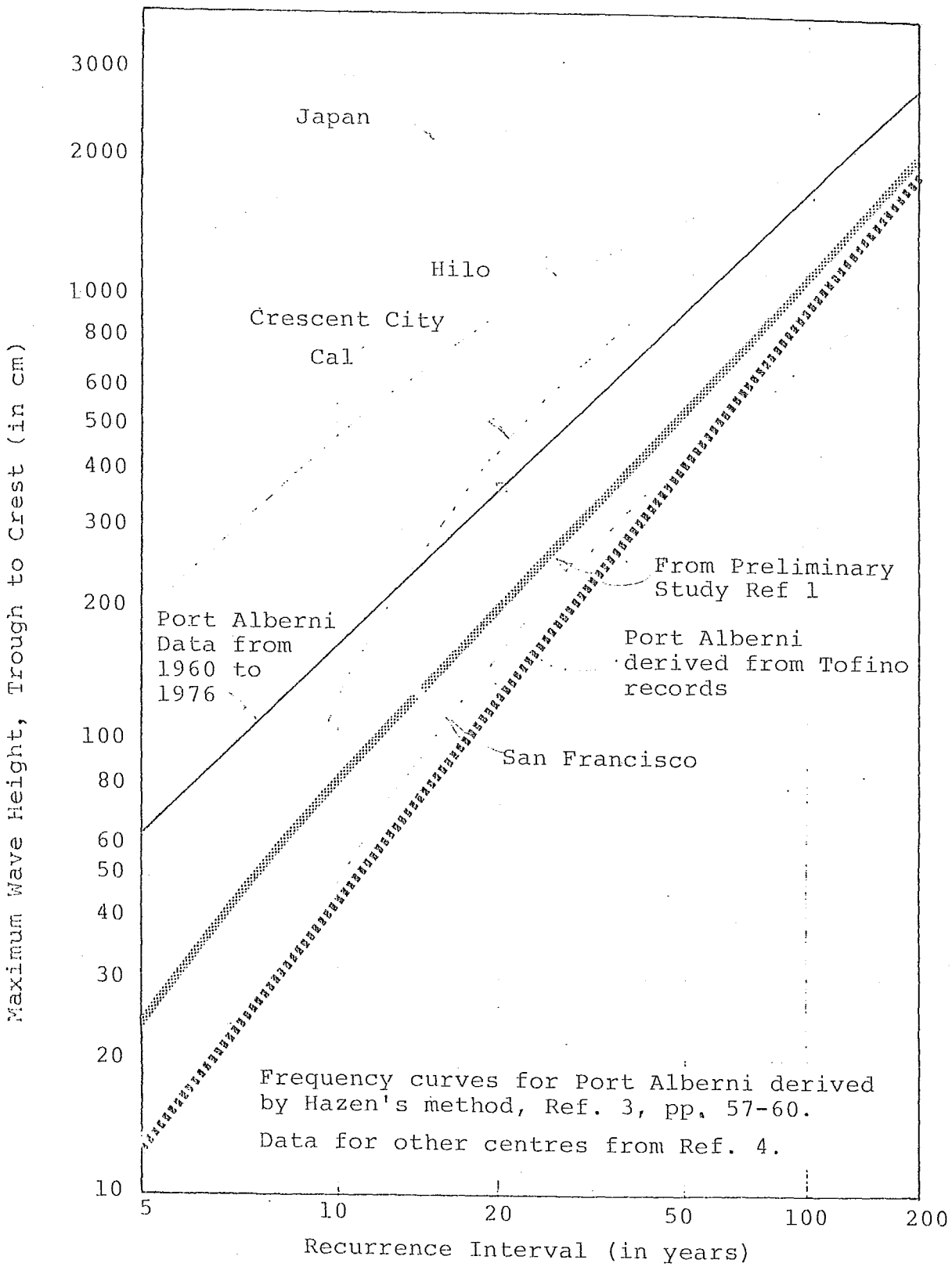

Figure 3. Maximum Wave Height - Alberni and Frequency Curves for other Pacific Ports

TABLE 2

Tsunami and Runup Water Levels

Recurrence Interval years	Maximum Wave Ht[a] cm	½ Max Wave Ht meters	½ Max Wave Ht from Prelim. Study 6 meters
50	404	2.0	2.8
100	970	4.9	5.4
200	1840	9.2	9.7

[a]From Figure 3, Port Alberni derived from Tofino records.

[b]See Ref. 1, Table 3.3, p. 3.13.

6. FINDINGS AND CONCLUSIONS

Following is a summary of the principal findings and conclusions of this review.

6.1 Mr. S. O. Wigen has produced a complete catalogue of tsunami events recorded at Tofino and Port Alberni.

6.2 Newspaper reports of 1896 describe a large tsunami occurring on the west coast of Vancouver Island. When time permits further searches for historical reports should be undertaken.

6.3 Dr. Walter Muir reviewed the data and concluded maximum wave heights and frequencies are related logarithmically. The correlation between the rank of tsunami intensity and the natural logarithm of the MWH is 0.96.

6.4 MWH - frequency analyses were carried out on Tofino records using Hazen's method. These are shown on Figure 2.

6.5 Dr. Walter Muir analysed the coincident data for Tofino and Port Alberni. This indicated a high correlation (0.97) between the two locations. The regression equation for estimation is:

MWH Alberni = 3.12 X MWH Tofino - 31.0 (units in cms)

6.6 MWH - frequency curves for Port Alberni were derived from the Tofino curves using the regression equation. The results

indicate maximum wave heights slightly lower than originally projected in the preliminary study (Ref. 1).

6.7 MWH - frequency curves for Port Alberni were developed using the measured tsunamis occurring since 1960. This analysis projects MWH larger than those translated from Tofino. The period of measure however contains a greater number of large events as shown in Figure 1.

6.8 The statistical method employed for analysis is one of a number that could be used. The method is commonly employed for the projection of extreme values particularly flood flows using annual peak flow records. The extreme range of the tsunami data makes the method only marginally applicable. Time limitations have not allowed the analysis of the data with other methods. Because of the importance of the projections to the development of the city and the safety of its citizens, it is recommended that further analyses be carried out.

6.9 In conjunction with additional statistical projections, it is recommended that an analysis of the alternative actions available to the City and Province be carried out to quantify the risks and consequences of the adoption of alternative policies.

6.10 This study provides no basis for modifying the conclusions of the preliminary assessment of the tsunami threat to low lying areas of Port Alberni contained in the "Development Feasibility Study Lugrin Creek Area."[1]

Respectfully submitted,

A. M. McCrae, P.Eng.

References

[1] *Development Feasibility Study Lugrin Creek Area*, Reid Crowther & Partners Limited and Allan M. McCrae for City of Port Alberni and Ministry of the Environment, April 1965.

[2] Muir, Walter Meno to author, March 22, 1979.

[3] *Design of Small Dams*, Bureau of Reclamation, U.S. Dept. of Interior, U.S. Gov't Printing Office, 1965.

[4] Wiegel, R., *Earthquake Engineering*, Prentice-Hall, 1970.