FAR-FIELD CHARACTERISTICS OF THE TSUNAMI OF 26 DECEMBER 2004

T.S. Murty*, N. Nirupama**, I. Nistor* and S. Hamdi*

*Department of Civil Engineering
University of Ottawa, Ottawa, Canada
**School of Administrative Studies
York University, Toronto, Canada

ABSTRACT

The tsunami of 26 December 2004 in the Indian Ocean not only propagated throughout the Indian Ocean, albeit with varying amplitudes at different coastlines, but also travelled into the Pacific and Atlantic Oceans via the southern ocean route. In this study, the emphasis is on the far-field characteristics, where the tsunami amplitudes are much smaller than those in the Indian Ocean, and are somewhat devoid of local resonance amplification effects as in the Indian Ocean, where the tsunami was generated.

KEYWORDS: Tsunami, Indian Ocean, Far-Field Characteristics, Travel Time

INTRODUCTION

Tsunamis are mostly generated by earthquakes, volcanic eruptions and landslides. The basic features of tsunami generation from under-ocean earthquakes are described by Murty (1977). Generation by submarine landslides, either triggered by an earthquake or completely independent of an earthquake, was treated recently by Murty (2003a, 2003b). Here we focus on the Sumatra tsunami. For some data on earlier tsunamis in the Indian Ocean, the reader could refer to the works by Murty and Bapat (1999) and by Murty and Rafiq (1991).

In this paper we define a global tsunami as one that propagated into at least three of the four global oceans. In historical times, the first global tsunami was the one generated by the eruption of the volcanic island of Krakatoa in the Sunda Strait between Java and Sumatra. Since modern instrumentation was put in place, the tsunami of 26 December 2004 in the Indian Ocean is truly the first global tsunami, as it propagated into the Atlantic and Pacific Oceans, in addition to covering most of the Indian Ocean.

The data set for this tsunami presents a unique opportunity to describe the observed variability of this tsunami, not only in the near field, but also in the far field. Murty et al. (2005) has discussed the inconsistencies in the data posted on the web by various survey teams.

AMPLITUDE OF THE FIRST WAVE

The amplitude and period of the first tsunami wave is described here by making use of the data posted on the Internet by Rabinovich et al. (2005). Table 1 lists this data as adapted by us from the above source. The corresponding geographical locations of stations listed in Table 1 are illustrated in Figure 1. In this study the data we used is mostly for the eastern Pacific Ocean only, and specifically for the Pacific coasts of North and South America and a few islands in the northeast Pacific Ocean.

Table 1 (third column) shows that the amplitudes of the first tsunami wave in the eastern Pacific varied from 0.04 m in Hawaii to 0.255 m on the coast of South America and 0.26 m on the coast of Alaska. There appears to be no systematic variation, and local topographic effects could have played a role.

AMPLITUDE OF THE SECOND WAVE

The amplitude of the second wave varied from 0.08 m near Hawaii to 0.82 m on the South American coast (Column 4 of Table 1). The geographical variation of the amplitude of the second wave is more regular than for the first wave. In general the wave amplitude has gradually decreased as one goes northward along the Pacific coasts of South and North Americas. It is evident that the tsunami from the Indian Ocean entered the Pacific Ocean south of Australia and New Zealand, and more tsunami energy was directed towards the Pacific coast of Chile, rather than towards Hawaii.

Table 1 (Column 7) gives the difference in heights between the 2nd and 1st wave. Again, the variation is irregular, denoting the role of local topographic and bathymetric effects. The fact that this height difference is positive everywhere confirms that it is not only in the near field in the Indian Ocean that the 2nd wave is the highest, but the same relative result holds even in the far field in the Pacific Ocean.

Table 1: Data Adapted from Web Dataset by Rabinovich et al. (2005)* and from Kowalik et al. (2005)**

No.	Location	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
1	Adak Island, AK, USA	0.095	35 00	50.0	0.210	38 10	50.0	0.115	3 10	0.0	-
2	Dutch Harbour, AK, USA	0.095	37 50	40.0	0.140	41 50	50.0	0.045	4 00	10.0	-
3	Sand Point, AK, USA	0.180	35 30	37.0	0.285	38 00	39.6	0.105	2 30	2.6	-
4	Kodiak, AK, USA	0.260	39 00	70.0	-	-	-	-	-	-	-
5	Neah Bay, WA, USA	0.070	33 21	32.5	0.130	37 31	33.5	0.060	4 10	1.0	-
6	Crescent City, CA, USA	0.220	36 05	22.0	0.610	39 30	21.3	0.390	3 25	−0.7	-
7	Monterey, CA, USA	0.175	34 00	32.0	0.200	40 00	25.6	0.025	6 00	−6.4	-
8	Port San Luis, CA, USA	0.230	35 18	52.0	0.530	37 43	43.0	0.300	2 25	−9.0	-
9	Santa Monica, CA, USA	0.220	34 24	35.0	0.260	36 31	36.0	0.040	2 07	1.0	-
10	Los Angeles, CA, USA	0.065	32 00	45.0	0.265	36 43	63.0	0.200	4 43	18.0	-
11	La Jolla, CA, USA	0.050	32 25	24.0	0.115	35 25	22.0	0.065	3 00	−2.0	-
12	San Diego, CA, USA	0.120	31 25	53.0	0.225	35 29	36.0	0.105	4 04	−17.0	-
13	Honolulu, HI, USA	0.040	26 47	43.0	0.095	30 27	22.4	0.055	3 40	−20.6	-
14	Kahului, HI, USA	0.125	26 49	36.0	0.300	31 07	35.0	0.175	4 18	−1.0	-
15	Kawaihae, HI, USA	0.040	25 43	26.0	0.085	31 07	40.0	0.045	5 24	14.0	-
16	Hilo, HI, USA	0.085	26 31	10.5	0.180	30 32	33.0	0.095	4 01	22.5	-
17	Cabo San Lucas, Mexico	0.060	29 27	12.0	0.240	34 52	11.5	0.180	5 25	−0.5	-
18	Acajutla, El Salvador	0.140	31 56	50.0	0.320	36 16	43.0	0.180	4 20	−7.0	-
19	Baltra, Galapagos Islands, Equador	0.140	29 27	34.0	0.360	34 05	41.0	0.220	4 38	7.0	-
20	Callao, Peru	0.200	28 50	38.0	0.680	31 24	36.0	0.480	2 34	−2.0	-
21	Arica, Chile	0.255	27 03	46.0	0.720	31 29	39.0	0.465	4 26	−7.0	-
22	Iquique, Chile	0.130	26 36	50.0	0.245	32 46	14.4	0.115	6 10	−35.6	-
23	Antofagasta, Chile	0.075	26 26	46.0	0.275	33 26	44.0	0.200	7 00	−2.0	-
24	Caldera, Chile	0.130	26 17	31.0	0.220	29 47	16.5	0.090	3 30	−14.5	-
25	Coquimbo, Chile	0.205	24 54	33.0	0.360	30 40	34.5	0.155	5 44	1.5	-
26	Valparaiso, Chile	0.085	24 05	32.0	0.180	28 11	36.5	0.095	4 06	4.5	-
27	San Antonio, Chile	0.085	23 13	50.0	0.150	34 13	54.0	0.065	11 00	4.0	-
28	Talcahuano, Chile	0.240	24 36	33.0	0.430	32 50	IRG	0.190	8 14	-	-
29	Corral, Chile	0.190	24 50	34.0	0.290	29 12	36.0	0.100	5 22	2.0	-
30	Punta Corona, Chile	<0.050	24 45	20.0	-	-	-	-	-	−20.0	-
31	Chennai	-	2 36	-	-	-	-	-	-	-	2 20
32	Male, Maldives	-	3 25	-	-	-	-	-	-	-	3 18
33	Hanimaadhoo, Maldives	-	3 41	-	-	-	-	-	-	-	3 30
34	Diego Garcia, UK	-	3 55	-	-	-	-	-	-	-	3 40
35	Hillarys, Australia	-	6 41	-	-	-	-	-	-	-	6 36
36	Salalah, Oman	-	7 17	-	-	-	-	-	-	-	7 06
37	Pt. La Rue, Seychelles	-	7 25	-	-	-	-	-	-	-	7 24
38	Lamu, Thailand	-	9 09	-	-	-	-	-	-	-	8 30
39	Zanzibar, Tanzania	-	9 49	-	-	-	-	-	-	-	10 38
40	Portland, OR, USA	-	10 39	-	-	-	-	-	-	-	10 18

41	Richard's Bay, South Africa	-	11 13	-	-	-	-	-	-	-	11 12
42	Port Elizabeth, South Africa	-	12 28	-	-	-	-	-	-	-	12 06
43	Jackson Bay, New Zealand	-	18 18	-	-	-	-	-	-	-	19 30
44	Arraial Do Cabo, Brazil	-	21 56	-	-	-	-	-	-	-	21 30
45	Arica, Chile	-	26 36	-	-	-	-	-	-	-	29 20
46	Charlotte Amalie, US Virgin Islands	-	28 42	-	-	-	-	-	-	-	33 30
47	San Diego, CA, USA	-	31 25	-	-	-	-	-	-	-	35 30
48	Halifax, Canada	-	31 30	-	-	-	-	-	-	-	32 06
49	Atlantic City, NJ, USA	-	31 48	-	-	-	-	-	-	-	33 30
50	Tofino, Canada	-	32 01	-	-	-	-	-	-	-	38 30
51	Adak, AK, USA	-	35 00	-	-	-	-	-	-	-	40 00

Column 1: 1st Wave Height (m)
Column 2: 1st Wave Travel Time (hr, min)
Column 3: 1st Wave Period (min)
Column 4: 2nd Wave Height (m)
Column 5: 2nd Wave Travel Time (hr, min)
Column 6: 2nd Wave Period (min)
Column 7: Height Difference (m)
Column 8: Travel Time Difference (hr, min)
Column 9: Period Difference (min)
Column 10: Computed Travel Time (hr, min)
IRG: Irregular
*Observed data from tide gauge records
**Observed data (Column 2) and computed travel time (Column 10) for 5 cm amplitude tsunami

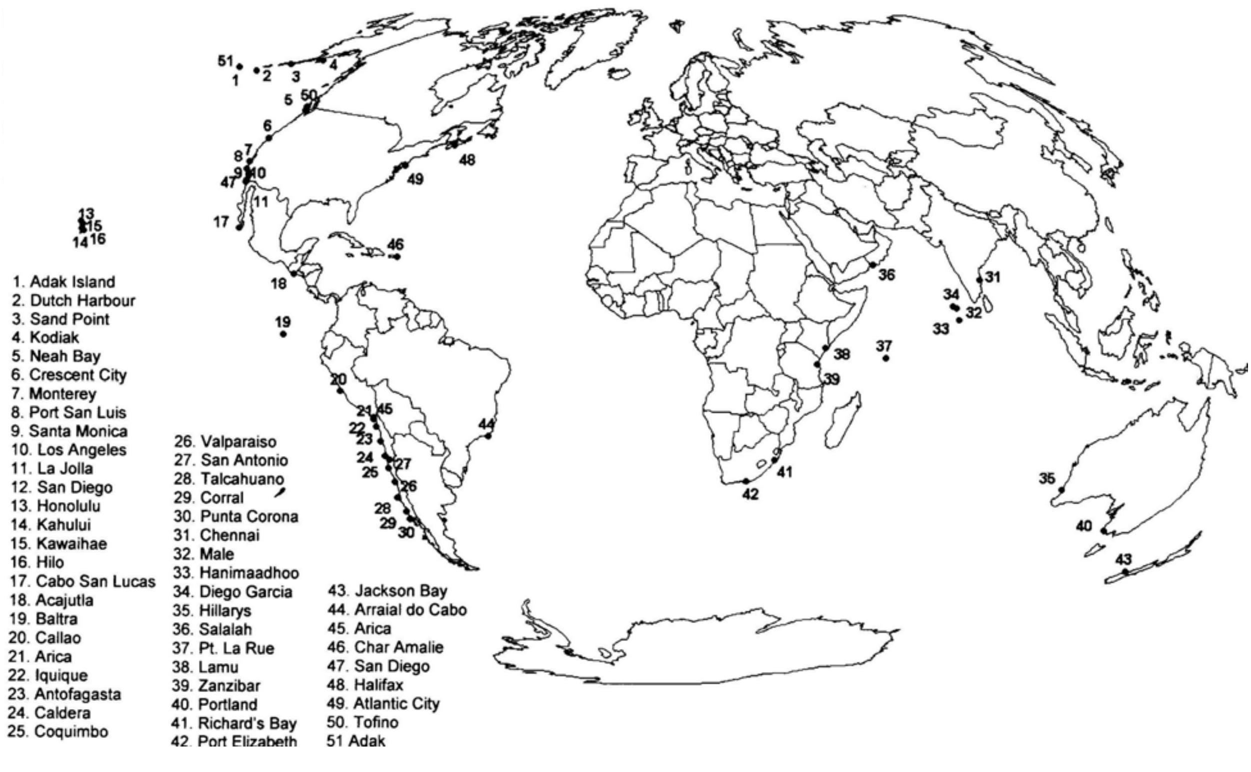

Fig. 1 Geographic locations of the stations listed in Table 1

PERIODS OF THE FIRST AND SECOND WAVES

The periods listed in Table 1 are adapted from the data of Rabinovich et al. (2005) and Kowalik et al. (2005). These data suggest that the first and second waves are the leading waves of different tsunami wave trains that have arrived at these locations by different paths. It can be seen from Table 1 (Column 3) that the period of the first wave varied from about 10 minutes in the Hawaii area to about 53 minutes in a few locations in North and South America. The irregular variation again indicates the influence of local topography. The periods of the second wave (Column 6) are slightly higher, varying from 11.5 minutes to 63 minutes, and geographical variation is slightly more regular. The differences in the periods between the second and first waves (Column 9) are both positive and negative. This means that it is not always the period of the second wave that is greater, even though as far as amplitudes are concerned, it is always the second wave that has the higher values.

TRAVEL TIMES

Here we describe the travel times of the first wave, second wave and the difference in the travel times between the second and first waves given respectively in Columns 2, 5 and 8. In general the travel times increase northward, as is to be expected from the fact that the tsunami from the Indian Ocean entered the Pacific Ocean via south of Australia and New Zealand. It is probable that some tsunami energy could have entered the Pacific Ocean through the Indonesian Straits also. The travel times of the first wave varied from about 25 hours to 39 hours. A close examination of Table 1 reveals several discrepancies and inconsistencies in the observed travel times as reported by various sources, especially on the coast of Chile.

For the second wave the travel times varied from 28 hours to 42 hours. Reflected waves could have provided multiple paths to the same location and also augmented wave amplitudes. The difference in the arrival times between the second and first waves varied from about 2 to 11 hours.

Kowalik et al. (2005) presented observed travel times and travel times computed through their numerical model. Table 1 shows the observed travel times as presented by Kowalik et al. (2005). These travel times appear to be much more regular than presented by Rabinovich et al. (2005) and are somewhat shorter for the eastern Pacific. These results clearly indicate that the tsunami from the Indian Ocean entered the Pacific Ocean via south of Australia and New Zealand. The tsunami also entered the Atlantic Ocean via south of the Cape of Good Hope at the southern tip of Africa. In general, the travel times increased northward both in the Pacific and Atlantic Oceans, confirming that the tsunami entered these oceans from south.

Table 1 also illustrates the percentage error in the travel time, which was determined by comparing the travel times computed by Kowalik et al. (2005) with the reported observed travel times. The percentage errors varied from zero to about 17%. Any differences between the observed and computed travel times are most probably due to poor bathymetric data and not to any shortcoming of the numerical model. With improved bathymetric input, the criterion of ±1 minute of error for each hour of travel time can also be achieved for the Indian Ocean, as for the Pacific Ocean.

CONCLUSIONS

The Indian Ocean tsunami of 26th December 2004 is the second truly global tsunami in historical time and the first one after modern instrumentation is put in place. It propagated from the Indian Ocean into the Atlantic and Pacific Oceans via the Southern Ocean, albeit with small amplitudes in these two other oceans. We studied the far-field characteristics of this tsunami, with particular reference to the travel times, maximum amplitude and tsunami periods. For this study, far field is defined as the Pacific and Atlantic Oceans. It is interesting to note that the second wave was having, in general, greater amplitude than the first wave, not only in the near field, i.e., the Indian Ocean, but also in the far field.

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