

On the Dependence of the Transit Velocity of Seismic Waves on the Nature of Path.

By

F. OMORI, Sc. D.,

Member of the Imperial Earthquake Investigation Committee.

1. Introduction. Calculating by the "difference method," the transit velocity v_1 of the 1st preliminary tremor of the Guatemala earthquake of April 19, 1902, is found to be 16.02 km per sec., for the limits of the epicentral distance of $38^\circ.6$ (=4290 km) to $149^\circ.3$ (16590 km)*. On the other hand, the velocity v_1 (difference method) of the Indian (Kangra) earthquake of April 4, 1905, is found to be 11.36 km per sec., for the limits of the epicentral distance of $27^\circ 57'$ (=3110 km) to $121^\circ 16'$ (=13470 km)**. Finally, the velocity v_1 (difference method) of the San Francisco earthquake of April 18, 1906, is found to be about 13.97 km per sec., for the epicentral distance of $30^\circ 36'$ (=3400 km) to $108^\circ 21'$ (=12040 km)*. Thus it will be noticed that the transit velocity v_1 of the Guatemala earthquake was greater respectively 2.05 and 4.66 km per sec. than those of the San Francisco and Indian earthquakes. These differences in the values of the transit velocity of the three great earthquakes are not likely to be the result of accidental errors in the time determinations, or of inaccuracies in the location of the seismic centres; as each of the velocity calculations, which has been made according

* See the "Bulletin," Vol. I, No. 1.

** See the "Publications" No. 24, p. 155.

to the “difference method,” is based on the observations at a large number of seismological stations. In the “difference method,” there is no need of the knowledge of the time of earthquake occurrence at the epicentre, while the error relating to the position of the latter affects generally to a comparatively small degree the results of the calculation. I shall next examine the broad features of the paths, along which the waves of the earthquakes under consideration reached the different seismological stations.

2. Guatemala earthquake of April 19, 1902. The majority of the great circles connecting the different seismological stations with the earthquake origin, whose position was, according to Mr. R. D. Oldham, at $\varphi=14^{\circ}\frac{1}{2}$ N, $\lambda=91^{\circ}\frac{1}{4}$ W, are sub-oceanic as follows:—

Station or District.	Path of the Seismic Waves.
(i) Great Britain, Spain.	Off the E. coast of Yukatan, then off the coast of the United States to the vicinity of Newfoundland, thence across the Atlantic to Great Britain or to Spain.
(ii) {Belgium, Germany, Austria, South Russia.	Nearly in the same direction as (i).
(iii) Central and Southern Italy.	Across the Atlantic to Bay of Biscay, thence passing into the Gallic and Tyrranean Seas.
(iv) Tokyo.	Along the coast of Mexico up to Southern California, then across the Pacific, passing close to the Aleutian Islands and along the Tuscarora Deep off the north-eastern coasts of Japanese islands.
(v) New Zealand.	Across the South Pacific.
(vi) Perth, W. A.	Across the South Pacific and then off the southern coast of Australia.

Station or District.	Path of the Seismic Waves.
(vii) Batavia.	Across the Pacific.
(viii) Calcutta.	Across the Gulf of Mexico, the E. part of the United States, Central Canada, the Arctic, Siberia, and Tibet, passing almost exactly through the North Pole.
(ix) Kodaikanal, Bombay.	Similar to (viii).
(x) Irkutsk.	Through the United States, Canada, the Arctic, and Siberia.
(xi) Cape Town.	Across Columbia and Brazil, then across the South Atlantic.
(xii) Toronto.	Through Guatemala, Yukatan, Gulf of Mexico, and the E. part of the United States.
(xiii) Baltimore.	Similar to (xiii).
(xiv) Victoria, B. C.	Across Mexico and the W. part of the United States.
(xv) Cordova.	Partly under the Pacific, and partly through South America.

The paths of the seismic propagation to the 18 stations in Europe (Groups i, ii, and iii) were almost entirely sub-Atlantic, while those to the 5 stations of Tokyo, Wellington, Christchurch, Perth, W.A., and Batavia, (Groups iv, v, and vi), were almost entirely sub-Pacific. The three Indian stations of Calcutta, Kodaikanal, and Bombay, were very nearly in, or not much out of, the great circle passing through the origin and the North Pole. The paths to the 5 stations of Irkutsk, Cape Town, Tashkent, Tifis, and Cordova, A.R., were partly sub-marine and partly through land; only those to the 3 stations of Toronto, Baltimore, and Victoria, B. C., being essentially continental.

3. Indian (Kangra) earthquake of April 4, 1905. The Indian (Kangra) earthquake of April 4, 1905, which originated among the sub-Himalayan chains in the Punjab, with the epicentre at about $\varphi=31^{\circ} 49' N$, $\lambda=77^{\circ} 0' E$, was observed at a great number of seismological stations*. The main features of the paths of the seismic waves to these latter are indicated in the following table.

Station or District.	Path of the Seismic Waves.
(i) { Colaba (Bombay), Kodaikanal.	Across the Indian Peninsula.
(ii) Calcutta.	Along the convex, or outer, side of the Himalayas.
(iii) Tashkent.	Across the Hindu Kush and the plateau of Pamir.
(iv) Irkutsk.	Across the mountain ranges of the central part of Asia.
(v) Zikawei (Shanghai).	Across Tibet and China.
(vi) Japan.	Through the plateau of Tibet, and across North China and Corea.
(vii) Formosa, Manila.	Across the plateau of Tibet, and the mountainous districts of South China.
(viii) Caucasus.	Across Afghan and Trans-Caspian districts.
(ix) Beirut.	Across Afghanistan and Persia.
(x) { Great Britain, North Germany, Jurjew, Upsala.	Across the flat regions of Europe.
(xi) { Austro-Hungary, North Italy, Serbia. Nicolajew.	Across the Caspian and along the northern border of the Black Sea.
(xii) Batavia.	Across India and the Bay of Bengal.

* For a full discussion of the seismographical observations of the Kangra earthquake the reader is referred to the "Publications," No. 24.

Station or District.	Path of the Seismic Waves.
(xiii) New Zealand.	Through India, along the coast of Burma and Annam, and across Borneo and Australia.
(xiv) Spain.	Across the Caspian and Black Seas, and along the northern border of the Mediterranean.
(xv) Azores.	Across Europe, from the Caspian to France.
(xvi) Porto Rico.	Across Europe and the Atlantic.
(xvii) Honolulu.	Across North China and through the Pacific.
(xviii) Samoa.	Across the south-eastern Asia and through the Pacific.
(xix) Rio de Janeiro.	Across Arabia, Africa, and the Atlantic.
(xx) Mauritius.	Across India and the Indian Ocean.
(xxi) Cape Town.	Across India, through the Arabian Sea and the Indian Ocean, and across the south-eastern Africa.
(xxii) Tacubaya.	Across Siberia, the Arctic, and North America.
(xxiii) { Toronto, Victoria, B. C. ; Washington, Cheltenham, and Baltimore.	Similar to (xxii).

The routes of the earthquake propagation to the different stations of the 11 groups, (i) to (xi), were each entirely continental; especially, those relating to the five groups (iii) to (vii) being laid across the plateau of Tibet or the great mountain ranges in the centre of Asia. The seismic paths to the stations of the 4 groups (xii) to (xv) were also for the greater part continental, while those for the remaining 8 groups were partly submarine

and partly continental. The stations of the two groups (xxii) and (xxiii) were situated approximately on, or not very much out of, the great circle passing through the origin and the North Pole.

4. *San Francisco earthquake of April 18, 1906.* The paths of the seismic waves to the different stations were as follows.

Station or District.	Path of the Seismic Waves.
(i) Sitka (Alaska).	Off the Pacific coast.
(ii) Honolulu.	Entirely under the Pacific.
(iii) Japan, Formosa.	Do.
(iv) Batavia.	Do.
(v) New Zealand.	Do.
(vi) { Spain, Great Britain, Germany, Italy, Austria.	Through Canada, then across the North Atlantic.
(vii) Victoria, B.C.	Along the Pacific coast.
(viii) { Tacubaya, Toronto, Ottawa, Washington, Cheltenham, Baltimore.	Entirely continental.
(ix) Porto Rico.	Through the United States and the Caribbean Sea.
(x) Tiflis, Tashkent.	Nearly through the North Pole.
(xi) British India.	Along or off the Pacific coast of North America, then through Asia, from the north-eastern part of Siberia to India.

The seismic waves reached the stations of the first 5 groups by entirely sub-oceanic paths, and those of the 3 groups, vii, viii, and ix, by entirely or almost entirely continental paths. The great circles connecting the earthquake origin with the stations of the remaining 3 groups, vi, x, and xi, are partly sub-oceanic and partly continental.

5. Remarks. From § 2, it will be seen that the motion of the Guatemala earthquake reached the majority of the seismological stations by *trans-Atlantic* or by *trans-Pacific* routes. On the contrary, the paths of the seismic propagation of the Indian (Kangra) earthquake were, according to § 3, mainly *continental*, being laid, in many cases, across the plateau of Tibet or the great mountain ranges in the centre of Asia. On these differences in the character of the regions, through which the earthquake movements were propagated, may possibly depend the marked discrepancy between the transit velocities of the two earthquakes under consideration. In other words, the earth's crust is to be supposed, in its continental parts and especially in the centre of Asia, to be abnormally deficient in rigidity, giving the low transit velocity of 11.36 km per sec. for the Indian earthquake. The earth's crust under the Pacific and the Atlantic Oceans is, on the other hand, to be supposed to be abnormally great in rigidity, giving the high velocity of 16.02 km per sec. for the Guatemala earthquake. In the case of the San Francisco earthquake, some of the seismic paths were sub-Pacific, while the others were continental, or partly continental and partly sub-marine (§ 4). Consequently, the velocity of this earthquake was about 13.97 km per sec., being nearly equal to the mean of the two earthquakes before considered.

The idea respecting the seismic velocity put forth in the present note is simply a suggestion, which, if correct, requires further verifications.

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