Meetings

Earth Movements: Alaskan Earthquake, 1964

The dynamics of the earth in the region of Alaska where the Good Friday earthquake occurred was the theme of a public symposium held at the University of California, Berkeley, on 29 May 1964. Five of the seven speakers had made field studies of the meizoseismal area (region of damage) following the earthquake.

In an introduction the chairman, B. A. Bolt (Seismographic Stations, University of California), mentioned the high interest stimulated in California by the earthquake, the most energetic in the United States since the San Francisco shock of 18 April 1906. It has important scientific, technical, and social aspects. Public attention, drawn again to seismic hazards, can be used constructively to obtain safeguards in building codes and town planning.

Bolt also outlined some background seismological information. The main shock occurred near the head of Prince William Sound at 03hr 36′ 13″ G.M.T., 28 March. A U.S. Coast and Geodetic Survey computation gives an epicenter at 61.1°N, 147.6°W, which is 120 km from Anchorage and 3130 km from Berkeley. The focus is shallow with a maximum depth of 60 km. The Richter magnitude from the Berkeley seismograms was estimated at between 8½ and 8¾. (The Chilean shock of 22 May 1960 was allotted 8¼.) The earthquake generated a Pacific tsunami, and seiches and water fluctuations in wells in North America. By 27 April, a sequence of about 520 aftershocks had been observed.

Previously, the greatest Alaskan earthquake studied had occurred near Yakutat Bay on 10 September 1899. The primitive instrumental records suggested a magnitude of 8½ and field evidence was found for large surface fault movements. The Lituya Bay shock of 10 July 1958 (magnitude 8) was closely studied by Miller, Davis, Sanders, Tocher, and others. Field surveys showed strike-slip displacements of about 30 meters along the Fairweather fault; the strike of a fault-plane solution by Stauder differed by 15 deg from the field measurements. Similar comparisons between seismic and field data from the Good Friday earthquake are awaited with interest.

A. Grantz (U.S. Geological Survey, Menlo Park, California) outlined the general geology of southern Alaska, described the broad movement of the earth's crust and superficial ground motions caused by the earthquake, and, finally, gave some tentative thoughts on the relation of this earthquake to major structural features of Alaska.

Proceeding northward from the Gulf of Alaska, one encounters first a series of Coast Ranges, then a valley province, and finally an extensive mountain system. The Mesozoic and Tertiary histories of these provinces are similar, respectively, to those of the Coast Ranges, Central Valley, and Sierra Nevada in California. The Aleutian arc swings in from the oceanic area, abuts against the continental margin, and intersects the continental structures at a very low angle. Volcanoes of the arc extend well onto the continent. Further field work is necessary to show the different structures where the continental and Aleutian arc structures intersect.

Areas within about 280 km of the epicenter were extensively damaged. The earthquake triggered numerous rock falls and avalanches in the mountains. The amount of snow avalanched onto glaciers, however, seems inadequate to trigger a glacial advance; if this earthquake does trigger an advance of the glaciers, it will be by some mechanism more subtle than knocking down snow and ice by avalanching. The earthquake also triggered submarine slides off the steep fronts of deltas filling the fjords of Prince William Sound. Such slides carried away docking facilities at Seward and Valdez. Tsunamis struck many coastal towns about half an hour after the earthquake. There were also numerous local swashes of large amplitude, many of which were caused by submarine slides. These waves struck adjacent shores during the earthquake and within minutes after it.

Fissuring of unconsolidated sediments occurred in areas as far apart as the Copper River Delta, the Kenai Peninsula, and Kodiak Island. Locally these water-saturated deposits were made mobile, and sand and mud spouts occurred at the surface. No evidence was seen of surface fault movement during early post-earthquake reconnaissance studies, but detailed follow-up studies have already demonstrated that large surface fault movements occurred on Montague Island in Prince William Sound.

A tectonic hinge line, approximately parallel to the Aleutian arc structure, separates an area to the southeast in which the earth's crust rose as much as 9 meters from an area to the northwest in which the crust subsided as much as 1.5 meters. Evidence for these movements comes from tide gauges, changed elevation of shoreline features, and intertidal life zones. It is necessary, but sometimes difficult, to distinguish crustal or tectonic movements from subsidence caused by compaction of sediments. For example, the spit at Homer subsided 2 meters; it was possible to establish that almost 1 meter of this subsidence was due to compaction of sediments.

The trend of aftershocks as well as the tectonic hinge line seems to be more nearly parallel to the Aleutian arc structure and its related seismic belt than to the older structures of the continental margin. This belt trends into the interior of Alaska; it intersects rather than parallels the continental margin. This earthquake seems, therefore, to be genetically related to the volcanic arc rather than to the continental structures.

W. K. Cloud (U.S. Coast and Geodetic Survey, San Francisco) spoke on the observational program undertaken by the Coast and Geodetic Survey after the Good Friday earthquake. The program is concerned with oceanography, geodesy, cartography, and seismology.

In oceanography, a number of survey ships have begun a survey of channels and harbors; magnetic profiles have also been obtained. Tide gauge measurements show apparent uplift of 2 meters at Cordova and subsidences at Kodiak of 1.6 meters; Whittier, 1.6 meters; Anchorage, 1.6 meters; and Valdez and Seward, 1.2 meters. These displacements are a combination of regional crustal movements and local compaction and slumping; the measurements are tied to the old bench marks. In geodesy, the old survey lines are being resurveyed as the snow melts. The existing bench marks in the meizoseismal area are now quite uncertain and 4000 km of releveling is to be undertaken. Possible warping or tilting of the crust will be estimated by triangulation surveys in the Anchorage-Whittier-Seward region.

Mariners will be informed of post-earthquake, nautical conditions as soon as possible. Preliminary charts based on aerial photographs show changes in channels and shorelines and have already been published and distributed. Some important changes may be enumerated: Crescent City, California—changes to 2.4 km of shoreline; Valdez—entire waterfront in ruins; Whittier—destruction of two 230-meter oil piers and shoreline changes; Seward—destruction along the entire harbor and 20-fathom line shifted 180 meters shoreward; Kodiak—port facilities destroyed.

By 05 hr G.M.T., the U.S. Coast and Geodetic Survey tsunami warning system located a tentative epicenter for the main shock at 61°N 147.5°W. Some 30 minutes later estimated seismic sea wave arrival-times were issued. In order to study aftershocks, six special seismographic stations were installed in the region within 8 days. Preliminary results show that the aftershocks extend in a strip from the main shock to the southern tip of Kodiak Island.

No strong-motion accelerographs were in operation in Alaska prior to the main shock. An instrument had been installed at Elmendorf Air Force Base near Anchorage by Monday, 30 March. One record from a large aftershock (magnitude 6) near the main shock was obtained by 16 May. There was no damage at Anchorage in this case and the maximum acceleration recorded was 5 percent of gravity. A zero-damped response spectrum showed peaks at 6/10 second and a little over a 2-second period. If extrapolation back to the main shock is allowed, this spectrum may explain why small buildings were less damaged than tall structures. Additional strong-motion instruments are now installed. At the time of the Lituya Bay earthquake an accelerograph triggered at Seattle. On 28 March, the instrument at Tacoma, Washington, rather than the one at Seattle, triggered. The Tacoma record indicates that amplitude displacements of over 3 mm occurred there at a 5-second period.

Seismic waves generated by the earthquake and its aftershocks were recorded on seismographs all over the world. Some results of his early analyses of waves recorded at the seismographic stations of the University of California were described by A. Nowroozi (Department of Geology and Geophysics, Berkeley). Standard Wood-Anderson seismographs at the Berkeley seismographic station recorded horizontal ground motion with an amplitude of 1 cm at a period of 17 seconds after the Alaskan earthquake. The vertical motion was comparable. Such large amplitudes at a distance of 3100 km from the epicenter appear important from the standpoint of engineering design of sensitive scientific equipment, such as nuclear accelerators. Displacements of the earth with periods of the order of minutes were recorded on ultra-long period seismographs at Berkeley. These may be regarded as normal modes of vibration of the earth. Both power-spectral and classical harmonic analyses have been made already of some records. Normal vibrations in the torsional mode have been detected for orders up to $n = 25$. The periods are close to those obtained after the great Chilean earthquake. The results may provide evidence not only on earth structure, but also on conditions of generation at the earthquake source.

B. A. Bolt reported on atmospheric waves recorded at the Byerly Seismographic Station, Berkeley, after the main earthquake. These exceptional air waves resembled waves previously recorded from high-altitude nuclear explosions; they were recorded on a sensitive microbarograph in the seismic vault. Synoptic weather charts have a broad stable ridge of 1016-millibar pressure from Alaska to San Francisco at the time of the earthquake. The barogram shows about 4 hours of pressure variations of the predominant 15-second period, which commenced 14 minutes after the earthquake. These are coupled to the seismic surface waves.

An even more conspicuous pressure pulse arrived about 2 hours 39 minutes after the earthquake. If the source is at the earthquake epicenter, the first rarefaction maximum has a group velocity of 317 m/sec and a period of about 3 minutes; a later variation with a 1-minute period has a velocity of 300 m/sec. Frequency analysis shows similar dispersion to that in acoustic-gravity waves from nuclear explosions. If the pulse was recorded at other observatories, the air wave may provide information on the tilting of the displaced region.

The tsunami arrived in San Francisco Bay about 2½ hours after the seismic air wave. U.S. Coast and Geodetic Survey mareograms show seiches subsequently in the bay with predominantly 40-minute periods. [A discussion of seiches in this bay is given in Charles Davidson's *A Manual of Seismology* (1921).] The generation of seismic air waves after large Pacific earthquakes may provide an additional method of rapid prediction of tsunami generation.

R. Kachadoorian (U.S. Geological Survey, Menlo Park, California) discussed damage related to compaction of unconsolidated sediments, submarine slides, and landslides. He illustrated general features of damage by means of selected examples.

Over a wide area, compaction occurred beneath highway and railroad rights-of-way that crossed areas of unconsolidated deposits; the material was gravel, sand, and silt, or tidal flat debris. The highway near Portage, built on fill over tidal flats, failed continuously for a distance of about 4 km by (i) compaction, (ii) deep cracking down the centerline, and (iii) rotation and lurching of the highway fill. There is some evidence that Portage subsided 1.2 meters by regional subsidence and 1.5 meters by compaction; the town is now under water at high tide. The Homer spit, which is about 1 km long, subsided almost 1 meter by compaction. Most of the compaction seems to occur in the upper 15 to 18 meters; bridges built on piles of that length subsided less than their approaches which are built on fill over the same substratum. Near Portage wooden piles pierced with explosive force 15-cm slabs of reinforced concrete.

A number of coastal towns are built on deltas at the head of fjords. Submarine slides off the fronts of these deltas, and waves caused by these slides, caused much damage. Cracks parallel to the heads of the slides occur in Valdez and Seward and these towns have subsided, perhaps by a combination of effects of compaction and slumping.

Landslides were widespread, but the slides in Anchorage are best known. Slides there occurred along cliffs in outwash gravels overlying silt and sand. Several slides were more or less conventional rotational slides. The Turnagain Heights slide which was the largest is quite different; it consists of a series of slices that slid down and then away from the cliff, along what seems to be an almost horizontal surface. This sliding stopped when the earthquake stopped. Incipient cracks occur on the relatively undisturbed land surface behind the head of the slide.

Structures built on bedrock were less severely damaged than structures built on unconsolidated sediments. For example, large buildings at Anchorage built on unconsolidated sediments were extensively damaged, whereas large buildings built on bedrock at Whittier, only half as far from the epicenter as Anchorage, suffered minor damage. It is hard to estimate intensity because so many factors affect the damage. Large structures of reinforced concrete were significantly damaged although adjacent small, woodframe structures were undamaged. The amount of damage is affected not only by epicentral distance but also by the kind of foundation material, bedrock or unconsolidated deposits, the type of construction, the height of the structure, and the duration of shaking.

Kachadoorian commented that during a comparable earthquake near the San Francisco Bay area he would expect compaction to occur in the marginal lands around the bay that are being developed with engineered fill over bay muds. He noted that much of the highway fill in Alaska could be called engineered fill, yet in most places in the meizoseismal region where the highways crossed unconsolidated sediments they were disturbed by the earthquake. He had no examples of the behavior of large buildings on engineered fill over loosely consolidated, water-saturated sediments. He thought that frozen ground had little influence on the damage because the frost zone was only a small fraction of the thickness of unconsolidated sediments. He noted that steel railroad bridges as far north as Hurricane had buckled in compression. Many highway bridges had pounded and damaged their terminal piers.

An account of the structural damage

in Anchorage was given by K. V. Steinbrugge (Pacific Fire Rating Bureau, San Francisco). As a possible cause of the compression in bridges mentioned by Kachadoorian, lurch-cracks parallel to many streams, which had been observed from a helicopter, might be considered. Steinbrugge stressed the close connection between the behavior of both the building and the ground. More attention must be given to the quantitative measurement of ground motion in an earthquake. The character of this motion is a function of distance. In the Good Friday earthquake, the changes in ground motion over the 120-km distance from the focus to Anchorage evidently were the reason for selective damage to tall structures in comparison with the usually undamaged, small rigid buildings. Similar selective damage occurred in Mexico City from the 28 July 1957 earthquake, located just off the Mexican coast. The three key factors of poor construction, poor foundation material, and long-period ground motion were also common to the two cases.

The different effects produced by long-period and short-period motion make intensity scales difficult to apply. An extreme example of intensity variation is the Turnagain area with both total destruction (intensity XII) and little or no damage to many houses on the bluff (intensity VII), including their unreinforced, concrete-block chimneys. The duration of the earthquake motion is an important datum; in one case a group of men left and reentered a building twice while shaking continued. In certain single-story shops in Anchorage moveable goods were undisturbed on shelves. This indicated a small proportion of short-period accelerations. The damage studied in detail was that due to vibraton in structures whose substrata had not failed by compaction, lurching, or landsliding. Most of the vibration damage could be explained as failure to meet standards of construction or design of the quality accepted in the San Francisco Bay area. Some doubt must remain, however, on the adequacy of even this relative standard; Anchorage was about the same distance from the primary shock as Sacramento is from San Francisco. With many modern structures such as precast concrete, the interconnections between elements are critical. There were numerous examples of failure in joints and connections. Some failures within reinforced concrete columns were related to the irregular manner in which reinforcing steel was tied together before the concrete was poured.

Only close examination of particular structural damage provided reasonable conclusions in many cases and these were instances of ineptly handled design or construction, or both. This raises the question of whether special knowledge of effects of earthquakes should not be taught more widely in schools of structural engineering. In the case of one multi-storied, damaged building, initial opinion blamed the foundation soils. Excavations now made show that the poor quality of the concrete foundations allowed them to fail in this building. The pattern of damage in Anchorage should not lull us into a sense of security; a strong earthquake nearer to Anchorage could give quite a different pattern.

During the questions, the chairman asked if there was an earthquake building code in Anchorage. Steinbrugge replied affirmatively and commented that interpretation and enforcement are important. In answer to a question of whether any concrete, multi-storied building was undamaged, he indicated that of the buildings over six stories personally inspected only the New Providence Hospital had little damage. Other questions raised concerned (i) the correspondence between the free periods of buildings and the predominant ground motion and (ii) the effect of the extreme seasons on the curing of concrete. The reply in the first case was that only the strong-motion record from the aftershock referred to by Cloud was available. A period of 6/10 second would probably affect more the taller buildings. In the second case, reasons other than frozen concrete could usually account for the damage. In response to a question concerning damage at Spenard High School, F. McClure (consulting structural engineer) replied that the key to failure in that case was in execution of the design rather than in the design itself.

Before turning to a general discussion, the chairman invited R. E. Goodman (Department of Mineral Technology, Berkeley) to report on his field observations in Alaska of the relation between soil mechanics and damage to structures. Goodman observed that we are ignorant about many factors that are fundamental to the safety of structures now being erected in the San Francisco Bay area. We do not fully understand the mechanics of soils under dynamic loads. We do not know how foundations interact with structure. Much current research on these problems is based on data from smaller earthquakes. Shaking table experiments with soils indicate that we cannot scale up effects of small earthquakes to anticipate effects of large earthquakes because there is a transition from elastic to inelastic behavior. The magnification factor of ground accelerations and displacements on soft grounds in laboratory models subjected to shaking is much higher in response to horizontal forcing motion than in response to vertical. Furthermore, it has been demonstrated that horizontal shaking has a much larger effect on slope stability than the vertical component of motion. Because there are no strong motion records in Anchorage of the Alaskan earthquake, there is little information that can be of use in soil mechanics about the design of foundations. We urgently need the installation of more strong-motion seismographs in seismic areas. We must evaluate all the exceptions to the generalizations on the relation of damage to substrata and all possible relevant variables, in order to acquire further understanding.

After Goodman's remarks, the chairman invited comments and a lively discussion took place. Kachadoorian commented that although there is much we need to know in order to develop criteria for design, the geologic observations very clearly point out the problems with which engineers must deal. He disputed the point that, because of the lack of strong motion records, little useful information has been acquired from the Alaska earthquake; strong motion records would certainly be valuable, but the available information on the ways that foundations and structures fail should be very useful. Steinbrugge noted that experience in how structures fail, even where we do not have all the data we wish, provides an empirical basis for future design. C. A. Wahrhaftig (Department of Geology and Geophysics, Berkeley) remarked that the report of the State Earthquake Investigation Commission on the 1906 earthquake in California showed a nearly perfect correlation between intensity of damage and nature of the substratum. Lines of equal damage are parallel to contacts of alluvium with bedrock and roughly follow the contours of depth of alluvium, not only within San Francisco, but also over the coast ranges and central valley. G. B. Oakeshott (California Division of Mines) reported a few of his observations in Alaska. Cordova is about as far east of the epicenter of the earthquake as Anchorage is west. Cordova is built on bedrock and the town suffered no shaking damage. The highway to the Cordova airport crosses the delta of the Copper River on gravel fill over mud and muskeg for a distance of about 2 km. Over this interval there was almost total failure of the pavement; the part of the highway built on bedrock was not even cracked. The town of Girdwood is in the area of highest intensity of damage; railroad and highway beds on filled ground failed completely, but the windows were not broken in a schoolhouse built on bedrock even though it had a concrete block foundation.

The question was next raised as to whether the correlation between substrata and damage is as clear as previous speakers had implied; in the Arvin-Tehachapi earthquake of 1952 railroad tunnels in bedrock were severely damaged whereas dams and other structures on loose ground at comparable epicentral distances were not damaged. Oakeshott replied that the tunnels at Tehachapi are in deeply weathered, granitic rock; they were dug without the use of explosives. Wahrhaftig added that three of the four damaged tunnels were along the line of surface breakage on the fault.

A number of salient scientific and practical points emerged as a result of this symposium. The earthquake has drawn attention to a region that is of exceptional geological and geophysical interest because of the intersection of island arc and continental structures, and has revealed an unexpected pattern of regional crustal movement. The continuing lack of records of ground vibration in epicentral areas was emphasized. Valuable information was obtained and questions were raised regarding problems of design and execution of buildings that must withstand shaking. The knowledge necessary for design of stable structures built on unconsolidated materials is apparently very incomplete; fills that were stable enough for operations under static conditions failed abruptly under seismic conditions. The problems for expanding metropolitan areas in seismic zones where marginal land is being developed are grave.

Details of much of the material presented by Grantz and Kachadoorian are available in the U.S. Geological Survey Circular 491. For additional material, Cloud referred to the U.S.

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This symposium was sponsored by the Department of Geology and Geophysics, University of California, Berkeley.

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Botanical Field Meeting

Each year, usually toward the latter part of June, the North East Section of the Botanical Society of America has a field meeting. The central theme is plants in their natural environment. This year Drew University at Madison, New Jersey, was host (14–17 June 1964).

Kemble Widmer (state geologist for New Jersey) spoke on the relationship between the extremely complex geology (formations from archaeozoic to the last glaciation are represented) and the distribution of plants in the Garden State. An exhibit of herbarium specimens of the flora of the Great Swamp was arranged by Florence M. Zuck. Visits by the group were made to the Great Swamp (the newest National Wildlife Refuge, dedicated 29 May 1964) and the Cedar Bog at High Point. The rather rare submerged aquatic *Hottonia inflata*, first reported from the Great Swamp by R. K. Zuck, was, perhaps, the outstanding botanical feature. The bog at High Point is one of the rare sites where all plants expected in a particular environment are well represented and can easily be seen from an encircling road. The display of the swamp calla was spectacular.

Louis Hand and Dorothy Everett spoke on the plants of the Pine Barrens of New Jersey in preparation for a field trip to this area. Everett's slides, produced by her and her husband, were some of the most technically perfect ever done for the flora of this area. The Pine Barrens are among the richest areas in the temperate region for number and variety of species of plants. Two outstanding and rare plants, the curly grass fern, *Schizaea pusilla*, and a curious morning glory, *Breweria Pickeringii* var. *caesariensis*, the latter a true endemic, were seen in the field, as well as hosts of three species of sun dews (*Drosera rotundifolia*, *D. intermedia*, and *D. filiformis*) and two orchids (*Pogonia ophioglossoides* and *Calopogon pulchella*).

At Island Heights, New Jersey, John Small (Rutgers University) spoke on the general botanical aspects of New Jersey and about Island Beach State Park in particular. He discussed the relationship of wind and wave action to the formation of Island Beach and the stabilizing influence of plants on the sand dunes in the area. Plant life is delicately balanced, and man's inroads must be curtailed if the area is to be maintained in its present state. Here we saw sea rocket (*Cakile edentula*), beach plum (*Prunus maritima*), and Spanish Oak (*Quercus falcata*) as plants typical of the region.

The host institution for the 1965 summer field meeting will be the University of Maine.

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Forthcoming Events

September

16–18. American Assoc. of **Medical Clinics**, annual, Bal Harbour, Fla. (The Association, Box 58, Charlottesville, Va.)

17–18. **Computing**, 7th annual Northwest conf., Seattle, Wash. (R. K. Smith, Northwest Computing Assoc., Box 836, Seahurst, Wash.)

17–18. **Engineering Management**, conf., Cleveland, Ohio. (Inst. of Electrical and Electronics Engineers, Box A, Lenox Hill Station, New York, N.Y. 10021)

17–18. **Polypropylene Fibers**, symp., Southern Research Inst., Birmingham, Ala. (W. C. Sheehan, SRI, 2000 Ninth Ave. S., Birmingham, Ala. 35205)

17–19. **Cancer**, 5th natl. conf., Philadelphia, Pa. (American Cancer Soc., 219 E. 42 St., New York, N.Y. 10017)

17–19. British Assoc. of **Urological Surgeons**, annual, Sheffield, England. (Joint Secretariat, 47 Lincoln's Inn Fields, London, W.C.2, England)

17–20. **Science Education**, intern. conf., Banff, Alberta, Canada. (S. Trieger, Faculty of Education, Univ. of Alberta, Edmonton, Canada)

18. Hungarian **Chemical** Soc., Tihany. (M. T. Beck, Szabadsag ter 17, Budapest 5, Hungary)

19–26. **Gynecology and Obstetrics**, 4th world congr., Buenos Aires, Argentina. (R. Lede, Primera Catedra de Ginecología, Hospital de Clínicas, Córdoba 2149, Buenos Aires)

19–27. **Scientific Films** Assoc., 18th intern. congr., Athens, Greece. (SFA, 38, Avenue des Ternes, Paris 17e, France)

20–23. **Ceramic-Metal Systems**, American Ceramic Soc., French Lick, Ind. (ACS, 4055 North High St., Columbus, Ohio)

20–23. American Inst. of **Chemical Engineers**, Las Vegas, Nev. (F. J. Van