Reservoirs and earthquakes

Incident at the Aswan Dam

from R.D. Adams

LIKE the phenomenon itself, interest in reservoir-induced seismicity seems to run in cycles. In recent months the first detailed reports have appeared of a major new event at the Aswan Dam in Egypt, and there have been several re-appraisals of familiar events of the past. The effect of man-made reservoirs on local seismicity has been recognized since Carder's¹ early work at Lake Mead in Colorado, but the subject first attracted wide publicity in 1967 following the dramatic paper by Galanopoulos² giving details of the upsurge of seismicity following the filling of Lake Kremasta in Greece, when for the first time damage was attributed to an induced earthquake (see *News and Views* 295, 9; 1982).

It was soon realized that earlier large earthquakes at Xinfengjiang in China (1962) and Kariba in Central Africa (1963) were also reservoir-induced, and late in 1967 the largest induced event to date occurred at Koyna in India, with a magnitude of 6.5, causing more than 200 deaths and considerable damage.

Since then, more and more cases have been found, some spectacular and others evident only after careful statistical analysis. Recent compilations³ list more than 100 instances of reservoirs presumed to have induced earthquakes. Analyses of these cases suggested that minimum values of volume and depth were needed for induction, and that depth was by far the more important, reservoirs more than 100 m deep being much more prone to produce a seismic effect.

It was not therefore unexpected that Lake Nasser, behind the Aswan High Dam in Egypt, had induced no earthquakes since its initial impounding in 1965, for although it is the second most voluminous artificial reservoir in the world (exceeded only by Bratsk in the Soviet Union) its maximum depth is only about 72 m, and this was not reached until 1975. A recent article by Kebeasy and his colleagues⁴ shows, however, that an earthquake has now occurred — near the edge of the lake, 65 km to the south-west of the dam on 14 November 1981. It had a local magnitude of 5.6 (Helwan), body-wave magnitude about 5.25 (NEIS and ISC), was felt as far as Khartoum, 900 km to the south, and caused some damage at Aswan, although not to the dam or installations.

The event occurred at a considerable distance from the deepest part of the lake (65 km) and a considerable time after impounding (16 years since starting, 6 years since attaining full depth), and it is therefore natural to ask whether the earthquake was an induced event at all. Although there appear to be existing east-

west features in the epicentral area, and surface cracking was observed that could be associated with these, no instrumentally determined earthquakes have previously been located in the upper Nile Valley. Furthermore, Simpson's⁵ theory of mechanism for induced earthquakes suggests that the first events should be at some distance from the deepest part of the reservoir, and occur some time after impounding when the inducing effect of increased pore pressure first overcomes any inhibiting effect of loading. Thus a strong case can be made for an induced origin for this event, particularly as there appears to be a long-continuing aftershock sequence, which is another usual feature of reservoir-induced seismicity. These aftershocks were initially studied with portable recorders by the Geological Survey of Egypt and are now being monitored with a telemetered seismograph network in a joint venture between Helwan Institute of Astronomy and Geophysics and Lamont-Doherty Geological Observatory, New York.

Early studies of reservoir-induced earthquakes were mainly concerned with questions of seismicity, such as locations and numbers of events, and their relation to fluctuations in water level. The growing awareness of the role of fluids in earthquake mechanism, brought about by the advent of the dilatancy-diffusion hypothesis and experiments in seismogenesis by fluid injection, has recently rekindled interest in the subject.

It is therefore not surprising that as well as studies of new cases, many of the early induced sequences are being re-examined with newer techniques in the light of modern geophysical concepts, and in particular, detailed studies are being made of variations in position and mechanism with time.

The Kremasta sequence is the subject of a recent review⁶ which shows that the mechanism of the aftershocks changed after 9 months from normal faulting (which is the favoured mechanism for induction) to thrusting with a different orientation, and the suggestion is made that this change reflects the end of the induced phase and the resumption of normal regional seismic activity.

Another article⁷ continues the work of Simpson and his Soviet co-workers on activity near the Nurek Reservoir in Central Asia, which in contrast with Lake Nasser is high (315 m) with a small area and in a region of predominantly compressive tectonics. These induced earthquakes have not been particularly large, but have been carefully monitored and related to seasonal changes in water level. Following a rapid

rise in level in 1976 there was a spectacular increase in activity and detailed studies show that the foci do not correlate with planes associated with surface faults, but form short segments of alternating strike-slip and thrust faulting on a scale of a few kilometres.

A major aftershock of the Xinfengjiang event is studied by a group from the Seismological Bureaus of Yunnan and Guangdong Provinces⁸ who use geodetic methods to obtain focal parameters, including seismic moment and stress drop, which complement well the conventional seismological investigations.

In yet another recent report⁹ the sequence following the Oroville, California, earthquake of 1975 is looked at in more detail, and it is shown that local seismicity decreases as the lake fills during winter and spring, and that the strongest shocks occur as the level drops during summer and autumn. The magnitude of these events seems to be decreasing with each seasonal drawdown. This was another case of late induction, with the main earthquake (magnitude 5.7) occurring nearly eight years after impounding.

As time goes on, more instances of slow-acting induction may be found, and more reservoirs such as Lake Nasser, assumed to be seismically inactive, may produce earthquakes. Continuing detailed study of such events should confirm whether this activity is or is not truly induced by the reservoir. It is generally accepted that induced seismicity only releases strain already stored in the region, perhaps bringing forward in time earthquakes which would have occurred in the future. In no cases should reservoirs increase the long-term seismic energy release, and it may be that an episode of induced seismicity will be followed by a compensating period of quiescence. Continuing monitoring of all existing reservoirs that have already induced earthquakes, and new ones that are likely to, should continue to produce scientific rewards as well as providing the information necessary to protect dams and associated engineering structures. □

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