Notes by Richard Meehan, as yet unpublished (except in Wikipedia under "Baldwin Hills Reservoir"

[edit] Significance and diagnoses of the failure

The failure of the Baldwin Hills Reservoir received an exceptional amount of attention from the civil engineering community and remains a subject of continuing interest. The reservoir had been conceived, designed, and built during and after World War II when the pace of dam building was accelerating even as some disastrous dam failures were indicating a need for safer technologies. The builders, Los Angeles Department of Water and Power, were aware of the difficult geologic conditions presented by the site and knew well, from the experience of the sudden collapse of their Saint Francis Dam in 1928, the serious consequences of a failure of even small reservoirs in an urban setting. But this was also an era of new engineering ventures on land, sea, and space, with new technologies boldly advanced to meet what were seen as hostile challenges from both nature and communist ideologies. Dams, like nuclear technologies, were recognized as potentially dangerous but they were also considered by Americans as a showcase technology, a means of fending off danger and spreading progressive American technologies and associated social benefits at home and abroad.[2]

The Baldwin Hills dam designer, engineer Ralph Proctor, who had worked as resident engineer on the failed Saint Francis Dam and had subsequently devised new methods of producing compacted earth fill in building its replacement,[3] aggressively proceeded with the Baldwin Hills project even in the face of safety concerns and disagreements over important design details within his own department.[1]

Late 1963, when the failure occurred, was a time of notable public disasters; only a few weeks before the Italian Vajont Dam had failed, drowning 2000 people. The failure of the Baldwin Hills Reservoir, which was built to assure safe water for the people of Los Angeles in case of catastrophes such as earthquake, fire, and war, was a blow to engineering confidence, and its failure was the subject of many writings and two professional conferences (1972 and 1987, see references) in the twenty five years following the failure. The failure occurred shortly after the death of the authoritative Harvard engineer Karl Terzaghi whose ideas had long dominated both the engineering science of soil mechanics and earth dam engineering. Terzaghi had also made significant contributions to understanding subsidence in oilfields. This left the assessment of the Baldwin Hills failure in the hands of a new generation of engineers, some of whom took on conflicting roles as experts in various lawsuits.

The design and construction of the dam had been inspected and approved by the California Department of Water Resources, and a study published by that agency in 1964, soon after the failure, was meticulously documented but, even while pointing out various connections between oilfield operations in the Inglewood field and ground disturbances in the area, including beneath the resrvoir and at some distance from the reservoir, avoided a conclusive finding on oilfield causation, concluding rather vaguely that the failure was due to "an unfortunate combination of physical factors".[4]

The monetary damages resulting from the failure were large and some of the investigations which followed the state study were sponsored by litigants seeking more specific conclusions relevant to legal liability. This drew attention to oilfield operations in the area. From the outset it was clear that ground faulting, including the aseismic fault movements that destroyed the reservoir, were probably related to the many feet of ground subsidence which had occurred a half mile west of the reservoir over decades of oil extraction in the Inglewood field. The oilfield-related subsidence in the Inglewood field, though generally denied by the oil companies as a legal policy, was documented exhaustively by the US Geological Survey in 1969.[5] Subsidence following oil extraction from shallow deposits in unconsolidated sediments had been understood by oil industry experts since the 1920s[6]

Following the discovery in 1970 by geologist Douglas Hamilton of faulting and surface seepage of oilfield waste brines along the fault which traversed and extended south of the reservoir, Hamilton and Meehan concluded that oilfield injection for waste disposal and improved recovery of oil, a new technology at the time, was a significant cause of the failure, triggering hydraulic fracturing and aggravating movements on a fault traversing the reservoir even on the day of the failure.[7] Subsequently the US Geological Survey concluded in 1976 that displacements at the ground surface causing reservoir failure and also ground cracking in the Stocker-LaBrea area southeast of the reservoir were 90 percent or more attributable to exploitation of the Inglewood oil field, and that this faulting was likely aggravated by waterflooding with pressures exceeding hydraulic fracturing levels.[8]

By 1972, nearly a decade after the failure, the immediate legal issues had been settled out of court and the matter was reopened as a topic of discussion among investigators in a published engineering conference at Purdue University.

Engineer Thomas Leps, who had served as consultant on the 1964 state investigation, took on a role as neutral reviewer in this and most subsequent American studies of the failure. Leps concluded that there had been about 7 inches of offset on the fault beneath the reservoir during its life, about 2 inches of which had occurred in the months just before the failure. Leps associated the latter with repressuration of the oilfield. This, along with stretching of the ground due to subsidence of about 12 feet from oil extraction, had caused the lining failure which doomed the reservoir.[9]

Some prominent consultants including those on a team led by Arthur Casagrande, Harvard successor to Karl Terzaghi, held that oilfield operations were not a significant influence at all but that the failure was the result of defective siting and design with the heavy weight of the dam and reservoir being the significant cause of the fatal foundation movement.[10] This view exonerated the oil companies, namely Standard Oil, which had sponsored the study. Casagrande refused to acknowledge any ground movements in the area as being related to oilfield operations and argued that ground movements that affected the dam were found only beneath the reservoir, not in adjoining areas.

Most of these questions were examined once again in 1986 following investigations of a suspiciously similar major failure of the Bureau of Reclamation's Teton Dam in June, 1976, and a near failure of the Department of Water and Power's Lower Van Norman Dam in the 1971 San Fernando earthquake. Professor Ronald Scott of Cal Tech, who had participated in the Casagrande studies, noted at a followup 1987 conference on Baldwin Hills[11] that Casagrande had ignored or been unaware of ground movements clearly unrelated to the reservoir (eg those at Stocker-LaBrea) in his analysis. Another engineer, Stanley Wilson, who had also worked with Casagrande on the 1972 studies and supported the claim that oilfield subsidence was an insignificant cause, now conceded that analogous ground offsets extended well outside the reservoir area, notably in the Stocker-LaBrea area, so that the reservoir and othe fault movements could not be attributed to the reservoir itself, thus tacitly attributing responsibility for the failure to oilfield operations. Hence, there appeared to be convergence of opinion on the role of oilfield subsidence and repressurization.

The issue of oilfield causation was a central theme in most of these discussions, with little attention having been directed to the details of the failure. The absolute necessity of a lining for this site was generally taken for granted in these proceedings even as it had been by Proctor himself, regardless of the fact that almost all earth dams perform satisfactorily without linings. Some suggestions as to possible preventive design and construction techniques that might have made the dam safer were raised as engineering consensus reached a state of textbook knowledge in the late 1980s.[12] For example, the character of the compacted earth lining (which had been regularly referred to as clay but must have been substantially silt and sand, having been derived from the local Inglewood formation[4]) was raised, if obliquely, in the suggestion made in the end that improved performance might have come from the use of a different lining material.[13]

In 2001 a new angle on failure analysis was introduced by Mahunthan and Schofield, who concluded that overcompaction of the dam fill and lining was a significant aggravating factor in both the Baldwin Hills and Teton failures.[14] This assertion was based on Schofield's concepts of critical state soil mechanics,[15] a corollary of which was that heavily compacted but lightly confined soils could be dangerously unstable where seepage forces were present. This issue had not been raised in the previous American-dominated discussions and remains in some degree contrary to American ideas in both theoretical soil mechanics and practical geotechnical engineering. In fact the 1964 DWR failure study implied that heavy compaction was a favored technique for earth dam construction.[16] and this assumption appeared not to have been reexamined over the twenty five years of post failure investigation and discussion.

The failure of the reservoir has been a subject of ongoing interest in the field of dam breach studies. A recent study examined the dam failure as a two-stage process and succeeded in modeling the flood in the urban area downstream.[17]

Although the Baldwin Hills Reservoir site has now been dedicated as a community park and there is no further significant hazard associated with ground movements there, the associated faults to the southeast (Stocker-LaBrea and the Windsor School area) continue to move significantly as of 2012, causing damage to private and public facilities. The current oilfield operator, Plains Exploration and Production Company(PXP), which has intensified production and development efforts in the oilfield with the rising price of petroleum, does not, unlike its predecessor Standard Oil, acknowledge any causal connection between fault movements and oilfield activites, and has retained a team of consultants who support this

position or conclude that the causes of the movements are unknown.[18]The role of shallow hydraulic fracturing, which has recently been introduced as a means of stimulating production at depths of about 2000 feet in the southeast part of the Inglewood field[19], and at greater depths elsewhere in the field, has also generated public concern and controversy. However oil operators, while admitting that fracture pressures[20][21] are being exceeded[22]do not acknowledge the relationship of injection at fracturing pressure levels and fault movement. The PXP and PXP consultant conclusions, issued in a series of reports, that adverse effects are not present or unknown, is disputed by other reviewers.[23]
Recent discharges of oilfield gases in the Baldwin Hills may also be related to raised pressures resulting from injection and be of similar origin as the gas problems in the nearby Salt lake field..[24]

[edit] Coverage

KTLA, already a pioneer of live on the scene television coverage, used an airplane to cover the disaster. Common today, this was perhaps the first such live aerial coverage of a breaking news event.[25]

[edit] See also

- List of lakes in California
- St. Francis Dam

[edit] Notes

1. ^ a b Scott 1987
2. ^ Meehan, RL 2011
3. ^ Rogers 2011
4. ^ a b California 1964
5. ^ Castle 1969
6. ^ Geertsma 1973
7. ^ Hamilton 1971
8. ^ Castle and Yerkes 1976
9. ^ Leps 1972 p541
10. ^ Casagrande 1972
11. ^ Scott 1987
12. ^ James Ed Al 1988
13. ^ James et al 1988
14. ^ Muhunthan and Schofield 2001
15. ^ Schofield 2006
16. ^ California 1964 p 11 and Table V-2
17. ^ Gallegos et al 2009
18. ^ StrataGen Engineering 2012
19. ^ Moodie 2004
20. ^ Hubbert 1957
21. ^ Castle 1976
22. ^ Moodie 2004
23. ^ Meehan 2012
24. ^ Hamilton 1992
25. ^ http://articles.latimes.com/2003/dec/11/local/me-surround11

[edit] References

- California Department of Water Resources (April, 1964). *Investigation of Failure Baldwin Hills Reservoir*.
- Casagrande, A,; Wilson,, SD,; Schwantes, ED, (1972). "The Baldwin Hills Reservoir failure in retrospect". *Proceedings of the ASCE Specialty Conference on the Performance of Earth and Earth-Supported Structures, Purdue University*.
- Castle, RO; Yerkes, RF (1969). "A Study of Surface Deformations Associated with Oil-Field Operations:". *Report of the U.S. Geological Survey, Menlo Park, California.*.
- Castle, RO; Yerkes, RF (1976). "Recent Surface Movements in the Baldwin Hills, Los Angeles County California". *Geological Survey professional paper 882*.

- Cowen, Richard (11 February 2002). "CHAPTER XX: Man-made Subsidence". University of California, Davis. https://www.geology.ucdavis.edu/~cowen/~GEL115/115CHXXsubsidence.html. Retrieved 2009-04-05.
- Fireman's Grapevine (February 1964). "Firemen Save 18 Lives in Baldwin Hills Flood". *The Fireman's Grapevine*. http://www.lafire.com/famous_fires/631214_BaldwinHillsReservoir/121463_BaldwinHillsReservoir.htm. Retrieved 2009-04-05.[dead link]
- Gallegos, HA,; Sanders,, BF,; Schubert, JE, (August 2009). "Two-dimensional, high-resolution modeling of urban dam-break flooding: A case study of Baldwin Hills, California". *Advances in Water Resources Vol 32, Issue 8*.
- Geertsma, J (1973). "Land subsidence above compacting oil and gas reservoirs". *Journal of Petroleum Technology SPE_AIME*.
- Hamilton, DH; Meehan, RL (23 April 1971). "Ground Rupture in the Baldwin Hills". *Science* **172** (3981): 333–344. doi:10.1126/science.172.3981.333. PMID 17756033. http://www.stanford.edu/~meehan/la/pubs/pubbaldw.pdf. Retrieved 2009-04-05.
- Hamilton, DH; Meehan, RL (1992). "*Cause of the 1985 Ross Store Explosion and Other Gas Ventings, Fairfax District, Los Angeles," Engineering geology practice in southern California; ed. by Bernard W. Pipkin and Richard J. Proctor*. Association of Engineering Geologists. Southern California Section; also presented June 19-22, 2000, AAPG Pacific Section and Western Region Society of Petroleum Engineers Meeting in Long Beach, California. pp. 769. ISBN 0-89863-171-8.
- Hubbert, Wk and Willis, DG (1957). "Mechanics of Hydraulic Fracturing". *AIM Peroleum Transactions* (TP 5497).
- James, L. B.; Kiersch, G. A.; Jansen, R. B.; Leps, T. M. (1988). "“Lessons from notable events.”". *in Jansen, RB ed. "Advanced dam engineering for design, construction, and rehabilitation"*. NY.: Van Nostrand Reinhold.
- Leps, Thomas M, (1972). "Analysis of failure of Baldwin Hills Reservoir". *Proceedings of the ASCE Specialty Conference on the Performance of Earth and Earth-Supported Structures, Purdue University*.
- Meehan, RL (2012). "Ground rupture in the Baldwin Hills: fracking 2012". http://www.youtube.com/watch?v=c4sm7DdIMkk. Retrieved 2012-12-15.
- Moodie, WH; et al (2004). "Multistage Oil-Base Frac-Packing in the Thick Inglewood Field". *Society Peroleum Engineers* (SPE 90975): 9p.
- Muhunthan; Schoefield. *Liquefaction and Dam Failures, GeoDenver-2000, Denver, Colorado*.
- Rogers, David (2011). "Mechanical Compaction of Soils for Engineering Purposes". http://web.mst.edu/~rogersda/umrcourses/ge441/online_lectures/compaction/GE441-Lecture2-1.pdf. Retrieved 2011-06-15.
- Schofield, A. N. (2006). *Disturbed soil properties and geotechnical design*. Thomas Telford. pp. 216. ISBN 978-0-7277-2982-8. http://www.amazon.com/Disturbed-Soil-Properties-Geotechnical-Design/dp/0727729829/ref=sr_1_1?ie=UTF8&s=books&qid=1242332936&sr=8-1
- Scott, RF (1987). "Baldwin Hills reservoir failure in review". *Engineering Geology* **24** (1–4). ISSN 00137952.
- Stratagen Engineering Company (2012). *PXP Baldwin Hills Inglewood Oilfield: Review and Discussion of 2012 Surface Survey Results*. Consultant Report to PXP.
- Zhai, Zongyu; Sharma, Mukul (2005). "A new approach to modelling hydraulic fracturing in unconsolidated sands". *Society of Petroleum Engineers* **SP96246**: 14.

[edit]