13th World Conference on Earthquake Engineering
Vancouver, B.C., Canada
August 1-6, 2004
Paper No. 3268

Fire Following Earthquake – Flex Hose

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Summary

This paper describes the use of Flex Hose for use by water and fire departments to address the Fire Following Earthquake issue.

This paper starts with a history of the 1923 fire that destroyed part of the City of Berkeley. The paper describes how the water system infrastructure was insufficient to control this fire. This paper then discusses the pipe replacement and flex hose options that water utilities and fire departments can use to limit this kind of threat in modern cities for both urban-interface fires and fire following earthquake threats.

For a comprehensive examination of Fire Following Earthquake and urban conflagration issues, see FFE (2004), a 350 page report edited by Charles Scawthorn, John Eidinger and Anshel Schiff.

The Berkeley Fire of 1923

Berkeley California is located in the East Bay part of the San Francisco Bay Area, on the flat lands along the Bay shore and extending into the East Bay hills, which rise to about 1,000 ft. The region is subject to a phenomenon known as, *Diablo winds*, which are the local name for a hot dry wind coming down off a mountain range, rising in temperature as it descends. On September 17, 1922, a Diablo wind condition existed and a fire began about 2 pm in wildlands in the hills just east of Berkeley. The winds drove it into the hill portion of Berkeley, which was residential with many houses of a highly combustible brown shingle style – wood shingle siding and roofing. The fire department immediately made a request to neighboring cities and even to San Francisco across the Bay. The large city of Oakland to the immediate south had 13 fires of its own at the time, and could not respond.

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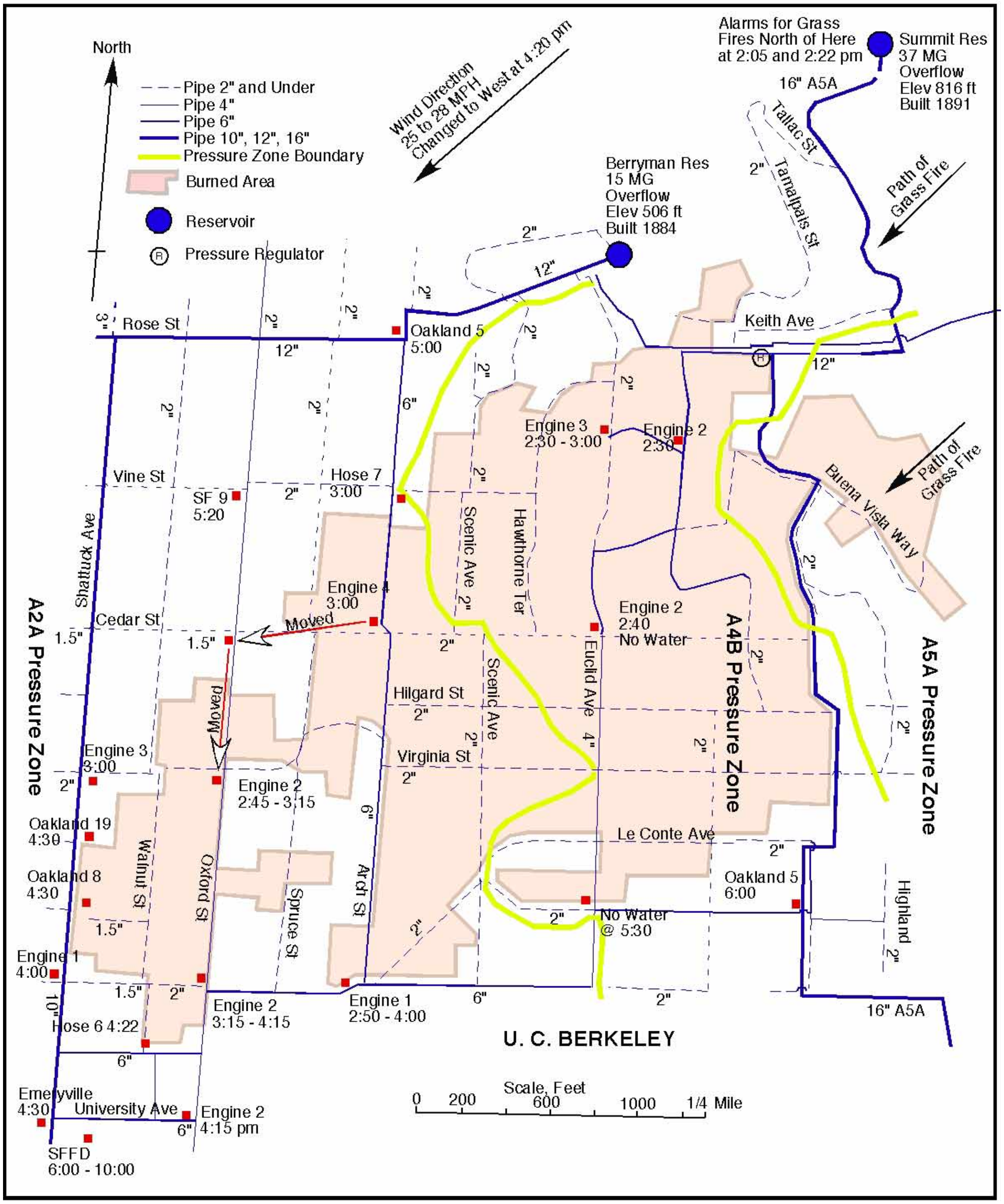

Figure 1. Map of 1923 Berkeley Hills Water System, Fire Spread and Response

A total of 584 buildings were wholly destroyed and about 30 others were seriously damaged. Only 7 buildings were masonry, the remaining of wood frame construction. About 8% of the buildings had fire retardant roof coverings. Many buildings had close set backs between each other (under 5 feet), although streets were moderately wide (60 feet).

The total loss was estimated at $10,000,000 ($1923). The fire rendered 4,000 persons homeless.

At the time of the fire, the local water utility had substantial infrastructure in place. Two large local reservoirs had been built in 1884 and 1891; these reservoirs were (at that time) filled from local springs and run-off, although these same reservoirs are now (2004) filled with treated surface water from sources over a hundred miles away. At an elevation higher than the ultimate burned area, there was a 37,000,000-gallon water reservoir that provided water into the "A5A" pressure zone, Figure 1. At about mid-elevation in the burn area, there was a 24,000,000-gallon reservoir (since downsized to 15 MG and operated at 11 MG) that provided water into the "A2A" pressure zone. The middle elevation A4B pressure zone got all its water via a pressure regulator from the higher elevation A5A zone. There were water pipelines along every city street that ultimately burned. In an after-incident analysis of why this fire could not be better controlled, several observations were made by the water utility:

- First, the fire spread from uphill (elevation 650 feet) to downhill (elevation 200 feet) locations.
- Second, there was plenty of water in local storage tanks at the time of the fire; these water sources were not depleted in the course of fighting the fire.
- Third, the street layout was fairly regular, with water pipe service on every street.
- Fourth, water distribution pipes in the burn area were commonly 2" diameter cast iron or redwood pipes
- Fifth, immediately adjacent to the burn area the pipes included 10", 12" and 16" diameter pipes.
- Sixth, the fire continued to burn downhill towards the central business district of Berkeley until about 5:00 pm that day, when a combination of factors worked together to halt the fire.

The factors that halted the fire were as follows:

- The winds were dying down by 5:00 pm, so the natural spread of the fire was slowed;
- As the burned area expanded down hill, the ability for fire fighters to apply water onto the fire greatly increased, as the water distribution system for the central business district of Berkeley included many large (10" and larger) diameter pipelines, thereby providing a much better water supply to control the fire at those locations. The use of a fireboat at the Berkeley shoreline some 4 miles to the westernmost bounds of the fire would have been decidedly ineffective.

In the years following this fire, the local water utility (East Bay Water, subsequently merged into the East Bay Municipal Utility District) decided that use of 2" diameter pipeline for city service was no longer acceptable, and undertook a large effort to replace every 2" diameter pipeline with new pipelines of at least 4" diameter or larger. This was an expensive effort, with the cost borne in general rates; apparently the decision to not replace 4" pipeline with larger pipes was in part a consideration to the overall cost; this decision would prove costly again in the Oakland Hills fire of 1991. In response to this fire, for the area seen in Figure 1, many improvements were made including the following: the 12" pipe to feed Berryman reservoir was upgraded to 24" in 1927; the bulk of the 2" pipeline seen in Figure 1 was replaced by 6" or 8" pipes by 1925; a few 2" pipes were replaced with 4" pipes by 1937. The 6" and larger pipelines (originally installed about 1901) seen in the figure are largely still in service in 2004. The single regulator station to provide water into the A4B pressure zone (middle level zone between the yellow lines in the figure) has been supplemented by two other regulators at geographically dispersed areas. It is interesting to note that the active Hayward fault cuts through the area in the figure on a north-north-west direction, more or less parallel to the 16" Summit pipeline; it remains to be seen how well this area does in future earthquakes.

In 1951, the NFBU rated the risk of fire in the area burned in 1923 as follows: "water supply varies from poor to fair"; about 1 in 50 new roof coverings are combustible; however there are still some districts with a large proportion of wooden shingle roofs; … with consideration of high winds and periods of low humidity, the conflagration hazard in the closely built residential districts is fairly severe; … steps taken to prevent grass and brush fires in the hills [will] help to keep the conflagration hazard down". The 1932 version of the NFBU report for the residential parts of Berkeley rated the risk of conflagration as "severe".

The rapid spread of this 1923 fire can be summarized as being caused by four principal factors:

- An ignition located outside the urban area where there were no water supplies to rapidly control it
- High winds (20 to 28 mph) spread the fire into the City of Berkeley
- The building inventory was comprised of mostly wooden buildings, most with shingle wall or roof coverings
- The inability of fire departments to get adequate flows out of hydrants along streets with 2" diameter pipelines

In the years following the 1923 fire, there were various panels established to examine and make recommendations to reduce the risk of fires in the Berkeley – Oakland Hills. Fire risk in this area remains a continuing high hazard, with 14 separate fires of at least 3 acres in size from 1923 to 1990, including the 1971 Claremont Canyon fire that burned 40 structures. Recommendations to remove shingle roof coverings, or at least not allow any news ones to be built, were sometimes recommended but not implemented. Some improvements in the 1980s were made to the hillside water systems including those in neighboring Oakland, albeit that these improvements were somewhat compromised by anti-development protests. Minor firebreaks were maintained. Still, with all these improvements, the 1991 Oakland Hills fire resulted in the loss of over 3,000 homes and 29 persons dead.

Pipe Replacement or Pipe Bypass?

It is well established that the primary type of damage to water systems in earthquakes is failure of buried pipelines. Other types of damage also occurs, such as failure to tanks, damage to buildings, loss of electric power that hampers pumping, damage to emergency generators, landslides into reservoirs that impact water quality, toppling of outlet towers, possible failure of dams, etc. However, the most prevalent kind of damage has been, will likely continue to be for the foreseeable future, leaks and breaks to underground pipes.

In a large water system of say 1,000 to 4,000 miles of distribution pipelines, having a few pipe breaks per week is not unusual. However, a large earthquake could generate about one pipe repair per mile of pipeline, should the pipeline inventory have the following features:

- Poor materials of construction. Cast iron pipe is one of the weakest styles of pipeline construction. Eidinger (2001) provides a comprehensive discussion of the fragility of other common pipeline materials. Overall, it would be fair to say that pipes designed to modern AWWA standards, are for the most part, not particularly reliable under earthquake conditions in locations subject to non-ideal geologic conditions. While pipe material and construction techniques are available to provide highly reliable designs, most modern water utilities do not install seismically-designed pipelines, even in high seismic risk areas.
- The pipelines traverse areas that are prone to ground failure. These areas include: fault crossing locations; landslide zones; liquefaction zones. It is not uncommon for about 5% of the entire pipeline inventory of a water utility in a large urban area to traverse these zones. Perhaps 70% or more of all pipeline damage in a water system will occur in these 5% of all areas. Depending on the hydraulic characteristics of the water system, heavy damage to these 5% of pipelines might result in a complete loss of water supply to 80% or more of the water system.

Given this problem, water utilities are faced with the following two extreme choices:

- Choice 1. Do nothing. This costs nothing up front, but can result in $ billions of losses after earthquakes. The Bay Area Economic Forum has suggested a $29 billion loss to the San Francisco Bay Area solely attributed to the failure of water systems; while BAEF's calculation might be too high as a more realistic calculation would indicate $6 to $7 Billion, either set of numbers suggests that water system performance is a potential "Achilles Heal" to a community.
- Choice 2. Replace all pipelines in soils prone to ground failure. Assuming that a large water utility has 250 miles of pipeline traversing poor soil areas, and allowing that the pipe diameters range from 6" to 36", averaging about 8" diameter, and allowing that special seismically designed pipeline can be installed in urban areas for about $20 per inch foot, then a complete seismic replacement program might cost: 250 miles * 5280 feet / mile * 8 inches * $30 per inch-foot = $317,000,000. This is a rather large capital cost, even for a moderately large utility. The utility might wish to do an even more comprehensive job, like

replacing all of its aging cast iron pipe, all or its 4" small diameter pipe, etc. that are located in areas with corrosive soils. This might involve replacing about 1,000 miles of pipe with new "standard" design pipe (often rubber gasketed PVC or ductile iron) pipe, which should perform reasonably well in soils not prone to permanent ground failure. This cost would be: 1,000 miles * 5,280 feet / mile * 8 inches * $20 per inch foot = $845,000,000. For this example, the total pipeline retrofit program would be about: $317 million + $845 million = $1,162 million.

Clearly, Choice 2 is preferable over Choice 1 with regards to post-earthquake performance of a water system. But, somebody has to pay the $1.2 billion capital cost for Choice 2. Using the benefit cost concepts, it will usually be found that a current capital cost of $1.2 Billion will not be worth the avoided losses ("benefits") from future earthquakes, if one uses a reasonable time value for money (say 4% to 7%).

Given this, some water utilities have tried to implement some sort of "middle ground" when dealing with the potential of damage to pipelines. This "middle ground" approach goes something like this:

- Identify all "backbone" pipelines in the system. Backbone pipelines are usually those pipes 12" and larger in diameter, that bring water from sources (water treatment plants, pump stations) to destinations (tanks, critical customers).

- Map out the hazards on these backbone pipelines. If there are no significant hazards (i.e.., the risk of failure of the pipeline is less than a few percent, given a major earthquake), then that pipeline might be adequate "as-is". If there are significant hazards (fault crossing, active landslide, substantial liquefaction) such that the existing pipeline cannot reliably accommodate the hazard, then this backbone pipeline is "not-reliable".

- Consider if the destinations served by these unreliable pipelines can be served by alternative reliable sources, including local wells, other pipelines, etc. If no other reliable alternative source exists, then consider building a new reliable pipeline to that destination, if hydraulic demands (increasing population, etc.) so require another pipeline over the 20 to 30 year planning horizon.

- If there is no need for a new pipeline for hydraulic purposes, then consider two style of backbone pipeline retrofit:

    - Option 1. Replace the pipeline in place with a new pipeline with better seismic design features, such that the new pipeline can reliably accommodate the hazard without failure; or

    - Option 2. Install a bypass system to allow the rapid restoration of water service using above ground flexible hose.

For fire fighting purposes, the first option (pipe replacement) is the best choice in terms of keeping water available immediately after an earthquake. For restoration of customer service, the second option (usually much cheaper to install) might be the most cost effective for purpose of rapid (under 24 hour) restoration of water to large areas in a water distribution system. For a 24" diameter pipe with a hazard crossing of length 1,200 feet, the pipeline replacement option might cost: 1,200 feet * 24 inch diameter * $30 / inch-foot, plus manually-operated valves = $864,000 + valves, say $1,000,000. The installation of a bypass system might cost: manually-operated valves + appurtenances = $200,000, plus some length of above ground flexible hose.

For a large water utility with perhaps 50 larger diameter pipes crossing high hazard zones, there might be situations where the pipe replacement option is best, or situations where the bypass option is best. When considering how much hose to have on hand, one also has to consider that not all pipes will fail at all hazards, and so the total hose needed to have on hand should be just sufficient to accommodate the total expected pipe failures.

Above Ground Ultra Large Diameter Hose Pipe Bypass

Figure 2 shows the actual deployment of above ground flexible hoses uses to bypass a 24" diameter pipeline that crosses the Hayward fault. In the foreground of this figure are three pipe elbows. Attached to the elbow on the left is a 12" diameter blue-colored "super aqueduct" hose manufactured by Angus. We call this 12" ultra large diameter hose, ULDH, in distinction to 5" large diameter hose, LDH, commonly used by fire departments. Attached to the middle elbow is another hose, but unpressurized. The third elbow is currently shown with no attached hose. The original 24" diameter steel pipeline is located in the road to the left of the hoses. The Hayward fault traverses across this street, a few hundred feet away from the elbows seen in the foreground. A similar set of three elbows is located at the other side of the fault, about 900 feet from the elbows seen in the foreground.

Figure 2. Flex Hose Deployment in EBMUD System

Figure 3 shows the same three elbows seen in the foreground of Figure 2, from a side view. The hose is attached to the elbows using victaulic couplings. The three elbows are in turn connected to a buried 12" diameter pipe which laterals off the main 24" diameter transmission backbone pipe. The street repair (new pavement) seen in Figure 3 shows where the new 12" lateral has been installed.

Figure 3. Flex Hose Deployment in EBMUD System

In actual practice, the flex hose can be deployed by a minimum of 2 men, and connected up in about 1 hour. In a post-earthquake environment, this might take longer, but with a reasonable emergency response plan, a crew of 8 people could reasonably deploy about 6 such installations in 8 hours. It would take these same 8 people about 15 to 20 days to repair the same damaged pipes. In this way, restoration of water service is spec up from 15 to 20 days, to perhaps 8 hours.

Should fires be occurring within the first 8 hours, then the flex hose installation technique will not be as ideal as the pipe replacement technique. This should be factored into the decision as to what type of pipe replacement option to undertake.

The flex hose option has some other drawbacks. First, the utility will be deploying above ground hose. At a pressure of perhaps 100 to 150 psi, the force within a 12" diameter hose is about 11 to 17 kips. If the hose should break for any reason, then the hose will move at great force, impacting cars and nearby passersby, and even structures. The likelihood of a hose break can be minimized by selecting suitable non-traffic crossings, or by closing the street to traffic. The quality of ULDH manufacture can be quite high, and the hose shown in Figures 2, 3, and 4 has a nominal burst pressure of 400 psi; connection fittings are stronger than the hose with regards to burst pressure. However, any motorist with a SUV could still try to straddle a 12" hose, and possibly a hot muffler will get caught on the hose. The author has witnessed taxi cab drivers driving over 5" hose with a similar outcome; and it should be understood that it is hard to restrain citizens from driving through street barriers and over hose. A 12" diameter pressurized hose looks like quite a formidable obstacle, but citizens with Hummers, taxi cabs and the appetite for unrestricted access by the news service (that led to failure of the 5" hose deployed in the 1991 Oakland Hills fire) must be considered.

Large diameter flex hoses can also be hooked up to fire hydrants, as for example in Figure 4. The hose is attached to a special fitting placed under the hydrant, in order to accommodate the change in diameter. A different fitting could be used to attach the hose directly to the screwed 4.5" diameter pumper outlet fitting on the hydrant. The small pipe outlets seen in Figures 2 to 4 provide an easy way to empty water from the large diameter flex hose when it is time to roll it up; and also to flush the hose should that be necessary.

Figure 4. Flex Hose Attachment To Fire Hydrant

Figure 5 shows a "flaking" truck being hauled by a heavy pickup truck. The large diameter hose (up to 600 foot length) is stored in the flaking box, and then driven to the site, and then deployed. Figure 6 shows a "hose reel" as an alternative way to store and deploy large diameter hose (in practice, the storage of hose in flaking boxes, Figure 5, might be most cost effective).

Figure 5. Deployment of Flex Hose

Figure 6. Alternate Deployment of Flex Hose

Above Ground Large Diameter Flexible Hose Pipe Bypass

Depending upon the length of hazard to be bypassed, and the required flow rates, it will sometimes be feasible to use large diameter (5" to 6") above ground flex hose to do, more-or-less, the same function as the 12" ultra large diameter flex hose. Fire departments are well versed with the use of large diameter flex hose. Figure 7 shows just one such deployment.

Figure 7. Deployment of Large Diameter Flex Hose

When using 5" diameter flex hose, it might be feasible to also install ramps to allow traffic to go over the hose. One such example is seen in Figure 8. These ramps will require additional time / manpower to set up the hose. Even with these ramps, there is no guarantee that vehicles will use them – as was evidenced when a taxicab got stuck on a 5" hose.

Hydraulics

The use of flex hose to bypass existing underground pipelines must consider the required flow rates and allowable pressure drops.

The use of a single 5" or 12" diameter flex hose over a moderate distance (say 950 feet) will result in the following pressure drops for typical flow rates:

- 500 gpm = 0.3 psi pressure drop (12") = 18 psi pressure drop (5")
- 1,000 gpm = 0.9 psi pressure drop (12") = 65 psi pressure drop (5")
- 2,000 gpm = 3 psi pressure drop (12") = 233 psi pressure drop (5")
- 5,000 gpm = 18 psi pressure drop (12")

Given these flow rates and pressure drops, it is apparent that a single 12" diameter flow rate can probably be sufficient to flow at 2,000 to 3,000 gpm rate over a 950 foot length, with acceptable pressure drops. If the target flow rate is to meet winter time demands, plus possibly a fire, then a single 12" diameter hose might be sufficient to bypass a 24" to 30" diameter pipe.

Smaller diameter flex hose (5" diameter) cannot handle flow rates much above 500 gpm over lengths of about 1,000 feet unless booster pumps are used. While a 5" diameter flex hose is often adequate for delivering water from a hydrant to a fire pumper truck, over a length of no more than 250 to 300 feet, it is not very useful for modest flow rates over the moderately long distances usually involved with pipelines that traverse hazard zones.

Figure 8. Use of Ramp Over A 5" Diameter Flex Hose

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