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PERFORMANCE TESTING OF EARTHQUAKE ACTUATED GAS SHUTOFF SYSTEMS

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ABSTRACT:

Fires resulting from damage to natural gas appliance or delivery systems in residential homes continue to be a factor for fire loss during earthquakes. Earthquake actuated gas shutoff valves (hereafter, simply "seismic valves" or "valves") have come into increasing demand in the United States, particularly in California, as one means of reducing such losses. Moreover, pressure has applied to pass public law requiring such valves to be installed in residential and commercial structures. In the process of updating the United States national standard for these valves, fifteen valves were tested including several different types. This paper presents a description of these tests, together with the results, and interprets the results as they reflect on the existing standard, and recommends the best characteristics for future valves based on these results.

KEYWORDS:

Gas, shutoff; valve; performance; testing; standards

OBJECTIVE:

The current United States national standard controlling the testing and qualification of seismic valves was developed by the American Gas Association (AGA) and issued in 1981 titled ANSI/AGA Z21.70 *Earthquake Actuated Automatic Gas Shutoff Systems* (hereinafter referred to as ANSI Z21, Reference 1). National standards must normally be reviewed every five years. The American Society of Civil Engineers (ASCE) has established a standards committee (hereinafter referred to as the Committee) to review and, if necessary, revise the standard.

Numerous seismic valves have been developed during the past fifteen years which meet the basic requirements of the standard. Their performance has come into question in terms of the concerns regarding the standard; namely frequency response and limits of actuation. The questions are, given the quality of the existing standard, how accurate are the current valves and how well do they do their job? How can the standard (and the valves) be improved? How good are these devices at preventing loss? Development of the new standard was postponed by ASCE in early 1995 in order to perform necessary research evaluating the actual performance of existing valves; both in the laboratory and in the field. The objective of this research was to develop better understanding of existing valves using a vibration table and actual earthquake motions in order to facilitate writing the new standard.

This research was supported by the Federal Emergency Management Agency, the Southern California Gas Company, the Pacific Gas and Electric Company, Mountain Fuel, and most of the seismic valve manufacturers. Complete details of the experimental test program are contained in References 2. and 3

Committee Concerns

The discussions of the Committee resulted in the following concerns:

1. ANSI Z21 tests sensors for actuation at three (3) frequencies: 1Hz, 2.5 Hz, and 10 Hz. What is the actual range of performance over a broad range of frequencies? Could valves meet the standard (illustrated by characteristics A and B in Figure 1) fail to trigger under typical earthquake motions? Will an independent test demonstrate that the valves do meet the existing standard?
2. Do some valves have different response in one axis than the other?
3. Are the valves robust to survive the very strong shaking of a near-field event with magnitude greater than 7?
4. Vertical response is not addressed in ANSI Z21. Damage to gas appliances has generally been attributed to horizontal motions which are always present and usually dominate the S-wave (shear wave) component of the ground motion. Early shutoff from P-wave (compression wave) arrival is not desired since the P-wave is not always indicative of the strength of subsequent S-waves. Is it possible that some valves are more sensitive in the vertical axis than the horizontal?

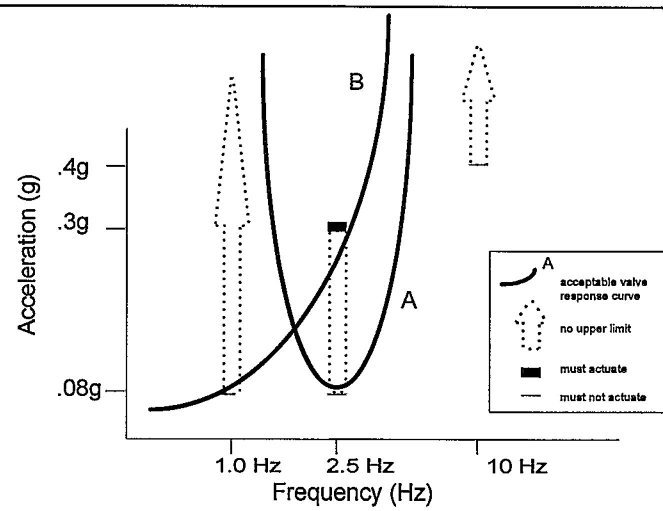


Figure 1 Valve Responses Acceptable Under the Current Standard

5. One of the major concerns about the existing standard was the large gap between "must not actuate" (.08g at 2.5 Hz) and "must actuate" (.3g at 2.5 Hz). What are the actuation levels of existing production valves relative to this wide range of acceptable levels?

Test Objectives

Based on these concerns, the test program described in Reference 3 was designed around the following principal objectives:

1. Identify resonance frequencies (if any) in three (3) mutually perpendicular axes of each valve assembly. The purpose here was not so much to see if there were resonances in the valves bodies (we didn't expect any), but to see if there were frequencies at which components of the actuator mechanism might resonate. For example, we knew that in some valves, a ball would fall into a silicone or rubber seat. Could it resonate and bounce? Would it matter?

   A secondary purpose was to verify the rigidity of the test setup.

2. Identify the applied vibration level at which the valve actuated (turned off) for discrete 1/3 octave intervals (where each octave is a doubling of the frequency) between 0.5 Hz and 15 Hz in each of three (3) mutually perpendicular axes. This data would be used to evaluate concerns 1, 2, 5, and 6 above.
3. Measure valve shutoff performance at selected earthquake time histories applied in three (3) axes simultaneously. This data would be used to evaluate concerns 3 and 4 above.

The performance tests were conducted on two, single axis (one horizontal and one vertical) hydraulic shaking tables. The earthquake simulation tests were conducted on a triaxial shaking table using six actual earthquake time histories.

Earthquake Motion Selection

The earthquake time-histories or accelerograms used for the earthquake simulation testing (Objective 3) were selected by Agbabian Associates and EQE (John Diehl and Doug Honegger, respectively). The bases for selection were several-fold:

1. The time-histories had to be real earthquake records. Simulations would not be permitted.
2. The earthquake records were selected from a major event in which we also had data on structural damage and gas related fires. The event which had the most extensive amount of such data was the recent Northridge Earthquake of January 17, 1994. It was found that the approximate border for most fire and structural damage coincided roughly with the .3 to .4g peak acceleration contours. (more information on this aspect is provided in Reference 4). These accelerations correspond to the estimated vulnerability of many gas appliances.
3. The ensemble of earthquake records had to represent a broad range of frequency content. This requirement was intended to address a concern for modification of frequency content by local soil conditions.
4. There had to be at least one event which tested the "survivability" of the valves, and represented a "worst case" event. The Lucerne Valley record from the Landers Earthquake of June 28, 1992, was selected for this purpose. The record was high-pass filtered at 0.3Hz (2-pole) to remove the long period, high displacement components to meet the capacity of the shaking table. In addition, the "transverse" component was eliminated because the motions were still too large (the longitudinal axis was used for both horizontal inputs). Even so, the peak accelerations were significant (nearly 0.8g vertical) and the duration was over 30 seconds. Interestingly, because this recording was made very near the fault and on shallow soil, the frequency content is quite high. Nevertheless, any valve subjected to this motion would be expected to close.

The following records were selected.

DESIGNATION	EARTHQUAKE	LOCATION	PEAK HORIZONTAL ACCEL. (G)	HORIZONTAL RESPONSE PEAKS*
24464	Northridge 1/17/94	CDMG, North Hollywood Hotel Basement	.116 and -.309	5 Hz, and 2 Hz
24605	Northridge 1/17/94	CDMG, UCLA Hospital Grounds	.493 and -.214	3 Hz, and 5 Hz
5081	Northridge 1/17/94	USGS, Topanga Fire Station	.326 and -.192	3-4 Hz, and 5 Hz
5082	Northridge 1/17/94	USGS, Wadsworth VA Hospital	-.376 and .303	4 Hz, and 5 Hz
5108b	Northridge 1/17/94	USGS, Santa Susana, Bldg 462	.243 and 332	5 Hz, and 6 Hz
LUCE	Landers 6/28/92	SCE Lucerne Valley	.859	11-13 Hz

* NOTE: "peaks" may be a misleading term since many records had energy in a broad range.

Table 1 Selected Earthquake Recordings for Earthquake Simulation

Valve Mounting

All valves were rigidly mounted to the shaking table. The following sketch illustrates the typical mounting for a valve being tested in the "transverse" direction (normal to the gas flow). The use of rigid mounting configuration reflects decisions reached by the Committee on mounting requirements and the current requirements

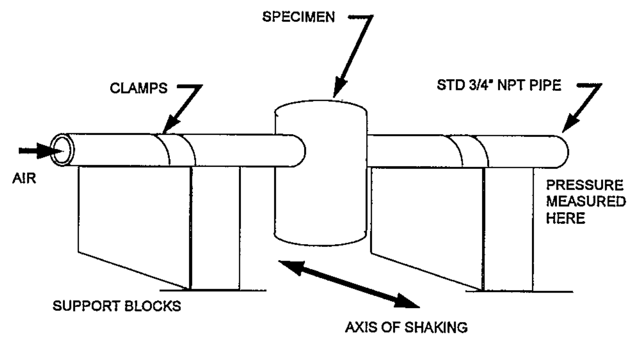


Figure 2 Typical Mounting Arrangement, Transverse Direction

The distance between the valve body and the support blocks was less than six inches. If leveling was required by the manufacturer, the valve was carefully leveled prior to testing.

RESULTS:

Fifteen valves were tested including several "ball-and-socket" valves, two "flapper" designs, and several seismic switch (contact closure) devices. In addition, the Southern California Gas Company submitted a so called "Smart Meter", developed in Japan, in which the metering device includes a seismic valve.

Discrete Frequency Actuation Tests

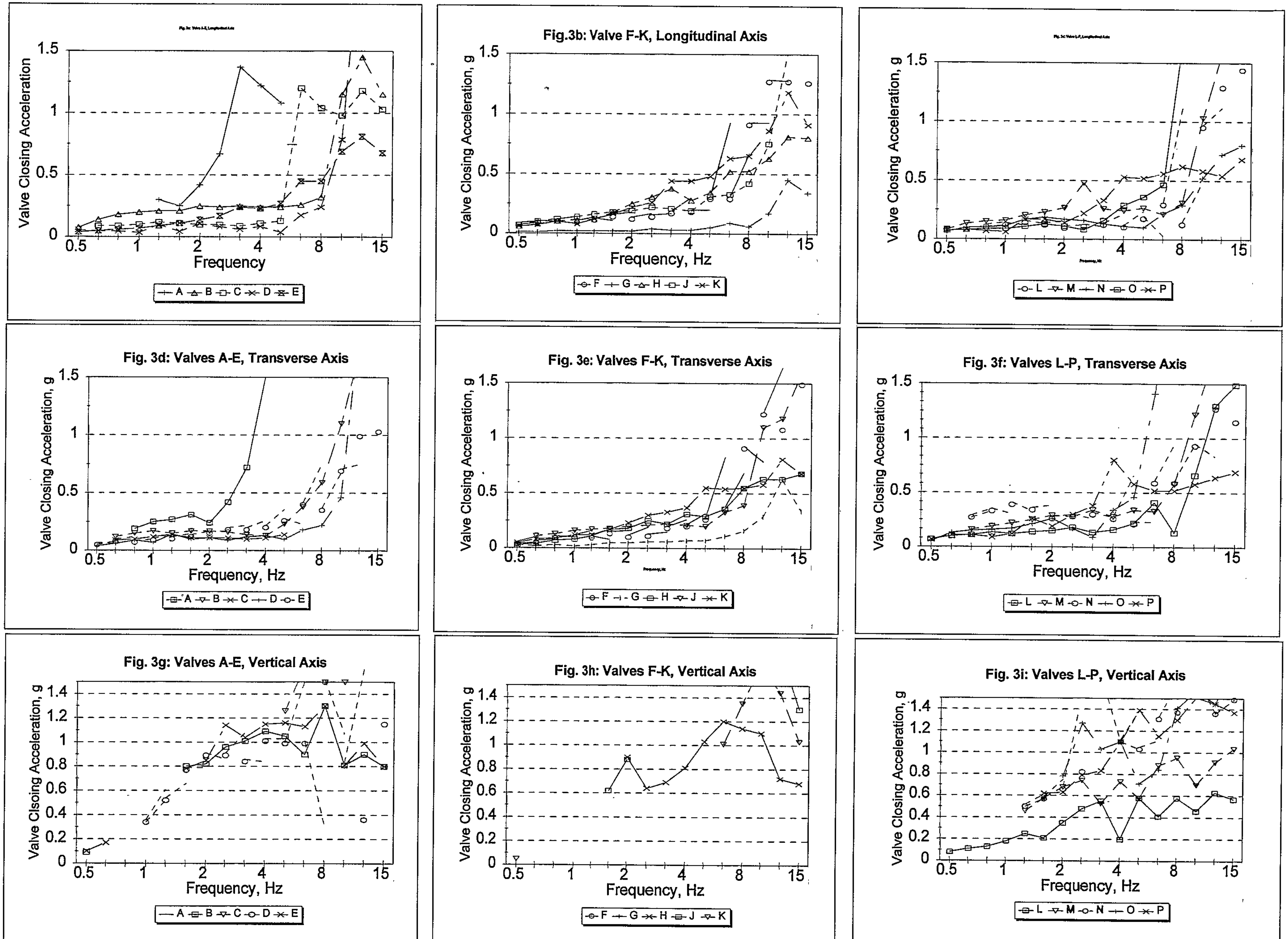
Each valve was tested at 15 frequencies (.5, .67, .83, 1., 1.33, 1.66, 2, 2.67, 3.33, 4, 5.33, 6.67, 8, 10.67, 13.33, and 15Hz) in each of three axes. At each frequency the displacement was slowly increased until the valve closed. The acceleration of the closure was determined using a two channel triggered event recorder which triggered on the change in pressure at the outlet of the pipe (see Figure 2) and recorded the entire event including some pre-event.

The results were reduced, collated and plotted in the "Gas Valve Actuation Levels" plots for each axis, superimposing the results of all the valves in Figures 3.

There was significant discussion among the committee regarding the method used to determine activation. Some were in favor a methods which would capture more accurately the moment of actuation using capacitative sensors or other devices mounted in and on the housing. This approach would have allowed us to measure the length of time it took for a valve to actually close. Unfortunately, such an approach would have meant devising different methods for each valve, and in some cases, modifying the valve to permit the measurement. The method of measuring the change in pressure was selected because it measured the specific performance expected of each valve, and it could be applied to all valves indiscriminately.

The shaking tables selected by NTS for this testing were single axis, hydraulically actuated, servo controlled shakers, each with a single actuator. For the horizontal machine, the table was mounted on linear bearings. In the case of the vertical table, the table was mounted directly on the vertical actuator. The limits of displacement were 8" double amplitude for both horizontal and vertical motion.

Figure 3 GAS VALVE ACTUATION LEVELS



Earthquake Simulation

Earthquake testing consisted of multifrequency earthquake simulations using actual time histories from the Northridge and Landers Earthquakes was conducted on a triaxial shaking table with 5 degrees-of-freedom at a facility in Detroit, Michigan. The selection criteria for the earthquakes is described in a previous section of this report.

The results of the earthquake similuation tests are presented in Table 2. A total of thirteen earthquake simulation tests were performed even though only eleven are summarized in Table 2. Two of the tests, one axis of 5082 and one of Lucerne, were repeated. Since the results were the same, the extra tests were not reported. The Northridge events were repeated with the axes rotated because, for some earthquakes, there is a significant difference in the frequency content between the two horizontal axes. Switching the horizontal inputs to the 3D table was easier than rotating all the valves.

Table 2 Earthquake Simulation Tests Conducted at Defiance STS/SMC, Detroit, MI

VALVE	5082	5081	5108B	LUCE	4605	24464	24464'	24605'	5081'	5108B'	5082'
D	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
J	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
N	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
O	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
G	← CONSTANTLY TRIGGERS DUE TO NOISE OF TABLE →										
A	no	no	no	no*	YES	no	no	YES	no	no	no
L	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
F	no	no	YES	YES	YES	YES	YES	YES	YES	no	YES
H	YES	YES	no	YES	YES	YES	YES	YES	no	no	YES
K	YES	YES	YES	YES	YES	YES	YES	YES	no	YES	YES
E	YES	YES	no	YES	YES	YES	YES	YES	no	no	YES
B	YES	YES	YES	YES	YES	YES	YES	YES	no	YES	YES
M	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
P	YES	YES	YES	YES	YES	no	YES	YES	no	no	no
C	YES	YES	YES	no	no	YES**	YES**	no	no	no	no
								ES**	ES**	YES**	YES**

NOTES:
1. 24464' is the same event as 24464, but with the horizontal axes swapped. For LUCE we used the same signal for both horizontal axes.
2. *indicates that this unit was functionally tested.
3. ** means the light (flow stopped) definitely went on AFTER the gas pressure was raised. Flow was increased temporarily after each test to assist in checking whether the valves had closed. The question arose after the third test whether the light indicator was observed before or after the flow was increased (for first 3 tests). This device also has an excess flow sensor which may have inhibited response.
4. "YES"indicates valve closed during the simulation.

Valve Response Characteristics

Most of these valves typically exhibit a relatively flat response up to a sharp corner frequency between 2 and 8 Hz after which the sensitivity decreases dramatically. This characteristic response follows the standard behavior of a second-order system with the "sensitivity" being the inverse of the frequency response. In most cases the first resonance for these valves occurred between 2 and 8 Hz.

Some valves exhibit significantly higher sensitivity at low frequencies (0.04g at .5 Hz) which could present problems in settings in which residual tilt might be expected after an earthquake. However, the amount of energy required to cause the same motion varies as the square of the frequency. In other words, the earthquake energy which causes a valve to close at 1 Hz will be four times the energy at 2 Hz for the same threshold. This means that this increase in sensitivity may work in the favor of better protection, as long as the valves are not too sensitive to small offsets from level. Most valve manufacturer's do require the valves to be leveled at the time of installation.

Most of the valves exhibited a satisfactory lack of sensitivity at higher frequencies (above 10Hz). However, with some valves, this change is not dramatic and may present a problem since it is not unusual for meter assemblies to receive minor horizontal "shocks" up to 1g at frequencies above 10Hz from non-seismic sources. For other valves, particularly valve A, the response was like characteristic B in Figure 1. Valve A begins attenuating response too soon and as a result fails to close in many of the earthquake simulations (see Table 2).

None of these valves exhibited markedly more sensitivity vertically than horizontally. Two of the valves, which were designed specifically for horizontal actuation only, showed little or no sensitivity in the vertical direction.

It appears that four (4) valves should never have passed testing under the current ANSI Z21 standard. These are D and G, for both axes, and N and P. in one out of two horizontal axis.

Several valves exhibited markedly different performance in one axis than another. These include Valves N, P, O, and G. Valve N is an extreme example as illustrated by comparing Figure 2c with Figure 2f. At some frequencies, Valve N is two to three times LESS sensitive in the transverse axis than in the longitudinal axis. Compare this to Valve J, shown in Figures 2b and 2c. The horizontal axis response in the region from 1 to 5 Hz is nearly identical.

Two of the valves exhibited characteristics which did not allow them to perform in this setting (electronic features).

Earthquake Performance

One goal of the tests was to obtain information on the vulnerability of these valves to physical damage. None of the valves exhibited any marked deterioration in performance after more than 50 resets in various settings during the tests, and after more than 13 earthquake events. Indeed, the large Lucerne Valley earthquake was conducted as the fourth of six events, after which the five smaller events were repeated with the axes switched, and there was no obvious change in performance.

The earthquake tests offered a range of events representing a variety of soil conditions and dominant frequencies. All of the earthquakes had peak accelerations in excess of 0.3g, while perhaps not in the frequency range near 2.5Hz, and perhaps not in both axes. Six of the valves closed on every earthquake no matter which orientation to the earthquake. One manufacturer's valves, of which we had four samples (different configurations) exhibited a sensitivity to the orientation of the earthquake.

One valve only triggered on one earthquake (out of six), and not on the largest event. This was valve A, which showed a strong attenuation to motion above 2 to 3 Hz (depending on the axis) in the discrete frequency tests (see Characteristics above).

It is important to note that while the current national standard for earthquake actuated valves is centered at 2.5 Hz, earthquake records selected to bound the occurrence of gas-related fires contain significantly higher frequency content. For some valves, which were designed for response at low frequencies, it was impossible to respond to these motions. Nevertheless, even though the Landers earthquake (a "maximum credible" event) has its largest response *above 10 Hz*, all valves in Yucca Valley would *still* be expected to close.

CONCLUSIONS AND RECOMMENDATIONS:

The results of the test program have justified the needs perceived by the Committee. It is clear that valves can meet ANSI Z21 and still not perform as intended in a realistic earthquake. It is concerning that four out of the fifteen valves were not in compliance with the current standard! A new standard is urgently needed to provide necessary guidance for a new generation of earthquake actuated gas shutoff devices. Suggested modifications to this new standard indicated by the test results include the following:

1. Valves must be tested at more frequencies. Three frequencies are simply not adequate. At least one testing frequency is needed between 2.5 hertz and 10 hertz; probably at 5 hertz (0.2 seconds, see 4. below).
2. The new standard must include more "must actuate" levels. The current standard allows too much leeway. Particularly in view of the Landers type of event, there should be a "must actuate" requirement at 10 Hz.
3. The fact that many valves seem too sensitive below 1 hertz is a concern, but possibly not a serious one, considering the energy required to produce significant low frequency accelerations. Therefore, the sensitivity may be appropriate.
4. A preliminary review of EQE's work also suggests that we should also be looking at frequencies in the range of 3 to 8 Hz, and not just 2.5 Hz. If this had been required before, then valve A would surely have triggered. Sensitivity should continue at least up to 5 hertz.
5. Multifrequency tests are probably not necessary. The earthquake simulations pretty much bore out the performance predicted by the discrete frequency tests.
6. Vertical tests are needed in addition to horizontal. Several of these valves exhibited some sensitivity in the vertical axis, approaching that of the horizontal. We cannot assume that valves will not trigger on vertical motion.

ACKNOWLEDGEMENT

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