Newsletter #30

Measurement of both Occupant- and Blast- Induced Crack Response Allows Calculations of their Relative Probabilities of Exceeding the Maximum Yearly Crack Response

This newsletter compares the probabilities that occupant-induced door openings and blast induced ground motions will add to the long term crack response so as to exceed the maximum yearly crack response. In other words, it provides a computational method to determine "which" straw might break the camel's back. This example employs measurements made at the Naples test house introduced in the first newsletter of this series, #27. It is the final newsletter in the 4 part series on the importance of measurement of occupant-induced and weather- induced crack response.

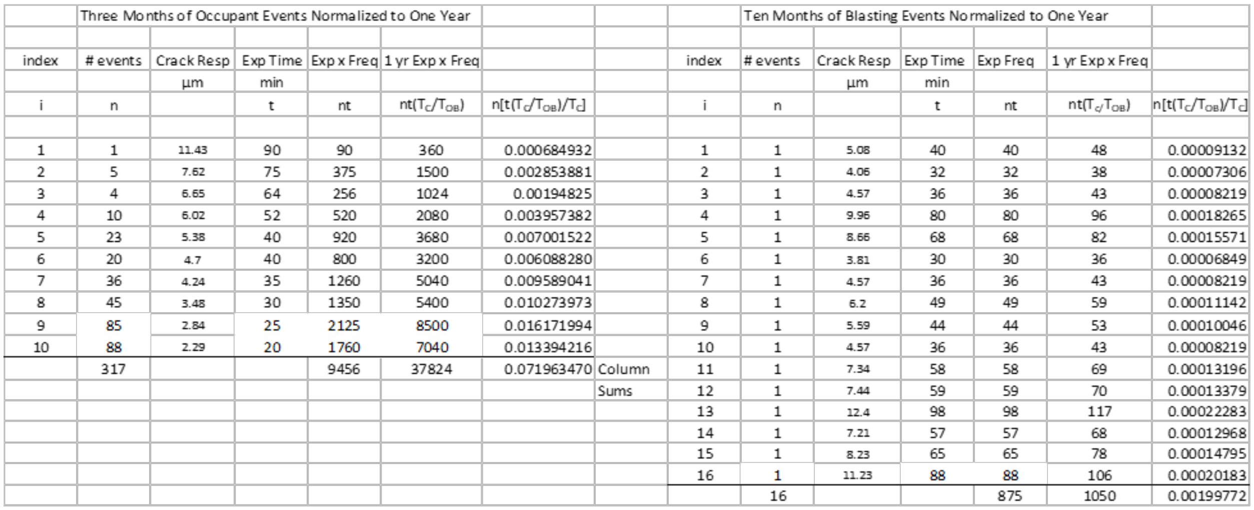
As described in Newsletter #29 probability of a given dynamic event adding to the long term crack response so as to exceed the yearly maximum can be calculated as

$$(n^* t)/T$$

where n = the number of events of a given intensity, t = time the crack is exposed to the event with this given intensity, and T is the length of the time period under consideration.

Table 1 displays the number of events, n_i, and their respective exposure times, t_i, for both blast and occupant induced dynamic events at various intensity or index levels, "i", for comparison during their periods of observation, T_{OB}. The period of calculation, T_C, is one year (525,600 min) because there is one long term maximum crack response or period of vulnerability during a year. This maximum results from annual events such as winter heating, summer cooling, changes in ground water, etc supposed on weekly weather front and daily temperature responses. The product n*t must be normalized by T_C/T_{OB} to account for the different lengths of the periods of observation. Blast induced dynamic crack response events are those from 10 months (438,000 min) of observation shown in the right half of Table 1. Occupant-induced dynamic crack responses from door closing are those from 3 months of observation (131,400 min) shown in the left half of Table 1. Since there were 16 blast induced events, each is shown. However, the large number, 300+, of occupant induced events required grouping for display purposes. Determinations of "t" showed that dynamic responses of 10 and 5 micrometers would produce "t's" of 80 and 40 minutes, and "t's" (exposure times) were interpolated as necessary and appear in Table 1 columns labeled "t". The exposure times should not be significantly extrapolated because of the parabolic shape of the maximum daily long term crack response as shown in Figure 2 in Newsletter 29.

Table 1: Comparisons occupant (left table) and blast (right table) induced N-S crack response intensity, "i" in terms of numbers, n, of responses and their respective exposure times, t. Also shown in the right-most column of each table are the probabilities that dynamic events of a given intensity (as reflected by the exposure time, "t") when added to the long term crack response will exceed the yearly maximum crack response and possibly enlarge the crack.



	Three Months of Occupant Events Normalized to One Year								Ten Months of Blasting Events Normalized to One Year					
index	# events	Crack Resp	Exp Time	Exp x Freq	1 yr Exp x Freq			index	# events	Crack Resp	Exp Time	Exp Freq	1 yr Exp x Freq	
		µm	min							µm	min			
i	n		t	nt	$nt(T_C/T_{OB})$	$n[t(T_C/T_{OB})/T_C]$		i	n		t	nt	$nt(T_C/T_{OB})$	$n[t(T_C/T_{OB})/T_C]$
1	1	11.43	90	90	360	0.000684932		1	1	5.08	40	40	48	0.00009132
2	5	7.62	75	375	1500	0.002853881		2	1	4.06	32	32	38	0.00007306
3	4	6.65	64	256	1024	0.00194825		3	1	4.57	36	36	43	0.00008219
4	10	6.02	52	520	2080	0.003957382		4	1	9.96	80	80	96	0.00018265
5	23	5.38	40	920	3680	0.007001522		5	1	8.66	68	68	82	0.00015571
6	20	4.7	40	800	3200	0.006088280		6	1	3.81	30	30	36	0.00006849
7	36	4.24	35	1260	5040	0.009589041		7	1	4.57	36	36	43	0.00008219
8	45	3.48	30	1350	5400	0.010273973		8	1	6.2	49	49	59	0.00011142
9	85	2.84	25	2125	8500	0.016171994		9	1	5.59	44	44	53	0.00010046
10	88	2.29	20	1760	7040	0.013394216		10	1	4.57	36	36	43	0.00008219
	317			9456	37824	0.071963470	Column	11	1	7.34	58	58	69	0.00013196
							Sums	12	1	7.44	59	59	70	0.00013379
								13	1	12.4	98	98	117	0.00022283
								14	1	7.21	57	57	68	0.00012968
								15	1	8.23	65	65	78	0.00014795
								16	1	11.23	88	88	106	0.00020183
									16			875	1050	0.00199772

First consider the probability that an occupant induced dynamic event occurs during the single maximum long term crack response. It is

$$P_O = \left.\frac{\sum_i n_i t_i (T_C/T_{OB})}{T_C}\right|_{\text{occupant}} = \frac{\sum_i n_i t_i}{T_{OB}} = \frac{9456}{131400} = 0.07196$$

Similarly for a blast event

$$P_B = \left.\frac{\sum_i n_i t_i (T_C/T_{OB})}{T_C}\right|_{\text{blast}} = \frac{\sum_i n_i t_i}{T_{OB}} = \frac{1050}{438000} = 0.0019977$$

and no dynamic event

$$P_N = \left.\frac{T_C - \sum_i n_i t_i (T_C/T_{OB})|_{\text{red ball}} - \sum_i n_i t_i (T_C/T_{OB})|_{\text{green ball}}}{T_C}\right|_{\text{no event}} = \frac{486726}{525600} = 0.92604$$

Thus the probability that occupant induced dynamic events would coincide with the maximum, yearly, long term crack response would be 0.07196 (P_O) and that for blast induced events coinciding with the maximum, long term crack response would be 0.00199 (P_B). It is some 35 times [P_O/P_B] more likely that an occupant induced dynamic event would occur during the period of vulnerability than for a blast induced event to occur at the period of vulnerability. This data set included blast induced peak particle velocities varied between 1 and 4 mm/s (0.04 and 0.16 ips). Other occupant and blast induced data sets would result in different probabilities.

Calculations show that with levels of ground motion between 1 and 4 mm/s occupant induced dynamic events are more likely than blast response to cause the crack response to exceed its year maximum response. The difference in probability is not small; in this specific case the probability of occurrence during the once a year period of vulnerability is some 30 times greater for the occupant-induced events than for blast-induced events. Thus the occupant activities in this house are more likely to be responsible for a crack exceeding its maximum yearly opening width. Peak particle velocity ground motion of 3 mm/s is important because this is a level at which annoyance becomes more and more of an issue, even though intensive studies (Siskind et al, 1980) have shown that more than 12 mm/s second are necessary to possibly begin to induce cosmetic, hair sized cracks in older, distressed one to two story structures with plaster and lath walls.

Taken to the extreme, if for some unusual reason the crack was at an unusually high response state (large width) at its yearly maximum, occupant activity is more likely to be the “straw that breaks the camel’s back” The location or crack would be at an unusually high response state because of some unusual circumstance like deactivation of the heating system described Newsletter #28.

A more detailed presentation of the calculation of the relative probabilities is presented in an unpublished paper by Dowding, Meissner and Chou, 2018, which will be available in the future. This paper describes three different means of calculating these probabilities, modified binomial process, arrival rates and likelihood of concurrence, and probabilities for specific intensity of events. All three approaches arrive at the same conclusion, for this site and data set; Occupant activity is more likely than blast activity to cause the long term crack response to exceed its yearly maximum response.

Sensitivity analysis

Since each crack, house and occupant behavior as well as quarry, and blasting practices differ, it is unwise to generalize the calculated likelihoods without an understanding of the sensitivity of calculations to changes in occupancy and dynamic excitation. First consider quarry operations. Toward the end of the above study the operator changed practices for additional, and more perturbing blasts. The charge per hole was doubled, distances declined by some 10 % and the number of holes increased. As a result during the end of July and August, there were 7 more shots with a larger average exposure time "t" of 83. The average "t" for the earlier shots was 55. When this new information is added to Table 2 for the $\Sigma_i [n_i(t_i/T)]$ analysis, the new ratio of probability of occupant to induced to blast induced exceedance of the yearly maximum crack response declined from 35 to 24.

Now consider changes in occupant activities. The 300+ door closing events were caused by a single occupant, who was often absent for several days. If the home were occupied by an average family of 4 members, it would be conservative to assume that the total number of occupant events would increase by 50% to 450 with the same distribution of "t's" in the three months of observation. Amending Table 1's $\Sigma_i[n_i(t_i/T)]$ analysis to include both a larger number of occupants and the more active quarry operation shows that ratio of probability of occupant to induced to blast induced exceedance of the yearly maximum crack response increases from 24 to 29.

Conclusion

Calculation of the probabilities of coincidence of dynamic events with the single, yearly period of vulnerability introduces a new consideration for the proximate cause of cosmetic crack generation or in popular terms the "straw that broke the camel's back". The new consideration is "which type of straw broke the camel's back?" Since occupant activity occurs in the natural course of events, it appears that the natural course of events has a higher probability of causation at levels of ground motion that begin to cause concern and annoyance. This natural course of events includes climatological effects as well as those produced by occupants.