2008-2009 REPORT
TEST HOUSE IN FRANKLIN, WI

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ABSTRACT

Cosmetic and structural cracks are a large concern for homeowners. Although these cracks can develop from a variety of causes: differential foundation settlement, occupant activity, climatological effects, as well as dynamic events, people tend to look to dynamic events like blasting, construction, or traffic vibrations to be the culprit. This report aims to assuage the concerns about blasting vibrations near a residential structure in suburban Wisconsin by comparing crack responses caused by weather fronts to those caused by ground motions.

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1. INTRODUCTION

To determine the relative influence of weather changes and dynamic events like mining operations, ITI ACM is monitoring several structures adjacent to different mining and quarry sites across the country. Cosmetic and structural cracks in residential buildings are a cause of concern for many homeowners. It is often difficult to establish why cracks appear, as they can be caused by a range of conditions, from construction errors to occupant activity. Some cracks develop gradually due to long term phenomena such as settlement of the building and foundation, while others are due to short term triggers. It has been established that homeowners and occupants are more likely to ascribe crack development to short term triggers that they perceive to be damaging (such as mining operations or vibrations due to traffic) than long term phenomena that are not as readily detected by a human observer (such as gradual changes in temperature and humidity) (Dowding, 1996).

The test structure discussed here is a residential building in suburban Milwaukee, WI. Blasting operations are conducted to the west of the house, between a 1500 and 2000 feet distance. ITI monitoring of this site began in August of 2000, and data has been collected intermittently since then. Data presented here were collected between January 2008 and July 2009. Two existing cracks in the house were chosen for monitoring, one located on a ceiling and one on a wall adjacent to a door opening.

Residential Test Structure

The test building is a one-story concrete masonry block structure, shown in Figure 1. The selected cracks have been present since ITI monitoring of the house began in 2000. McKenna notes that the cracks may be due to errors in construction or retrofitting of the structure: the room where the observed ceiling crack is located was created by knocking down a wall, and the door jambs are of unusual design. Cracks around door openings have been observed in several rooms in the building. (McKenna, 2002, pp. 102-103)

The building is situated next to a limestone quarry, see map in Figure 2. Blasting operations are conducted in an area 1500-2000 feet west from the house.

Figure 1 - Photograph of east face of house in Franklin, WI

Figure 2 - The red star indicates the location of subject house in Franklin, Wisconsin just east of the Vulcan Quarry. The test house is representative of a home closest to the quarry with blasts between 1500 and 2000 feet away.

Instrumentation Plan

To account for weather and blast effects, ground vibrations, air overpressure and temperature and humidity levels outside of the house have been measured. The locations of all sensors are indicated in Figure 3.

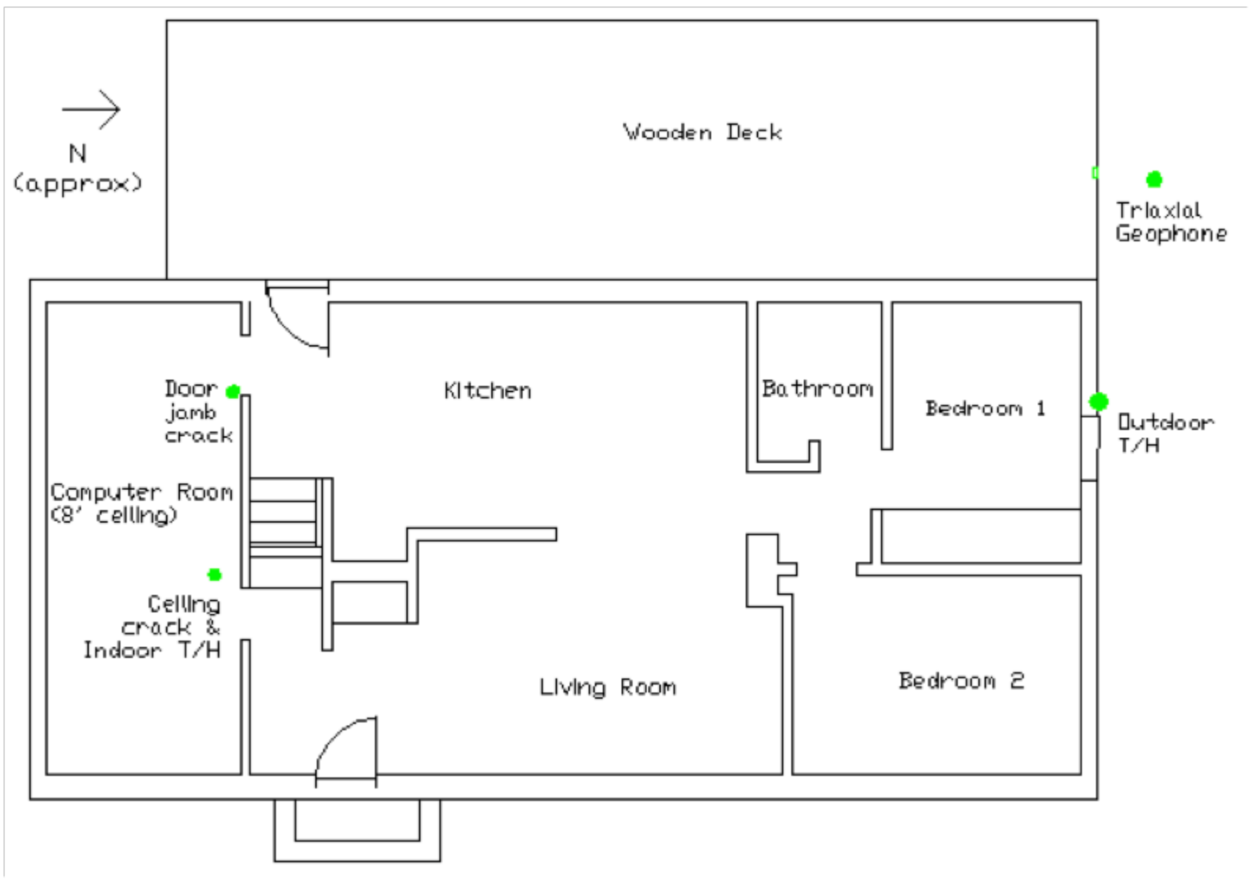

Figure 3 - Layout of the house with location of sensors

Cracks Monitored

Two cracks were selected for observation, one on a ceiling and one next to a doorway. Their respective locations can also be seen in Figure 4. To monitor crack development, similar sensors were installed across each crack and on the wall next to the crack. The latter acted as "null" sensors The ceiling crack sensors are LVDT gauges that were present from the beginning of the monitoring period. The door crack and null sensors are also LVDT sensors and were installed in March 2009.

Ceiling Crack

Door Crack

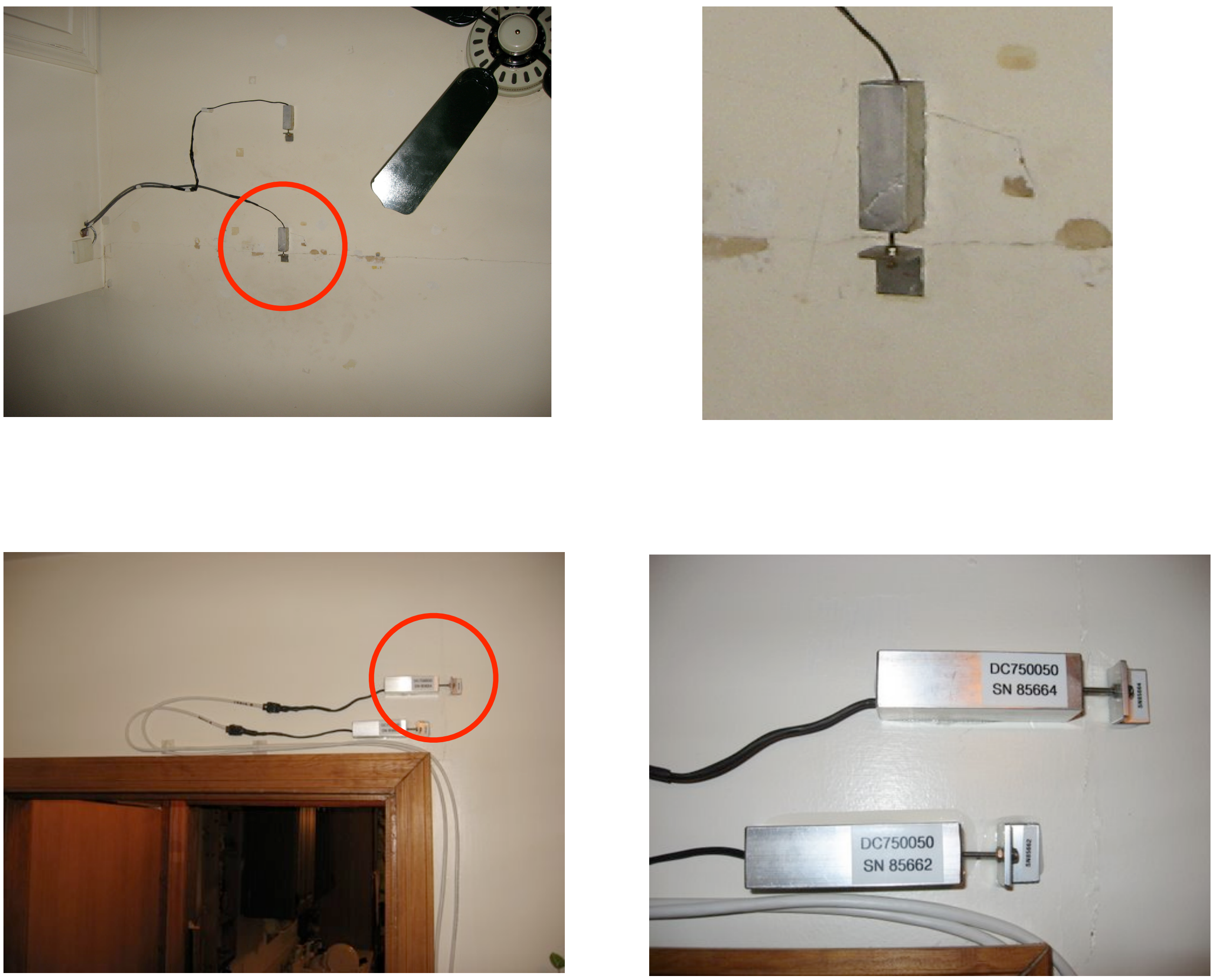

Figure 4 - Location of cracks monitored including context (left) and closeup (right). The ceiling crack appears on the top while the door crack appears on the bottom.

Auxiliary Sensors

A triaxial Geosonics geophone (shown in Figure 5) was installed in the ground on the north side of the house to monitor the propagation of shock waves from the quarry. This sensor registers movement in all three directions on separate channels and stores the results in the form of peak particle velocity (PPV) data.

A LARCOR overpressure microphone used as an air blast sensor was also mounted outdoors, on the north side of the house adjacent to the ground motion sensor. Unfortunately air overpressure readings were disregarded because of calibration difficulties.

Climatological conditions can have a noticeable effect on crack response. Outside temperature and humidity sensors were mounted on an exterior wall so as to determine environmental conditions.

Data from all sensors on the site are monitored by a Somat eDaq data logger (DAS). The system records long-term temperature and humidity levels and crack displacement every hour. When sudden dynamic events occur, the system triggers all sensors to record every millisecond (ms) for three seconds. The chosen trigger threshold is ground PPV exceeding 0.04 in/s. The DAS continually maintains a memory buffer of 1000 ms to ensure that the triggering event is recorded along with the ensuing response.

Although similar instrument systems have been successfully used previously, this installation was plagued by numerous "false alarms" where the DAS was triggered without a blast event taking place, because of random noise or possibly electrical signals interfering with the system. This may have been due to poor system performance or adverse electromagnetic interference. Several attempts have been made at obtaining access to the building in order to adjust the installation, but communication difficulties prevented correction. All reported trigger events were evaluated manually in order to exclude false triggers from the study.

Figure 5 - Triaxial Ground Motion Sensor

2. RESULTS

Crack Response to Climatological Conditions

The crack sensors and outdoors temperature and humidity sensors were read every hour, registering a total of 6503 data points during the observation period. The DAS experienced problems in February-March and May-June 2009, and data for these periods are unavailable. The results can be seen in Figure 6 where individual readings are plotted in blue, the 24-hour central moving average in red and the 30-day central moving average in black. This approach facilitates an analysis of crack displacement response to changes in the weather.

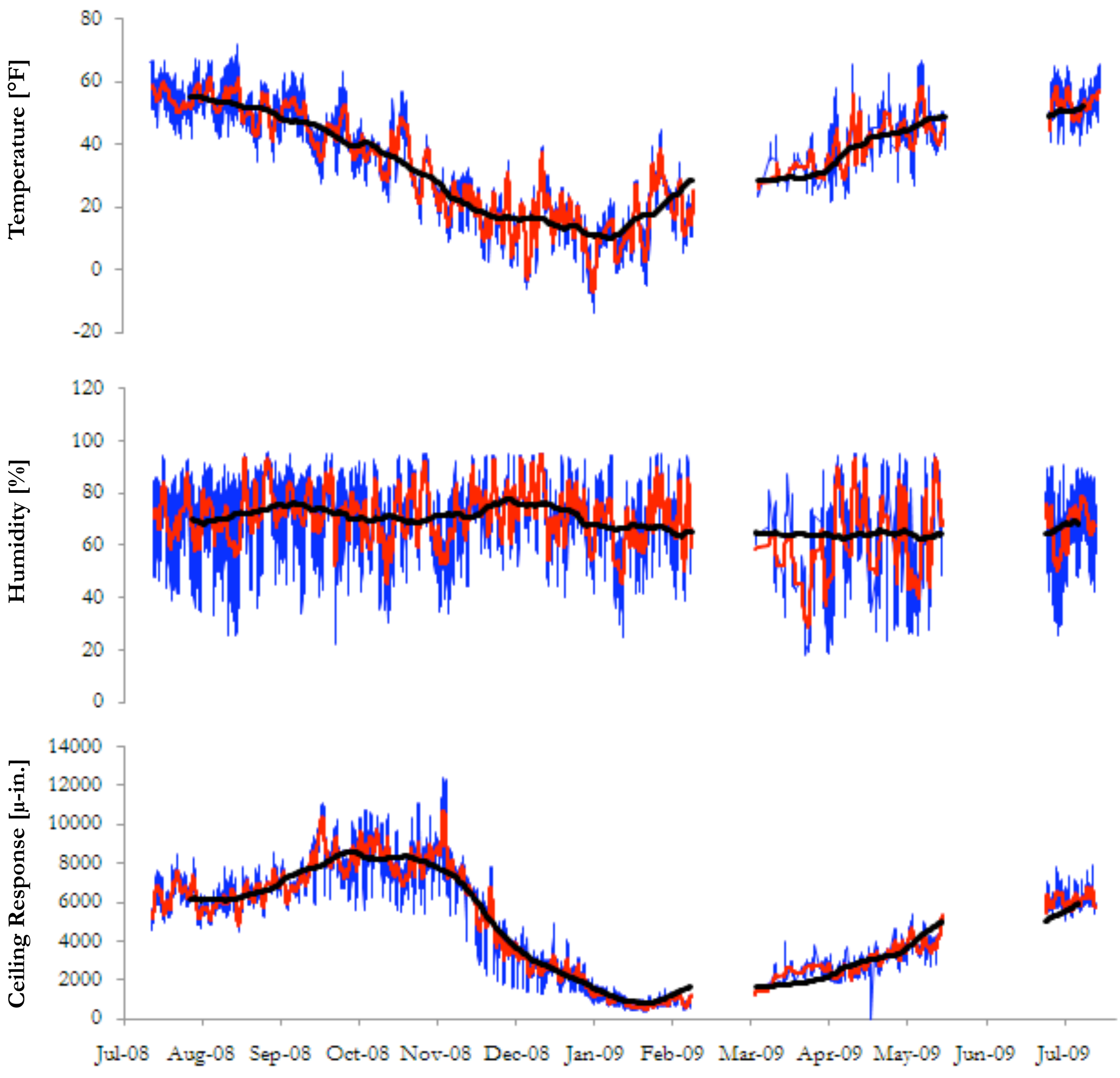

Figure 6 - Correlation of outdoor temperature and humidity with ceiling crack response over a 1-year period.

The same data plotted for a shorter period (October-November 2008) demonstrate that temperature variations correlate well with crack displacement. Since the red line is the 24-hour moving average and the black that for 30-day, the distance between them is indicative of the magnitude of change; a large, continuous change in temperature (indicative of the passage of a weather front) causes a deviation in crack response. The weather fronts near October 13 and November 5 (indicated by the arrows) resulted in substantial devations from the 30-day average crack displacement. The largest deviation occured around November 20th (3019 μ-in.).

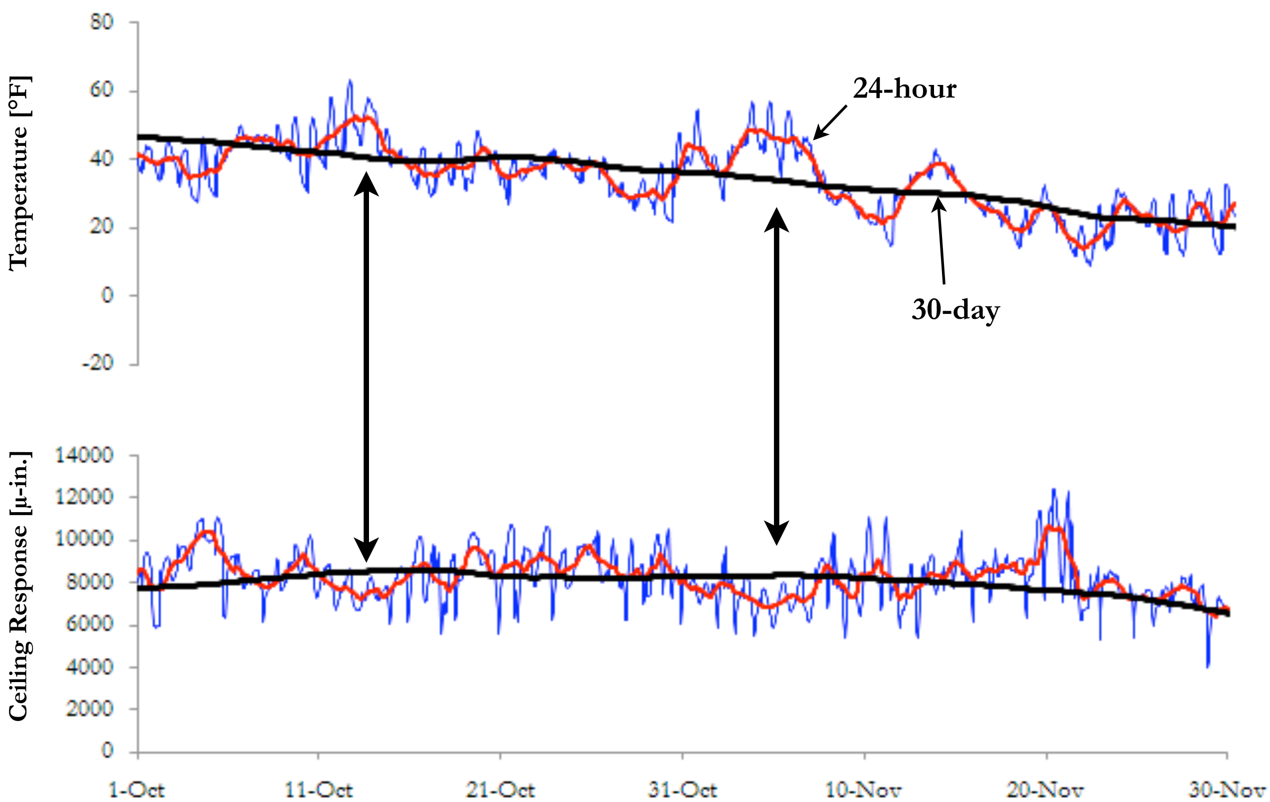

Figure 7 - Correlation of Temperature and Ceiling Crack Response over a two-month period

Crack Response to Dynamic Events

Crack response to 64 dynamic events are summarized in Table A in the Appendix. For each event, the peak ground motion in three orthogonal directions was recorded along with the crack response in microinches. The ceiling crack was monitored from the beginning of this project, while the door crack sensor was installed in March 2009. Figure 8 below compares the time histories of ground motion and crack response for an event on July 16th, 2009. The ceiling crack exhibits a zero-to-peak response of 192 μ-in while the door only responds 39 μ-in. Note that the ceiling crack responds significantly after the ground motion passes (to the air overpressure) while the door crack does not.

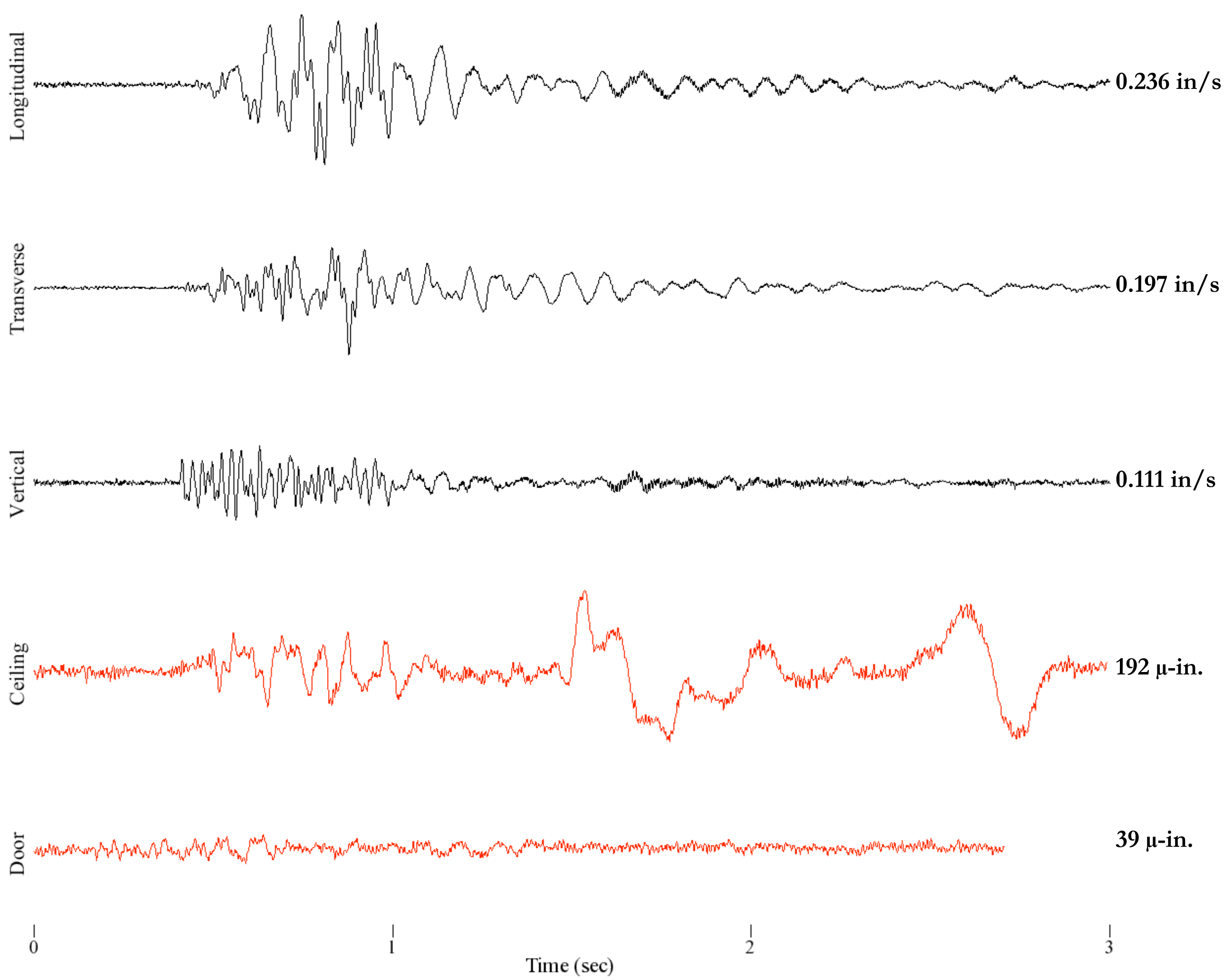

Figure 8 - Comparison of ground motion and crack response time histories for a blast on July 16th, 2009 at 10:45 AM

3. CONCLUSION

Comparison of Climatological to Dynamic Response

Figure 9 below compares the climatological response of the ceiling crack to its dynamic response. Response of the crack to weather fronts is 3x greater than the maximum response to blasting and 10x greater than response to ground motion at 0.1 ips. The ceiling crack often responds more to air overpressure than ground motion.

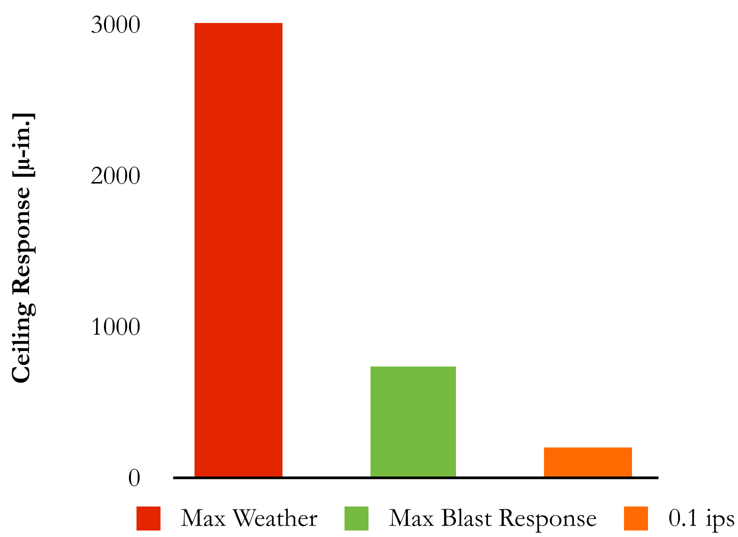

Figure 9 - Bar chart comparison of ceiling responses to weather fronts and blasting

REFERENCES

Dowding, C. H. (1996). *Construction Vibrations*. Prentice Hall, Upper Saddle River, New Jersey.

McKenna, L. M. (2002). Comparison of measured crack response in diverse structures to dynamic events and weather phenomena. Master's thesis, Northwestern University, Evanston, Illinois.

APPENDIX

Date	Geophone PPV [in/s]			Crack Response [μ-in.]	
	L	T	V	Ceiling	Door
8/1/08 12:57 PM	0.108	0.105	0.112	144	-
8/4/08 12:16 PM	0.117	0.095	0.134	96	-
8/4/08 12:44 PM	0.166	0.252	0.186	175	-
8/7/08 9:35 AM	0.158	0.149	0.110	256	-
8/7/08 9:36 AM	0.164	0.197	0.154	133	-
8/7/08 11:42 AM	0.226	0.160	0.205	185	-
8/7/08 11:47 AM	0.084	0.144	0.161	86	-
8/13/08 8:31 AM	0.112	0.071	0.058	126	-
8/13/08 10:49 AM	0.157	0.160	0.140	173	-
8/13/08 10:51 AM	0.094	0.106	0.132	154	-
8/15/08 9:44 AM	0.131	0.100	0.071	152	-
8/15/08 9:46 AM	0.103	0.079	0.056	220	-
8/15/08 12:02 PM	0.142	0.131	0.161	152	-
8/20/08 10:44 AM	0.100	0.116	0.078	223	-
8/20/08 10:52 AM	0.145	0.172	0.107	323	-
8/25/08 8:34 AM	0.134	0.165	0.169	166	-
8/25/08 11:04 AM	0.112	0.088	0.058	117	-
8/25/08 11:06 AM	0.097	0.066	0.072	136	-
8/28/08 8:51 AM	0.087	0.110	0.122	165	-
8/28/08 8:52 AM	0.143	0.240	0.143	197	-
9/4/08 9:22 AM	0.102	0.122	0.101	181	-
9/4/08 9:26 AM	0.133	0.140	0.125	155	-
9/4/08 12:09 PM	0.177	0.205	0.168	221	-
9/8/08 10:37 AM	0.155	0.237	0.130	246	-
9/8/08 10:45 AM	0.094	0.105	0.082	150	-
9/11/08 10:56 AM	0.157	0.200	0.211	205	-
9/11/08 10:58 AM	0.130	0.146	0.119	197	-
9/11/08 11:04 AM	0.095	0.073	0.064	215	-
9/16/08 11:20 AM	0.104	0.090	0.120	126	-
9/16/08 11:25 AM	0.133	0.199	0.138	315	-
9/16/08 11:26 AM	0.156	0.176	0.122	405	-
9/19/08 11:53 AM	0.128	0.112	0.131	174	-
9/19/08 12:01 PM	0.136	0.196	0.128	259	-
9/24/08 12:03 PM	0.233	0.173	0.112	683	-
10/1/08 8:43 AM	0.093	0.099	0.070	191	-
10/1/08 10:58 AM	0.143	0.079	0.073	215	-
10/1/08 11:00 AM	0.120	0.060	0.064	127	-
10/1/08 11:08 AM	0.105	0.146	0.064	264	-
10/8/08 9:00 AM	0.158	0.134	0.074	386	-
10/8/08 11:01 AM	0.128	0.097	0.083	288	-
10/8/08 11:07 AM	0.114	0.168	0.135	210	-
10/16/08 11:58 AM	0.088	0.078	0.057	264	-

Table A - List of ground motion event PPV's and their corresponding crack responses throughout the period

Date	Geophone PPV [in/s]			Crack Response [μ-in.]		Air Overpressure [dB]
10/16/08 12:04 PM	0.103	0.087	0.084	124	-	
10/16/08 12:09 PM	0.093	0.143	0.115	289	-	
10/23/08 12:53 PM	0.095	0.074	0.053	216	-	
10/23/08 12:55 PM	0.098	0.057	0.070	167	-	
10/30/08 11:09 AM	0.235	0.343	0.227	308	-	
10/30/08 11:13 AM	0.142	0.195	0.128	189	-	
11/4/08 10:51 AM	0.157	0.181	0.087	736	-	
11/4/08 12:24 PM	0.103	0.097	0.105	176	-	
11/6/08 11:36 AM	0.110	0.079	0.073	198	-	
11/6/08 11:47 AM	0.152	0.198	0.225	334	-	
11/6/08 11:53 AM	0.146	0.204	0.101	275	-	
11/13/08 9:55 AM	0.213	0.238	0.203	305	-	
11/13/08 12:22 PM	0.143	0.159	0.160	167	-	
3/24/09 1:22 PM	0.201	0.105	0.143	89	66	
3/31/09 10:06 AM	0.140	0.086	0.081	88	80	117
3/31/09 11:45 AM	0.202	0.224	0.197	118	84	118
4/8/09 2:36 PM	0.086	0.093	0.062	108	83	-
4/21/09 12:35 PM	0.207	0.211	0.208	93	91	123
4/29/09 1:09 PM	0.095	0.086	0.062	73	86	-
7/16/09 10:45 AM	0.261	0.223	0.142	192	39	121
7/22/09 10:52 AM	0.123	0.108	0.066	354	45	124
7/27/09 11:44 AM	0.083	0.108	0.086	98	47	113