5 GROUND DEFORMATION IN THE VERY NEAR FAULT REGION

5.1 Introduction

Initial reconnaissance of the residential neighborhoods in West Napa immediately following the earthquake on 8/24 and 8/25 noted extensive zones of surface deformations consisting of buckled sidewalks, curbs, and pavement. While some of this deformation was clearly associated with surface faulting, much of the observed deformation consisted of compressional features which could not be immediately attributed to any particular faulting mechanism. These features were particularly well expressed in the neighborhood of West Napa, CA bounded by Partrick Road and Browns Valley Road to the north and Buhman Avenue to the east (Figure 5-1) and, therefore, this area was mapped in detail over a period of three days, 8/26 to 8/28, 2014. Specifically, detailed measurements were made of compression and extension along streets and sidewalk parallel to the fault trace and along the cross streets, roughly orthogonal to the fault trace. A summary of these observations and recordings are provided in this section.

Figure 5.1: Observation and measurement sections of ground strain (red lines) and approximate observed fault trace (yellow line); produced in Google Earth; [NSF-GEER; Napa, CA; N 38.3040 W 122.3443; 8/26/14 - 8/28/14]

5.2 Overview of Ground Strain Observations

The compression features were predominantly concentrated in concrete sidewalks and were quite readily apparent while extension cracks were typically quite innocuous and required a careful inspection. A typical buckled compression zone and extension crack is shown in Figure 5.2. It should be noted that frequently there was no evidence of similar deformation in the adjacent bituminous pavement in the street.

Figure 5.2: Typical buckled compression zone (left) and extension crack (right) [NSF-GEER; N 38.3037 W 122.3433; 8/26/2014 15:41 (left); N 38.3055 W 122.3455; 8/26/2014 18:34 (right)]

5.2.1 Measurement Methodology

A consistent measurement procedure was developed in the field to standardize the observations of compression zones and extension cracks. First, a 100 meter tape measure with 1 millimeter increments was stretched in the road parallel to the sidewalk approximately 2 meters from the edge of the curb in 25 meter segments. This configuration was chosen since the road was essentially free of topographic expressions (primarily tree root uplift and buckled sidewalk pavement, etc.) that would cause the 25 meter segment to be shorter than it should actually have been. The ends of the 25 meter segment were marked with spray paint and numbered, and then the bearing along the segment was estimated with a compass. At intersections, the segment measurement was continued until the concrete curb contacted the asphalt and the reduced (or augmented) segment length was recorded.

Next, the sidewalk in the segment was carefully inspected and the compression zones and extension cracks were measured relative to the start of the segment. Extension cracks were measured to the nearest 1/16 inch with a ruler or tape measure spanning perpendicular to the crack at various locations, and then a representative value was reported. When possible, area residents were consulted as to which cracks existed prior to the earthquake. Small cracks filled with debris (<1/16 inch) were not considered since debris-filled cracks were observed with a modest (up to 1/8 inch) gaps on at least one side. This suggests that the debris-filled cracks with no gaps were not due to the earthquake. Additionally, cracks in sidewalk pavement that had been previously ground down were not considered. These cracks were often in expansion joints and had been shaved to offer a smoother transition between uplifted sections of pavement.

Deformation in the buckled compression zones was assessed by first measuring the lengths of the uplifted sidewalk section along the top surface on the same edge to obtain the original length of the section. Then, the distance between the new outer edges of the sidewalk was measured to obtain the new length of the section. The difference between the measurements was recorded as the compression in the zone. Measurements for a typical buckled section are shown in Figure 5.3 below.

Figure 5.3: Measuring a typical buckled compression zone in sidewalk pavement [NSF-GEER; N 38.3039 W 122.3430; 8/26/2014 15:24]

In some locations, compression in the sidewalk pavement manifested as an overlap instead of a buckled section. In such cases the overlap was measured and recorded as the compression in the zone. The measurement for an overlapping compression zone is shown in Figure 5.4 below. In cases where both gaps and overlaps were observed, the gaps were subtracted from the overlap measurement and this value was recorded as the compression in the zone. The measurement for an overlapping compression zone with a gap is shown in Figure 5.5 below.

Figure 5.4: Measuring an overlapped compression zone in sidewalk pavement [NSF-GEER; N 38.3065 W 122.3454; 8/28/2014 14:00]

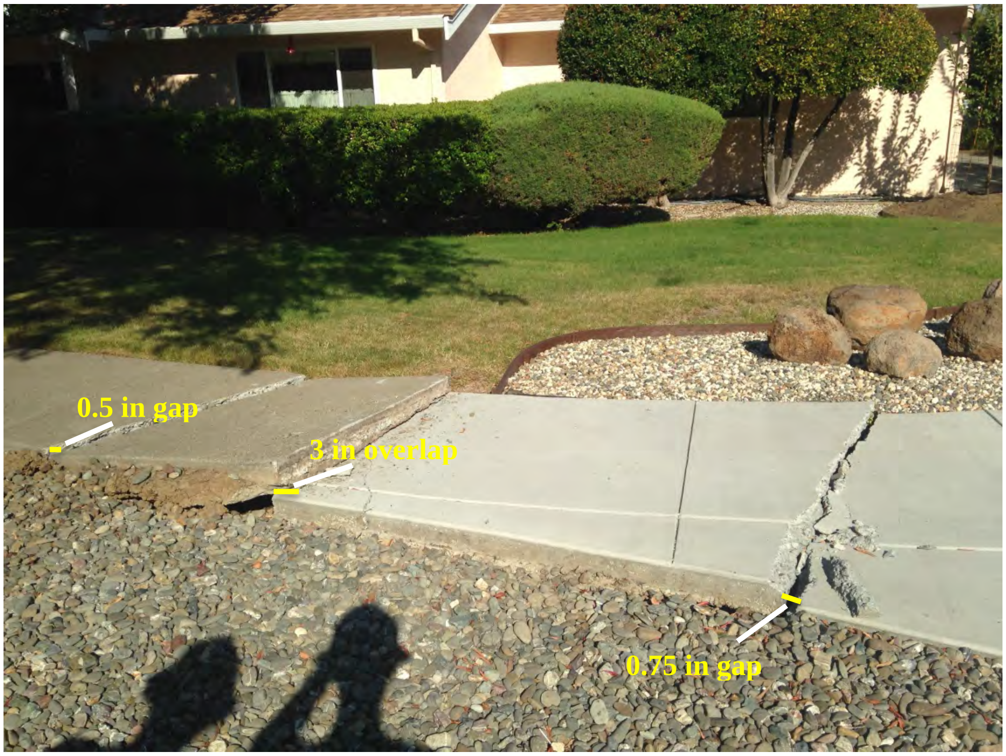

Figure 5.5: Measuring an overlapped compression zone with a gap in sidewalk pavement [NSF-GEER; N 38.3047 W 122.3459; 8/26/2014 16:52]

5.2.2 Ground Strain Computations and Map

Ground strain was computed over each 25 meter segment by adding the measured extension cracks (positive) and compression zones (negative) to the measured segment length to obtain the original segment length. This became the "gage length" of the strain measurement. Then, the difference between the measured and the estimated original length was divided by the estimated original length to obtain the decimal strain, which was converted to a percent strain. Additionally, the average strain for each sidewalk section as a whole was computed in a similar manner by considering all measured extension cracks and compression zones added to the total length of the segments of a single sidewalk. The results of the average strain over each total sidewalk are shown in Table 5.1 and Table 5.2 below for sidewalks parallel and perpendicular to the fault, respectively. The measurements and computations for individual segments are shown in Appendix D. A schematic showing the approximate location of each extension crack and compression zone is shown in Figure 5.6 below.

Figure 5.6: Observed and measured tension (orange) and compression (green) locations; produced in AutoCAD; [NSF-GEER; Luque, R.; Wagner, N.; processed 9/5/14]

Table 5.1: Summary of strain measurements in parallel trending roads [NSF-GEER; Wagner, N.; processed 9/3/2014]

N-S (PARALLEL) TRENDING ROADS				
	East Side		West Side	
	Total Length (m)	Average Strain (%)	Total Length (m)	Average Strain (%)
West of Fault				
Estates Dr	90.0	-0.01	77.5	-0.07
White Cliff Cir (West)	71.4	0.05	71	-0.02
Stonybrook Dr	459.2	-0.04	508.0	-0.03
Tall Grass Dr	N/A	N/A	199.0	-0.05
Casper Way	203.9	0.01	220.2	-0.01
Weighted Average Strain		**-0.01**		**-0.03**
East of Fault				
Twin Oaks Ct	69.8	0.00	69.8	0.00
Dellbrook Dr	75	0.00	44.15	0.00
Weighted Average Strain		**0.00**		**0.00**
Crossing Fault				
White Cliff Cir (East)	50.7	**0.01**	50.7	**0.36**

Table 5.2: Summary of strain measurements in perpendicular trending roads [NSF-GEER; Wagner, N.; processed 9/3/2014]

E-W (PERPENDICULAR) TRENDING ROADS				
	North Side		South Side	
	Total Length (m)	Average Strain (%)	Total Length (m)	Average Strain (%)
West of Fault				
Twin Oaks Dr	297.3	-0.02	274.1	0.01
White Cliff Cir	163.0	-0.05	164.5	0.04
Meadowbrook Dr	221.7	0.00	221.7	0.00
Weighted Average Strain		**-0.02**		**0.01**
East of Fault				
Twin Oaks Dr	212.1	0.00	208.9	0.00
Meadowbrook Dr	209.4	0.00	N/A	N/A
Weighted Average Strain		**0.00**		**0.00**
Crossing Fault				
Meadowbrook Dr	40	**-0.24**	30	**-0.17**

5.3 Additional Observations

In addition to the deformations in the concrete sidewalks compression features in the curb strip adjacent to the sidewalk, cracking in asphalt, damaged curbs and a fence adjacent to the fault trace were measured and documented.

5.3.1 Compression Features in Curb Strip

Compression features in the curb strip were observed at various locations adjacent and perpendicular to the sidewalk pavement. Two of the compression features (Figure 5.7 and Figure 5.8) are located across from the creek running parallel to the fault trace through the neighborhood. In these cases the sidewalk pavement moved laterally toward the free face of the creek. Additionally, it was noted that the compression feature in Figure 5.7 occurred at the end of the bend at a corner.

One of the compression features was located near the fault trace adjacent to a buckled compression zone in a sidewalk perpendicular to the fault trace (Figure 5.9). The compression feature is parallel to the fault trace. It was noted that there was separation between the asphalt and the curb in line with the compression feature in the curb strip.

Figure 5.7: Crushed section in pavement parallel to fault with compression features in curb strip perpendicular to fault, across from creek [NSF-GEER; N 38.3055 W 122.3467; 8/28/2014 14:30]

Figure 5.8: Compression feature in curb strip perpendicular to fault, across from creek [NSF-GEER; N 38.3065 W 122.3455; 8/28/2014 13:52]

Figure 5.9: Buckled section in pavement perpendicular to fault with compression features in curb strip and lawn parallel to fault, near observed fault trace [NSF-GEER; N 38.3018 W 122.3439; 8/25/2014 10:38]

5.3.2 Cracking in Asphalt

One of the more enigmatic observations was that bituminous pavement was largely devoid of compression features except immediately along the fault trace. Most of the cracks in bituminous pavement were transverse to the direction of the street and appeared to be extensional. In addition, most manholes and other penetrations in the pavement were ringed by apparently fresh cracks. (Figure 5.10).

Figure 5.10: Cracks in asphalt perpendicular to fault trace near manhole covers [NSF-GEER; N 38.3063 W 122.3458; 8/28/2014 14:15 (left); N 38.3068 W 122.3465; 8/28/2014 15:19 (right)]

5.3.3 Damaged Curbs

Damaged curbs were observed throughout the neighborhood along roads both parallel and perpendicular to the fault trace. The damage included crushing (Figure 5.11), extension cracks (Figure 5.12) and buckling failures (Figure 5.13). In general, the damaged curbs were not directly adjacent to the buckled compression zones in the sidewalk pavement. However, the curbs were not included in the detailed surveying because in most cases the broken pieces were missing or could not be reconstructed into the original configuration.

Figure 5.11: Crushed curb perpendicular to fault trace [NSF-GEER; N 38.3035 W 122.3411; 8/25/2014 14:47]

Figure 5.12: Extension crack in curb parallel to fault trace [NSF-GEER; N 38.3066 W 122.3475; 8/28/2014 15:08]

Figure 5.13: Buckled curb parallel to fault trace [NSF-GEER; N 38.3073 W 122.3443; 8/28/2014 13:41]

5.3.4 Strain Measurements in Fence

In addition to calculating strains in sidewalk pavement, strain was computed for a section of fence running parallel and adjacent to the fault trace (Figure 5.14). To compute the strain, the horizontal boards at the top of the fence were measured in segments to obtain an estimate of the original length of the fence. Then, the ground along the base of the fence was measured to obtain an estimate of the new length of the fence. The data and computations are shown in Table 5.3 below. Note that the average strain in the fence is the same order of magnitude as the average strain in the sidewalk pavement for roads crossing the fault trace (Table 5.1 and Table 5.2).

Figure 5.14: Buckled section of fence of the surveyed fence [NSF-GEER; N 38.3015 W 122.3442; 8/25/2014 09:57]

Table 5.3: Summary of strain measurements in parallel trending fence [NSF-GEER; Wagner, N.; processed 9/3/2014]

Section Number (Top)	Length (m)	Section Number (Bottom)	Length (m)
1	1.5	1	11.9
2	4.8		
3	2.4		
4	2.4		
5	4.9	2	9.8
6	4.9		
7	2.4		
8	2.4		
9	2.4	3	11.2
10	2.4		
11	2.4		
Total	33.0		32.9
		Average Strain	**-0.36**
		Average Disp. (m)	**-0.12**