Seismic Evaluation of Marin Elementary School

Prepared for
Albany Unified School District
Albany, CA

November 2012

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CONTENTS

1. Introduction

This report summarizes the seismic evaluation of seven buildings at Marin Elementary School. The school is located at 1001 Santa Fe Avenue, Albany. The buildings studied are Buildings A, B, D, E, F, and G (classrooms) and Building C (multi-purpose). The purpose of the study was to assess the vulnerability of the buildings for life-safety risk in a major earthquake.

The seven buildings are Category 2 buildings under the DSA AB300 classification system (Ref. 1). DSA reviewed all K-12 public school buildings that have concrete tilt-up or non-wood construction and were built prior to July 1, 1978. Category 2 building types are those requiring a detailed seismic evaluation. (Category 1 buildings are those expected to perform well).

The buildings were identified in our report of February 26, 2009 (Ref. 2) as having a Type RM1 Reinforced Masonry Bearing Wall Construction with Flexible Roof Diaphragms. This type of construction was assigned to structural vulnerability Category 2.

The evaluations summarized in this report represent an assessment of the buildings using the latest seismic evaluation methodology. The evaluation of each building included completion of checklists, preparation of structural calculations, and assessment of the structural system to withstand the seismic forces without collapse or creation of a serious life safety risk.

The report is organized as follows. The criteria used in the evaluation is described in Section 2. A description of the buildings and the results of the evaluation are presented in Section 3. Section 4 provides a summary and recommendations. References are given in Section 5.

2. Evaluation Criteria

Building Evaluation Criteria

The buildings were evaluated using ASCE Standard 31-03 “Seismic Evaluation of Existing Buildings” (Ref. 3). This is the state-of-the-art criteria for the seismic evaluation of existing buildings. It is used to establish whether there is a significant life-safety risk.

Each building was initially given a Tier 1 evaluation for the Life Safety performance level. This required completion of the Basic and Supplemental checklists and preparation of limited structural calculations called “quick checks.” For elements of each building’s structural system that did not meet the Tier 1 criteria, a Tier 2 evaluation was done. This involved preparation of more detailed structural calculations. For both Tier 1 and Tier 2, the ground shaking hazard at the site is first determined, and then the building is evaluated for its ability to withstand these motions without unacceptable behavior.

Earthquake Ground Motions

The school is located approximately 1 mile west of the Hayward fault. This is a large fault and believed capable of a magnitude 6.8 to 7.0 earthquake (Ref. 4). This would produce very strong shaking at the site.

Earthquake ground motions for the site were determined from U.S. Geological Survey software (Ref. 5). Ground motions were determined for the Maximum Considered Earthquake (MCE). This represents an earthquake with only 2-percent chance of being exceeded in 50 years (i.e., an earthquake with a 2,500 year return period). At this location, the MCE has a peak ground acceleration of 0.76g; however, only 2/3 of this level of motion (0.51g) is required to be used in the evaluations done under ASCE 31. The design ground motion parameters SDS and SD1 are 1.27g and 0.73g, respectively, and Site Class D (the default class) was assumed for the site soils.

Demand-Capacity Ratios

Results of the evaluation of each building are presented as demand to capacity ratios (D/C). These are provided for the main structural elements (i.e., structural members and connections) that make up the seismic force-resisting system of each building. A D/C ratio of 1.0 or less indicates that the element satisfies the ASCE 31 criteria. Demand is the combined earthquake and dead load force applied to a structural element, and capacity is the element’s usable strength. D/C ratios greater than about 1.1 to 1.2 indicate a deficient element that may need to be strengthened or replaced. Elements with D/C ratios of 2.0 or greater are considered seriously overstressed. Such large D/C ratios generally indicate a serious deficiency unless there are other structural elements present that can take up the “slack” when the element with the high D/C ratio fails or is no longer effective.

3. Results of Building Evaluations

3.1 Introduction

The seven Marin buildings were built about 1974 and have very similar construction with concrete block walls and wood frame roofs covered with plywood sheathing. Figure 1 shows a site plan of the buildings. Six of the buildings (A, B, D, E, F and G) are classrooms (see Figures 2, 3 and 4). The seventh building, Building C (Figure 5), is a multi-purpose building. As explained below, three buildings (A, C and D) were selected for evaluation.

Buildings B, D, E, F, and G are all very similar and Building D was chosen as representative for evaluation. Building A is somewhat similar to the other five classroom buildings, but one-half of the building has different wall layout, and this building was individually assessed. The multi-purpose building, Building C, is larger and has a much different footprint than the classrooms, and this was also individually assessed.

The architectural and structural drawings for the original construction (Ref. 6) were available and used in the evaluations. The original building construction quality appears excellent, and the buildings do not appear to have been altered or modified since the original construction.

All exterior walls are constructed of reinforced concrete block (also called CMU or concrete masonry units). The block units are “fluted” on both sides (see Figure 6). The drawings do not contain information on the strength of the CMU block or that of the grout used in the construction and there was also no indication that all cells of the block were filled solid with grout. For the evaluation, we assumed a compressive strength of 1,500 psi and that all cells were filled with grout. The latter seems highly likely but should be verified.

In buildings with this type of construction, particularly those constructed in the early 1970s, the principal seismic concern is separation of the walls from the roof. Concrete block walls behave very similar to the concrete walls of tilt-up buildings in this regard. In the worst forms of earthquake damage, the walls can separate from the roof and fall over, the roof can collapse locally, or both can happen.

A key assumption made in the analysis is that the roof diaphragms are considered “flexible” instead of “rigid”. The normal assumption for plywood sheathed roofs is that they are flexible diaphragms and not rigid diaphragms like a concrete floor. ASCE 31 requires that the wall-roof anchorage for flexible diaphragms be designed for 3 times the forces used for rigid diaphragms. The actual diaphragm construction of the buildings is complex because the roof framing is a combination of steel, glulam and wood beams with the steel beams interconnected. Diaphragms are irregular in shape. This geometry, and the roof framing, trends to make the classroom diaphragms a little less flexible than the usually wood roof. However, we felt that the roof diaphragms were more “flexible” than “rigid” and conservatively used the seismic forces ACSE 31 prescribes for flexible diaphragms in our evaluations.

3.2 Classroom Building D

Description

Building D is a single story structure. It has a triangular shape in plan, with each corner truncated. The building has a floor area of approximately 3,220 square feet. Overall dimensions are approximately 63' by 72' in plan.

The roof is framed with a combination of wood and steel beams and 2x10 wood joists. The 2x10 joists span from the exterior bearing walls to the beams. The beams are supported by six interior 3" diameter steel pipe columns. Large 6x18 wood hip beams span from each exterior wall corner and bear on a structural steel posts near the center of the building. The roof joists bear on a pressure treated wood plate at the exterior walls and project beyond for the roof eave creating an overhang. The entire roof is sheathed with ½ "plywood.

The masonry walls are constructed of nominal 6" thick concrete masonry units (CMU). However, the units are "flutted" on both sides and the net thickness is only 4 5/8" (instead of the usual 5 5/8"). The walls are supported by continuous shallow reinforced concrete strip footings. Interior pipe columns are supported on individual concrete spread footings. The perimeter footings are laterally restrained by the concrete slab-on-grade at the building's interior.

Seismic forces in both directions are resisted by the plywood sheathed roof diaphragm and the exterior masonry (CMU) walls acting as shear walls.

Results of the Building D Evaluation

Building D does not meet the ASCE 31. The anchorage of the tops of masonry walls to the roof is inadequate. This and other findings are discussed below.

The plywood roof diaphragm was checked and found to easily satisfy the life safety criteria. Diaphragm shear for forces perpendicular to a long exterior wall, and distributed along the skewed walls, has a D/C ratio of 0.91. A check of the diaphragm chords for similar force action yields a maximum D/C ratio of 0.57.

The 6" exterior CMU shear walls were checked for in-plane shear forces and out-of-plane bending and found to meet criteria. The D/C ratio for in-plane shear is a low 0.43. The D/C ratio for out-of-plane bending is 0.35.

Anchorage of the roof to the CMU walls was checked and found to be deficient. Detail 10 on Figure 7 shows the detail used to connect the 6" CMU walls to the roof in Building D. The ¾ " bolt has only about 2" cover, and the capacity of the bolt in shear perpendicular to the wall is only 12-percent of normal allowable due to the shallow cover. The D/C ratio for this detail is a very high 4.0.

Another very significant deficiency is the anchorage of the 6x18 wood hip beams to the 6" CMU walls (Figures 8 and 9). This connection is very deficient because the three 1" diameter anchor bolts embedded into the wall have only about 1 ¾" cover. Their allowable capacity is only about 7-percent. In other words, they are likely to be ineffective in resisting seismic forces tending to pull the walls away from the roof. Fortunately, the intersecting walls shown in Figures 10 and 11 will help stabilize the walls, but the CMU block in the vicinity of many of the hip beams is cracked (see Figure 9), making the effectiveness of the beam restraint at the top of the wall doubtful.

The base of the masonry walls are adequately tied to the foundations and laterally restrained by the slab-on-grade construction that was doweled to the continuous spread footings.

Discussion of Results

The principal structural deficiency found in the evaluation of Building D (and the other, similar classroom buildings) is the weak anchorage of the exterior walls to the roof. This is a serious deficiency. The ¾" and 1" anchor bolts connecting the walls and roof have very shallow cover. Although the original design attempted to compensate for this by adding two horizontal bars close to the anchor bolts, the cover is too shallow for the bolts to be very effective.

3.3 Classroom Building A

Description

Building A (Figure 4) is a single story, nine-side structure of approximately 3,450 square feet. Overall dimensions are approximately 68' by 72' in plan. Other than the different footprint, the construction of Building A is similar to Building D and the other classrooms. All exterior masonry walls are 6" CMU.

Results of Buliding A Evaluation

The roof diaphragm and CMU shear walls of Building A meet ASCE 31 requirements, but the wall-roof connections do not. D/C ratios for wall-roof connections are 4.0, similar to the results for Building D.

Discussion of Results

The results for Building A are essentially the same as those for Building D. The significant deficiencies are the same (weak anchorage of the walls to the roof that can lead to wall-roof separation).

3.4 Multi-Purpose Building C

Description

Building C (Figure 5) is a seven-sided single story structure. The building has a floor area of approximately 4,220 square feet. Overall dimensions are approximately 86' by 64' in plan.

The roof is framed with 2x10 roof joists and has ½" plywood sheathing. There is a clerestory on the east side. The roof is supported by a combination of large glulam beams, wood beams, wood bearing walls and the CMU walls.

Exterior walls are constructed of 6", 8", and 12" CMU. Similar to Building D, the wall strength was assumed to be 1,500 psi and all cells were assumed to be filled with grout. In the interior of the building there are 2x4 wood stud bearing walls, portions of which are sheathed with plywood. The exterior CMU walls are bearing on continuous shallow reinforced concrete footings. Interior bearing walls are also supported on continuous spread footings. The perimeter footings are laterally restrained by the concrete slab-on-grade.

Seismic forces in both directions are resisted by the plywood sheathed roof diaphragm and by the exterior CMU and interior plywood sheathed walls.

Results of Building C Evaluation

Building C does not meet the ASCE 31 criteria. The anchorage of the tops of masonry walls to the roof diaphragm is inadequate. This and other findings are discussed below.

The plywood roof diaphragm was checked and found to easily satisfy the life safety criteria. Maximum diaphragm shear for forces in the transverse direction, and distributed along the skewed walls, has a D/C ratio of 0.88. The diaphragm chord for the east-west force projection is reduced due to the presence of the mechanical well at the eastern edge of the roof. The D/C ratio is 1.61.

The 6", 8" and 12" exterior CMU shear walls were checked for in-plane shear forces and out-of-plane bending and found to meet criteria. The maximum D/C ratio for in-plane shear is a low 0.44. The maximum D/C ratio for out-of-plane bending is 0.35.

The interior wood shear walls have capacity to resist the in-plane shear, having a maximum D/C ratio of 0.43 at the northern interior wall. However, the wall sill plate anchorage is overstressed with a D/C ratio of 1.66 at the northern wall, and 2.49 at the southern wall.

Anchorage of the roof to the CMU walls was checked and found to be deficient. The D/C ratios ranged from 0.84 to 1.87. The connection shown in Detail 6 of Figure 7 has a D/C of 0.84. The connection shown in Detail 1 of Figure 12 has a D/C of 1.87. The connection of the two large 8 ¾" x 36" glulam beams to the 12" CMU walls is deficient for seismic anchorage forces. The D/C ratio is a high 3.86.

Discussion of Results

With the exception of the plywood shear wall anchorage, the roof diaphragm and the shear walls (CMU and plywood) of Building C easily meet ASCE 31 criteria. The main deficiencies found are the inadequate wall connections to the roof and glulam beams, the diaphragm chords, and the anchorage of the interior wood shear walls.

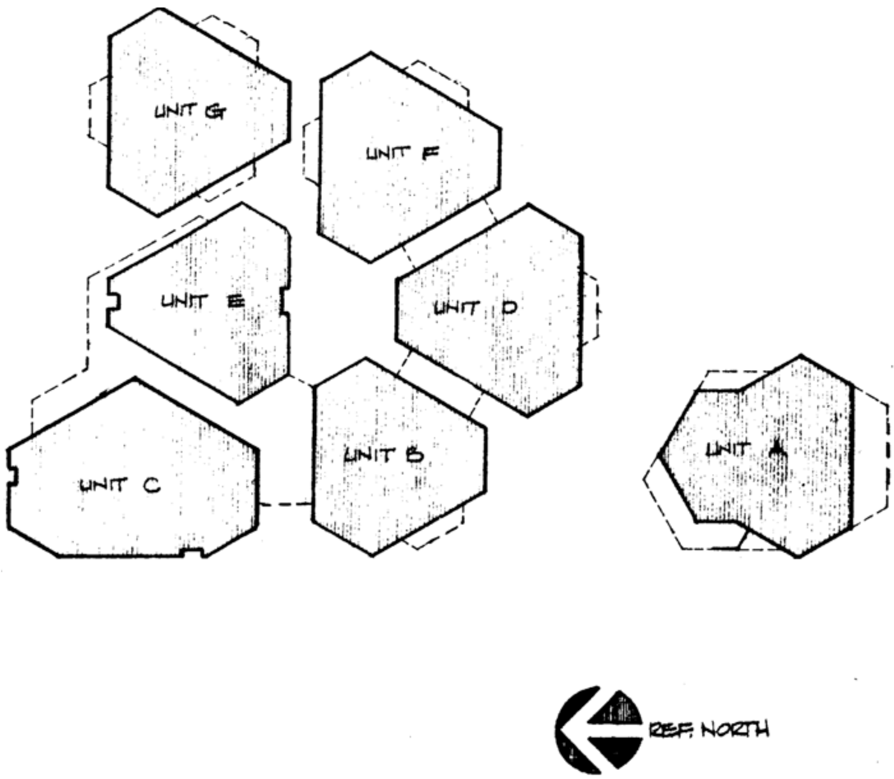

Figure 1 – Site plan of the seven buildings.

Figure 2 – Classroom Buildings D and F at Marin Elementary School.

Figure 3 – North elevation of classroom Building G.

Figure 4 – Classroom Building A.

Figure 5 – Multi-purpose Building C.

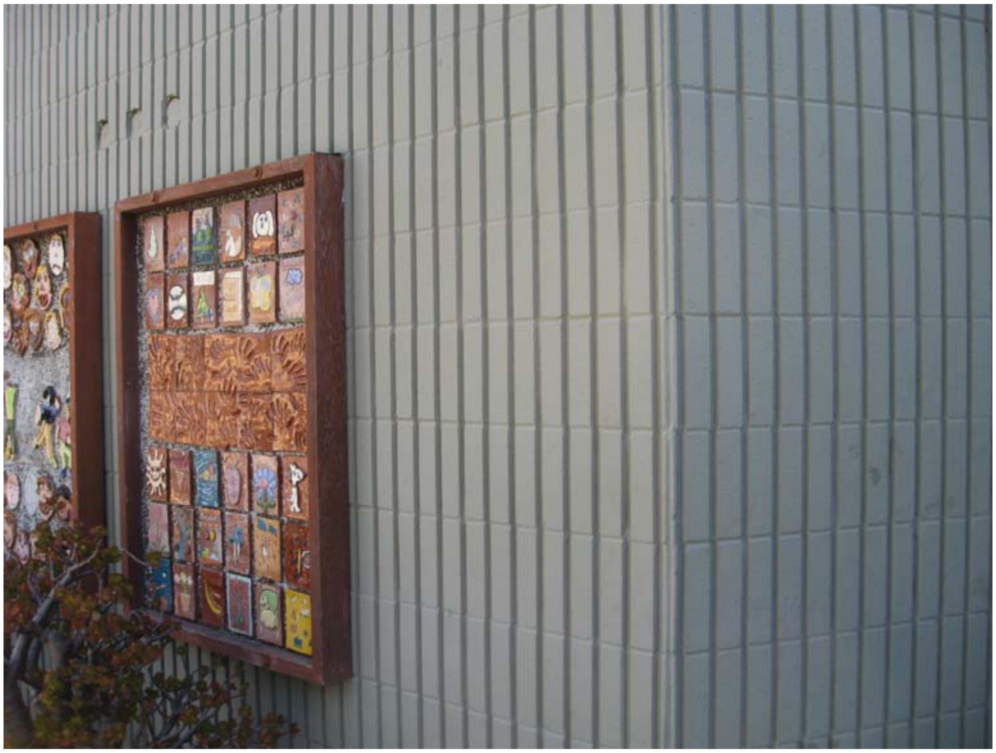

Figure 6 – Walls are constructed of "fluted" concrete block. Flutes occur on both interior and exterior faces and reduce the effective thickness of the walls.

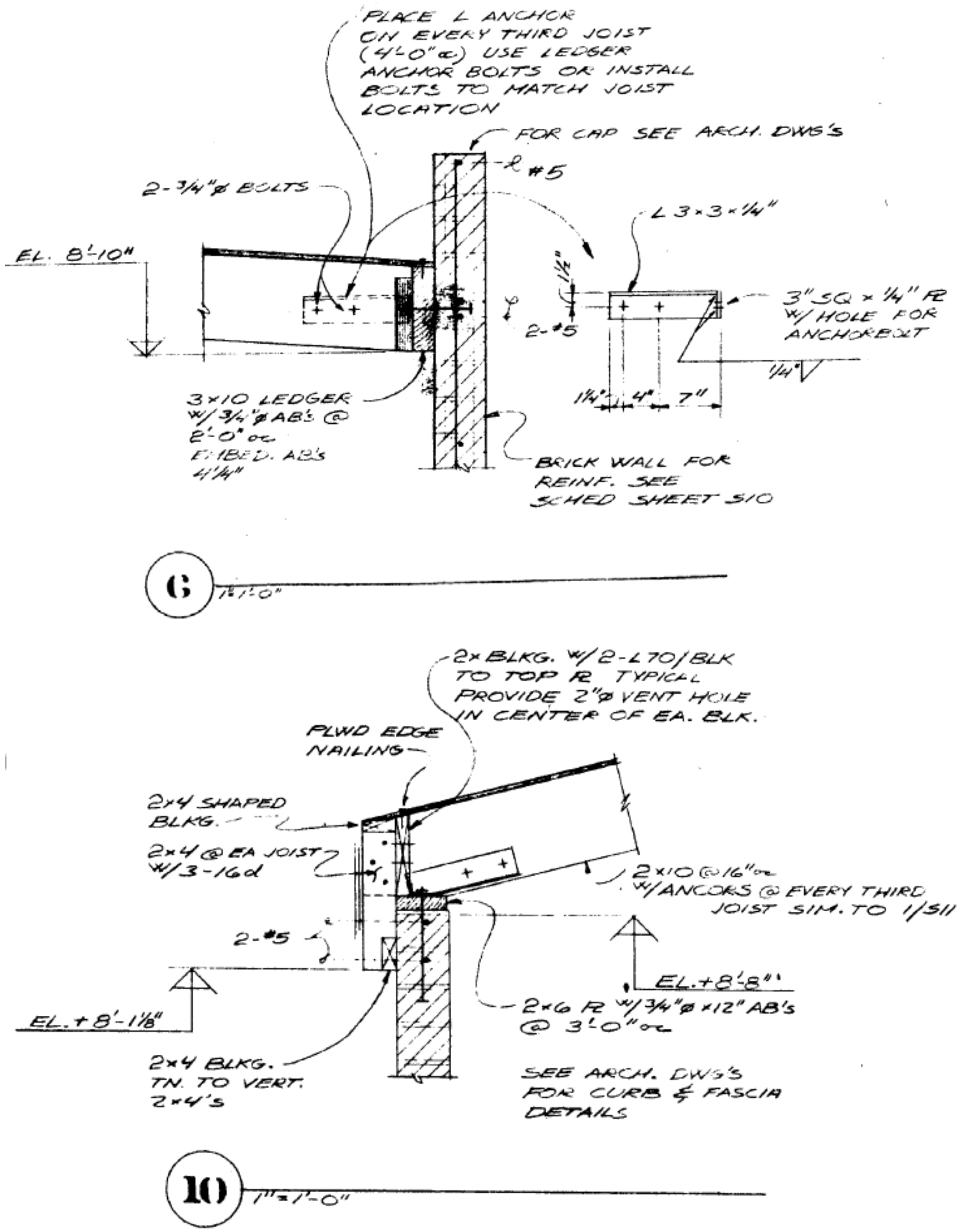

Figure 7 – Examples of wall to roof connections for the Marin buildings. Walls are 6" thick and the allowable capacity of the anchor bolts in Detail 10 is greatly reduced by the shallow cover (i.e., distance between bolt and outside face of block).

Figure 8 – The large 6x18 wood hip beams in the classroom buildings are supported by bearing on the 6” CMU walls. At this corner, the CMU wall has a very noticeable vertical crack close to the beam.

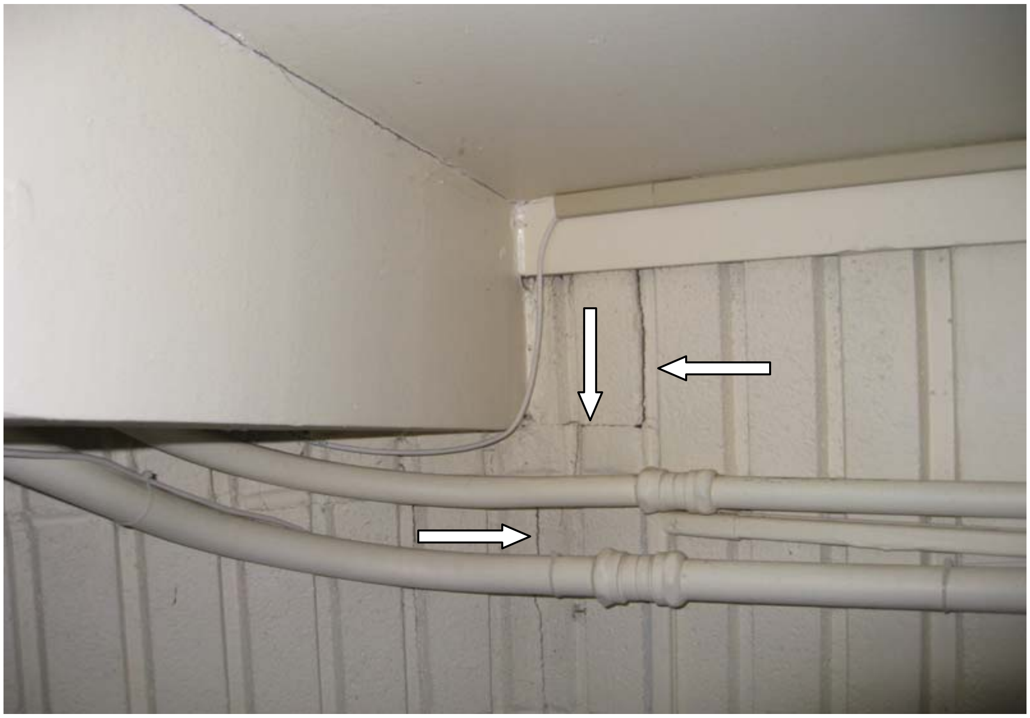

Figure 9 – Close up of cracks at 6x18 beam support shown in Figure 8.

Figure 10 – Example of typical 6x18 hip beam bearing on 6” CMU wall in a classroom building.

Figure 11 – Interior view of a typical classroom.

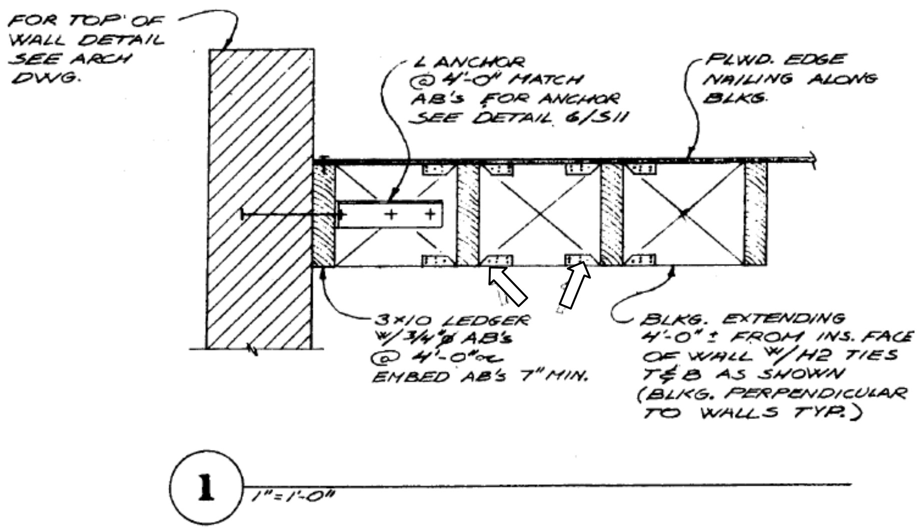

Figure 12 – One of the wall-roof connections used in Building C. In this particular connection, overstressed metal brackets (see arrows) are the weak links in the anchorage system.

4. Summary and Recommendations

4.1 Summary

Seven buildings at Marin Elementary School were evaluated for seismic safety. The evaluation criteria used were the requirements of ASCE 31 for the Life Safety performance level. Buildings evaluated were: A, B, C, D, E, F and G.

All buildings have concrete block wall construction with wood roofs and were built about 1974. Construction of this type and age is known to frequently have serious seismic deficiencies. The principal concern is the anchorage of the walls to the roof. These connections have frequently failed causing the walls and roof to separate, and in extreme cases the walls have fallen over and portions of the roof have collapsed.

Our review found that the buildings do not meet the ASCE 31 life safety criteria. The principal findings and deficiencies are described below.

(1) Classroom Buildings B, D, E, F, and G: Roofs and walls meet criteria, but the anchorage of the roofs to the 6" CMU walls is very deficient with D/C ratios of 4.0 (i.e., the connection is overstressed by a factor of four). Additionally, one end of each of the large 6x18 hip beams supporting the roof rests on a seismically very weak connection at the 6" CMU walls.

(2) Classroom Building A: Similar to the other classroom buildings, roof and walls meet criteria, but wall-roof anchorage is very deficient.

(3) Multi-Purpose Building C: Roofs and walls meet criteria with one exception. At the mechanical well, the diaphragm chord is overstressed. Similar to the other buildings, the wall-roof anchorages, including the anchorage of the two large glulam beams, are seriously deficient. Another significant deficiency is the anchorage of the two interior wood shear walls to the foundation. These are the most serious deficiencies.

4.2 Expected Performance of the Buildings in a Large Earthquake

The principal seismic threat to the school is a large earthquake on the nearby Hayward fault. A magnitude 6.8 to 7.0 earthquake on the northern segment of the fault would very strongly shake the site. The U.S. Geological Survey reports that the last five large events on the Hayward fault occurred at intervals of 95 to 160 years, with an average interval of 140 years (Ref. 4). The last large earthquake on the Hayward fault occurred in 1868, some 144 years ago.

Should a magnitude 6.8 to 7.0 earthquake occur on the Hayward fault, it is likely that the buildings, in their present condition, will suffer serious structural damage and be unusable. We believe that building collapse is unlikely, but some wall-roof separations may occur, resulting in possible localized sagging of roofs.

After the earthquake, we expect that the buildings will be Red-tagged by the authorities. They may be closed for an extended period of time (e.g., several months, to a year or more depending on the amount and severity of structural damage). If significant structural damage is experienced, DSA will require that they be repaired and upgraded before being put back in use.

In all buildings, extensive nonstructural damage will likely occur. Some of the existing classrooms (Figure 11) are very vulnerable. Bookcases and file cabinets may tip over. Contents will topple from shelves and tabletops. Some windows may break, and doors may jam.

4.3 Recommendations

To mitigate the seismic deficiencies found, we recommend that the buildings be strengthened to the Life Safety performance level of ASCE 41 "Seismic Rehabilitation of Buildings" (Ref. 7). This is the national standard for the seismic rehabilitation of existing buildings and has been accepted by DSA. The document represents the next step in an evaluation and rehabilitation process that starts with an ASCE 31 evaluation. An ASCE 31 Tier 1 nonstructural hazard survey is also recommended, and any hazards found should be mitigated.

Schools with seismic deficiencies are encouraged by DSA to voluntarily strengthen vulnerable buildings. Since the level of strengthening is voluntary, full or limited strengthening can be done.

While voluntary strengthening is recommended by DSA, this may also trigger other requirements. Generally, as part of a voluntary seismic upgrade, DSA will require each building to meet current access and fire/life safety requirements.

The next step in the process to mitigate seismic hazards is to develop a conceptual seismic upgrade design and cost estimate. At the conceptual upgrade stage, the impact of the structural strengthening on such things as the architectural finishes, walls, ceilings, and electrical and mechanical systems needs to be considered as well as DSA-mandated access and fire/safety requirements.

5. References

1. “Seismic Safety Inventory of California Public Schools, A Report to the Governor of California and the California Sate Legislature”, prepared by the Department of General Services, November 15, 2002.

2. “Initial Seismic Study of Albany USD Schools and Facilities”, report prepared by R.P. Gallagher Associates, Inc., Structural Engineers, Oakand, February, 24, 2012.

3. ASCE/SEI Standard 31-03, “Seismic Evaluation of Existing Buildings,” Structural Engineering Institute, American Society of Civil Engineers, 2003.

4. “The Hayward Fault – Is It Due for a Repeat of the Powerful 1868 Earthquake?”, U.S. Geological Survey Fact Sheet 2008-3019

5. “Seismic Hazard Curves and Uniform Hazard Response Spectra” software prepared by the U.S. Geological Survey, Version 5.09.

6. Architectural and structural drawings for Marin Elementary School, Corlett and Spackman Architects, San Francisco, and Shapiro, Okino and Hom and Associates, Structural Engineers, San Francisco, 1973, DSA Application No. 36252.

7. ASCE/SEI Standard 41-06, “Seismic Rehabilitation of Existing Buildings”, Structural Engineering Institute, American Society of Civil Engineers, 2006.