Seismic Evaluation of Ocean View Elementary School

Prepared for
Albany Unified School District
Albany, CA

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CONTENTS

1. Introduction

This report summarizes the seismic evaluation of Ocean View Elementary School (formerly Albany Middle School). The school is located at 1000 Jackson Street, Albany. The school consists of the three buildings studied as well as some newer modular buildings and portables. The latter were not reviewed as part of this study. The three buildings studied are the large classroom/library/administration building, the multi-purpose building, and the fifth grade wing. For purposes of this study, these have been designated as Buildings A, B and C, respectively.

The purpose of the study was to assess the vulnerability of the three buildings for life-safety risk in a major earthquake. Nonstructural elements were not included in the study.

The 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 preparation of structural calculations and assessment of the structural system to withstand 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 given a Tier 2 evaluation for the Life Safety performance level. This involved preparation of detailed structural calculations. For the Tier 2 evaluation, 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 1.7 miles 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 0.72g; however, only 2/3 of this level of motion (0.48g) is required to be used in the evaluations done under ASCE 31. The design ground motion parameters SDS and SD1 are 1.19g and 0.67g, 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 buildings were built about 1975 and have very similar construction with exterior concrete block walls and wood frame roofs covered with plywood sheathing. Figure 1 shows a site plan of the buildings, and Figure 2 shows an areal view of the school. Figures 3 through 9 show views of the buildings.

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 significantly since the original construction, although some minor modifications were noted. These will be discussed later in the report.

All exterior walls are constructed of reinforced concrete block (also called CMU or concrete masonry units). The block units are “fluted” on one side (see Figure 10) and the net thickness is reduced 3/8 inch. A nominal 8” block has a net thickness of 7¼ (instead of the usual 7 5/8”). The drawings do not contain information on the strength of the CMU block or that of the grout used in the construction. All cells of the block are indicated on the drawings to be filled solid with grout. For the evaluations, we assumed a compressive strength of 1,500 psi for the block.

In buildings with this type of construction, particularly those constructed in the early 1970s, a 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.

The configuration of the buildings in plan is very irregular. Forces on shear walls were determined by assuming flexible roof diaphragms and that forces are proportional to tributary roof area. There are a great many openings and clerestories in the roofs of Buildings A and C. There are also seismic separation joints between Buildings A and B and between Buildings A and C (see Figure 1).

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 roof. 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 three buildings is complex because the roof framing is a combination of glulam and wood beams with large openings for clerestories in Buildings A, B and C. Diaphragms are irregular in shape. 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 wall-to-roof connection evaluations.

3.2 Classroom Building A (Classroom/Library/Administration)

Description

Building A is a sprawling single story structure. Overall dimensions are approximately 192’ by 190’ in plan.

The roof is framed with a combination of wood and steel beams and mostly 2x8 wood joists at 16” oc. The entire roof is sheathed with ½“ plywood. Importantly, the roof “connects” a series of what would otherwise be individual small concrete block buildings.

In general, each classroom has a clerestory window with the clerestory framed on two sides by triangular stud walls with windows on the third side. The roof has a large “opening” at each clerestory. There are also a number of smaller openings in the roof for skylights. In general, the roof is extensively perforated and was modeled as “flexible”.

At the library, the roof has an elevated portion with windows that is supported by glulam beams. Some water-damaged areas were observed. It is not known if this is old damage that has been stopped by a new roof or repairs, or if there is still water leakage during the rainy season.

The masonry walls are constructed of nominal 8” and 12” thick concrete masonry units (CMU). The units are “fluted” on one side. The walls are supported by continuous shallow reinforced concrete strip 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 and interior masonry (CMU) walls and the interior plywood sheathed walls acting as shear walls and the cantilevered masonry columns.

In general, except for the water damage noted above, the building appears to be in good condition.

Results of Building A Evaluation

Building A does not meet the ASCE 31 life safety criteria. The anchorage of the tops of the masonry walls to the roof is inadequate in many places. This and other findings are discussed below and presented on Figures 11, 12 and 13.

The plywood roof diaphragms and clerestories meet the ASCE 31 criteria. Many shear walls also meet criteria. Figure 11 summarized D/C ratios for the various masonry and plywood shear walls. Overall, the demand on the various masonry walls for in-plane shear force resistance is, on average, about 20% of their capacity. The D/C ratios vary from 0.02 to 0.40 for the masonry shear walls. 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.

The plywood sheathed shear walls resist a considerable amount of the building’s seismic forces. The D/C ratios for in-plane shear are typically 0.70, indicating the walls are adequate for shear. The anchorage of the wood walls to the foundation, however, is not adequate. The element of concern is the sill plate anchorage to the foundations. The D/C ratios for sill plate anchorage range from 3.60 at the interior (east-west) wood walls separating Classrooms 3/4, 9/10, 19/20 and 27/28, to 4.30 at the west and east walls of Classrooms 15 and 16. The D/C ratios for sill anchorage at the north and south walls of Classrooms 15 and 16 are 1.13 and 1.65, respectively.

The masonry walls have adequate capacity for resisting out-of-plane seismic loading. However, the connection of the walls to the roof diaphragm is overstressed. Where the framing is bearing atop the masonry walls (see Figure 14), the minimal side cover of the anchor bolts results in a D/C ratio of 1.53. In other conditions where the roof framing is parallel to the masonry wall (see Figure 19 for an example), the H2 clips attaching the blocking limit the connection strength. Figure 13 summarize the D/C ratios for the wall-roof anchorage resisting out-of-plane forces.

The transfer of roof seismic forces to the various shearwalls is critical. This is summarized on Figure 12. A check of the collectors indicate susceptibility to damage because of the weak nominal connections along the length of these elements. Many of the beams (glulam or sawn lumber) rely on nominal bolting or anchors to drag forces into the resisting shear walls. Most of these connections have a D/C ratio greater than 2.00. The connections along the north-south corridors of Building A have a very high D/C ratio of 14.0 (see Figure 15).

Discussion of Results

The roof diaphragm and masonry shear walls meet criteria. The wood shear walls have deficient anchorage, and these must be strengthened to make these walls fully effective. The most serious deficiencies are in the connections of the roof to the shear walls. Some of these connections (e.g., collectors) have very high D/C ratios of 14.0 and require strengthening. Wall-roof anchorages are overstressed 50% for out-of-plane forces and also need strengthening.

3.3 Classroom Building B (Multi-Purpose)

Description

Building B is a two level, single story structure. Overall dimensions are approximately 119’ by 111’ in plan.

The high roof over the multi-purpose room has two large raised areas for clerestories and is supported by four large 36” deep glulam beams and reinforced CMU bearing walls. The glulams span approximately 60’ and run north-south. The sloped roofs have 3 x 12 joists at 16” oc with ½” plywood sheathing. At the stage area, the roof consists of 3 x 12 joists at 16” oc with ½” plywood sheathing.

The walls supporting the high roof area are nominal 8” and 12” reinforced CMU. CMU units are fluted on one side. The entire high roof is supported by the CMU bearing walls.

The low roof, with entry, kitchen and classrooms, is essentially flat and is framed by a combination of 15” deep glulam beams and 2 x 8 or 2 x 10 joists at 16” oc. Walls are nominal 8” reinforced CMU with block units fluted on one side. There is one interior, plywood sheathed shear wall.

Footings are reinforced concrete and are a combination of individual footings and continuous strip footings, with the individual footings integral with the continuous strip footings.

Seismic forces in both directions are resisted by the plywood sheathed roof diaphragms, and the CMU walls and one plywood sheathed wall acting as shear walls. Building B is seismically separated from the adjacent Building A by a 1½" separation joint.

The building appears to be in good condition.

Results of Building B Evaluation

Building B does not meet the ASCE 31 criteria. The connection of the walls to the roof is deficient in many places. This and other findings are discussed below and presented on Figures 16, 17 and 18.

The plywood roof diaphragms of the building are in conformance with the ASCE 31 criteria. The largest D/C is equal to 0.96 for the diaphragm over the multi-purpose room. Most diaphragms have concrete masonry walls functioning as the chord members, and the chords are adequate.

Figure 16 shows the D/C ratios for the in-plane strength of the CMU and plywood shear walls. All walls are in conformance with ASCE 31 requirements.

The principal structural deficiency of this building is the weak out-of-plane anchorage between the wood roof and the masonry walls. All masonry walls are not in compliance with out-of-plane anchorage requirements. The D/C ratios for various walls can be seen in Figure 18. These range from 1.12 to 4.81 with five walls having D/C's greater than 2.0. The large D/C ratios are due to the weak sheet metal brackets (H2 clips) shown in Figure 19. This detail is used at many walls throughout the building.

Another structural deficiency is the weak in-plane connection between wood roof and the walls of the building. The D/C ratios for various walls are given in Figure 17. This deficiency has two components: (1) the direct connection between the roof and the top of the wall; and (2) the strength of the collector (see Figure 15 for an example) which is the structural element that gathers the tributary roof seismic force and transfers it to the wall. Non-conformance of either component means that strengthening is required by the criteria. Only some of the walls are not in compliance, and most of these are those with overstressed collector connections.

Discussion of Results

The roof diaphragm and masonry and plywood shear walls meet criteria, but a number of the walls are inadequately connected to the roof and need to be strengthened. The most serious of the deficiencies are the connections of the west, south and east walls of the multi-purpose room to the roof for out-of-plane seismic forces. These are a high priority for strengthening.

3.4 Building C (Fifth Grade)

Description

Building C is a single story masonry structure with overall dimensions of approximately 102' by 66' in plan. The building is U-shaped in plan with a courtyard that opens at the north.

The roof is framed with mostly 2x8 roof joists and has ½" plywood sheathing. Joists are supported by wood beams, glulam beams, wood bearing walls and CMU walls. There are five clerestories. These supported by 18" deep glulam beams.

Exterior walls are constructed of 8"and 12" CMU. Units are "fluted" on one side. 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, the exterior CMU and interior plywood sheathed walls acting as shear walls and by cantilevered masonry columns. Building C is seismically separated from adjacent Building A by a 1½" separation joint.

The building appears to be in good condition.

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 and summarized on Figures 20, 21 and 22.

The plywood roof diaphragms and clerestories meet the ASCE 31 criteria. Shear walls also meet criteria. Figure 20 summarizes D/C ratios for the various masonry and plywood shear walls.

Overall, the demand on the various masonry walls for in-plane shear force resistance is, on average, about 20% or less of their capacity. The interior masonry walls are expected to resist a greater amount of loading. The D/C ratios vary from 0.01 to 0.36 and are well within criteria.

There is one plywood sheathed shear wall in Building C. This separates Classrooms 35 and 36. For in-plane shear, the D/C ratio is a low 0.19, and the anchorage of the wall to the foundation has a D/C ratio of 0.82.

There are a number of collectors that take tributary roof seismic forces and transfer these to the shear walls. A check of the collectors shows a range of D/C ratios from 1.34 to 10.20. Collectors are typically glulam roof beams. The connections of the glulam beams to the tops (or sides) of masonry walls lack adequate strength for transfer of the expected forces. Walls along the perimeter are typically longer, and have smaller breaks along their lengths, and the D/C ratios are within acceptable ranges. Figure 21 shows the D/C ratios for the transfer of the roof seismic forces to the shear walls.

The masonry walls have adequate capacity for resisting out-of-plane seismic forces. However, the connection of these walls to the roof diaphragm is overstressed. Where the framing is bearing atop the masonry walls, the minimal side cover of the anchor bolts results in a D/C ratio of 1.53. In other conditions where the roof framing is parallel to the masonry shearwall, the H2 clips attaching the blocking limits the connection strength. This connection has a D/C ratio of 1.42. Figure 22 shows the D/C ratios for anchorage of the masonry walls to the roof for out-of-plane seismic forces.

Discussion of Results

The roof diaphragm and masonry and plywood shear walls meet criteria, but a number of the walls are not adequately connected to the roof. Collectors are a serious concern with D/C ratios has high as 10.2 and six collectors having D/C's larger than 2.0.

3.5 Main Entrance Structure

The main entrance to the school is shown in Figure 3. It appears that the original 3 x 4 wood posts for the fence and gates have been replaced by metal tubes. We had no information concerning this change. The entrance structure is laterally supporting the new gates and tube fence. It consists of a built-up horizontal wood box beam supported by two 12" CMU columns and 8" CMU walls at the ends. The 12" CMU columns are supported by spread footings. This structure was reviewed for ASCE 31 seismic forces and found to meet criteria.

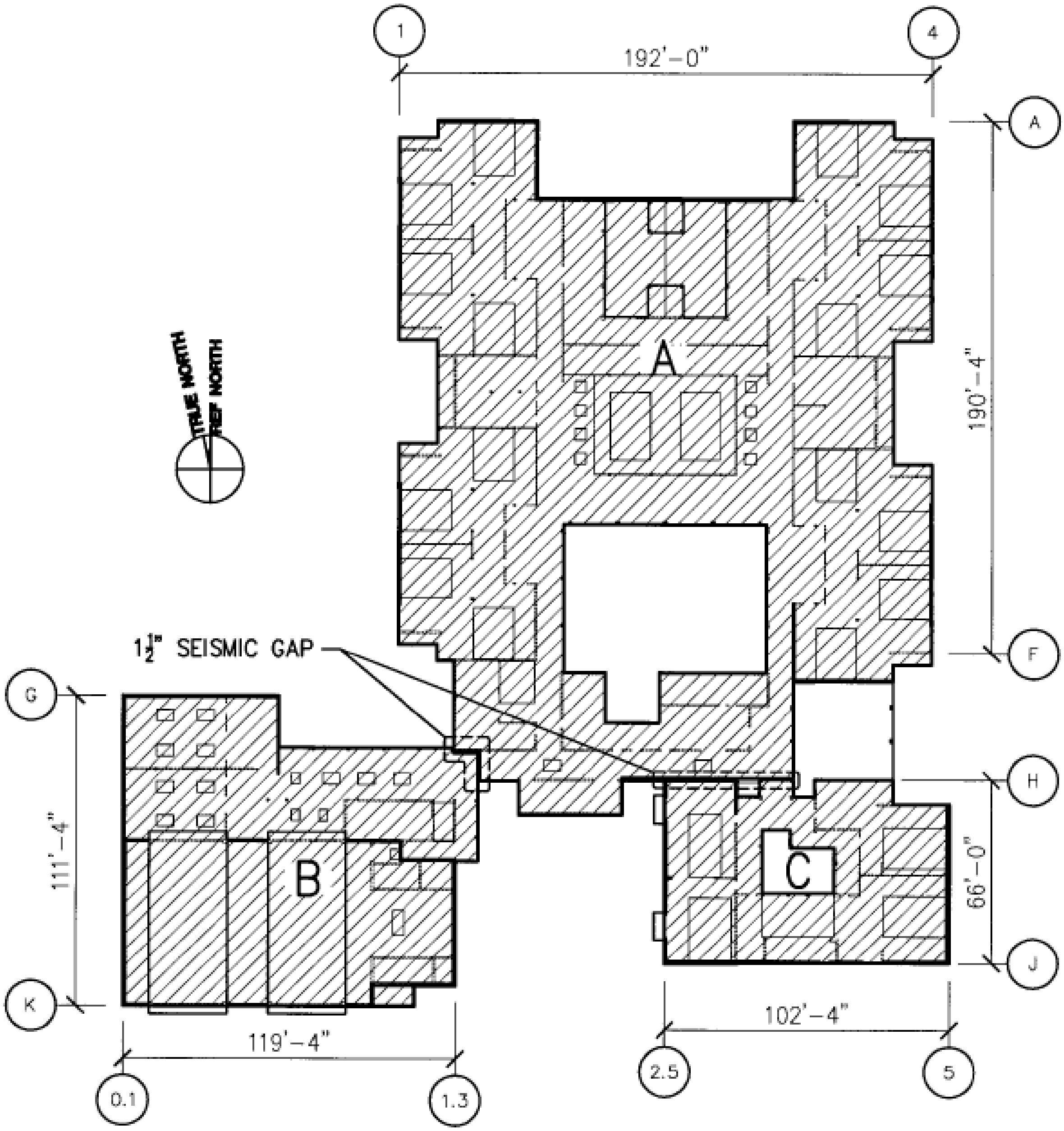

Figure 1 – Site plan showing Buildings A, B and C.

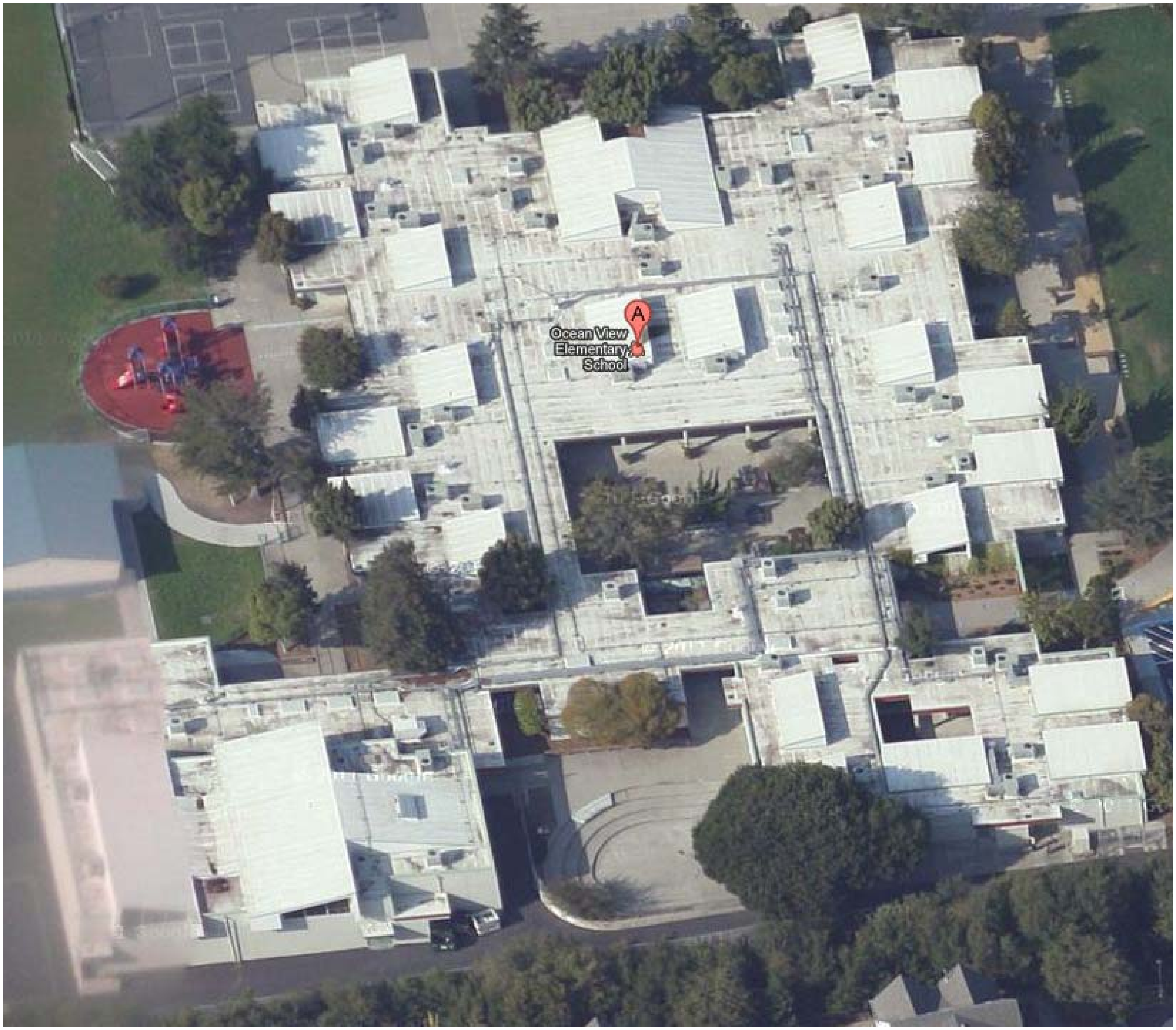

Figure 2 – Aerial view of Ocean View School.

Figure 3 – Main entrance to Ocean View Elementary School.

Figure 4 – East Side of Building A (Classrooms/Library/Administration).

Figure 5 – North side of Building A.

Figure 6 – Northwest corner of Building A. Note clerestory windows above classrooms.

Figure 7 – Southeast corner of Multi-Purpose building (Building B).

Figure 8 – West side of Multi-Purpose building (Building B).

Figure 9 – East side of Building C (Fifth Grade Wing).

Figure 10 – Concrete block is flutted on one side for all buildings. Flutes are 3/8 inch deep.

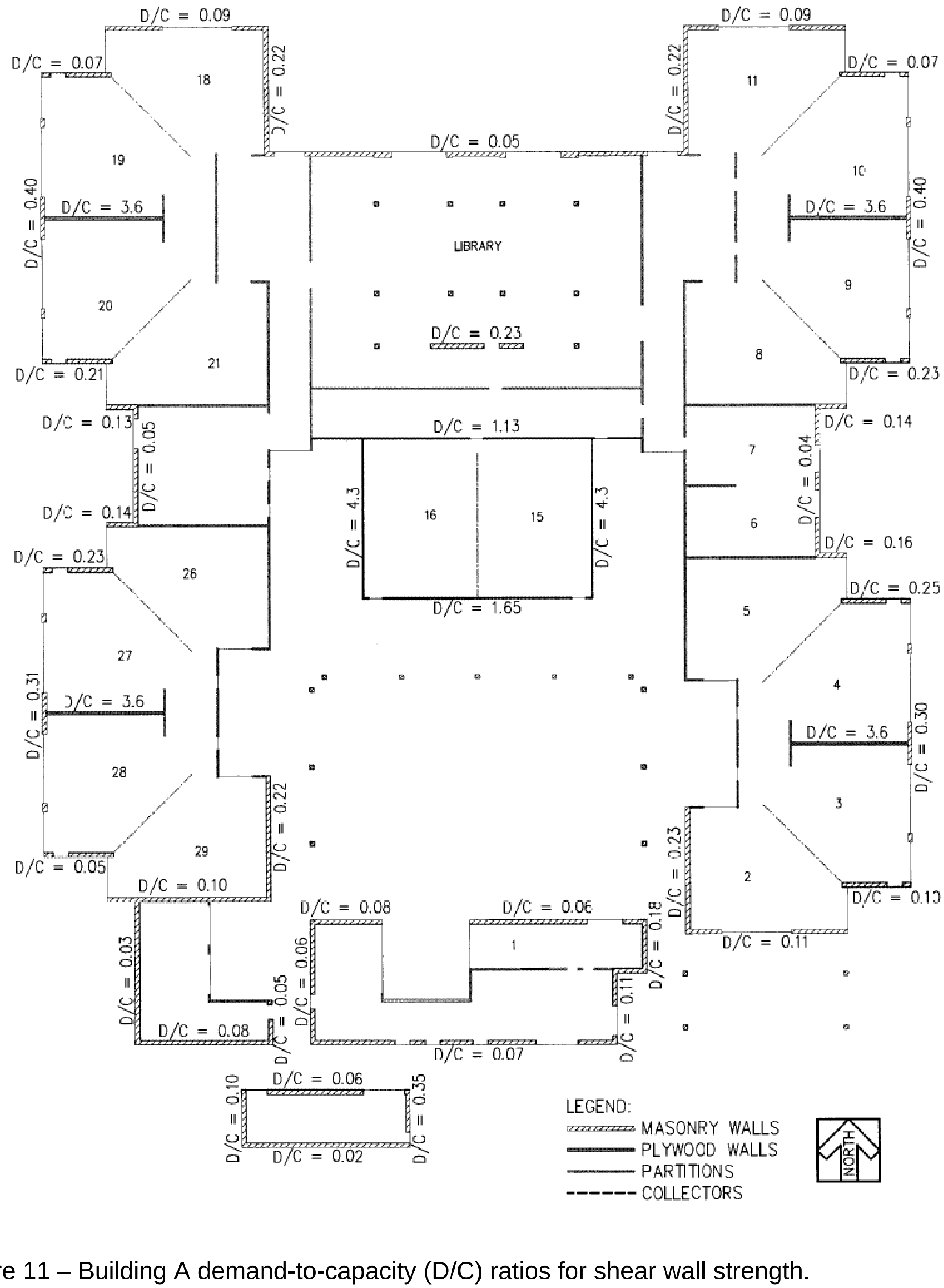

Figure 11 – Building A demand-to-capacity (D/C) ratios for shear wall strength.

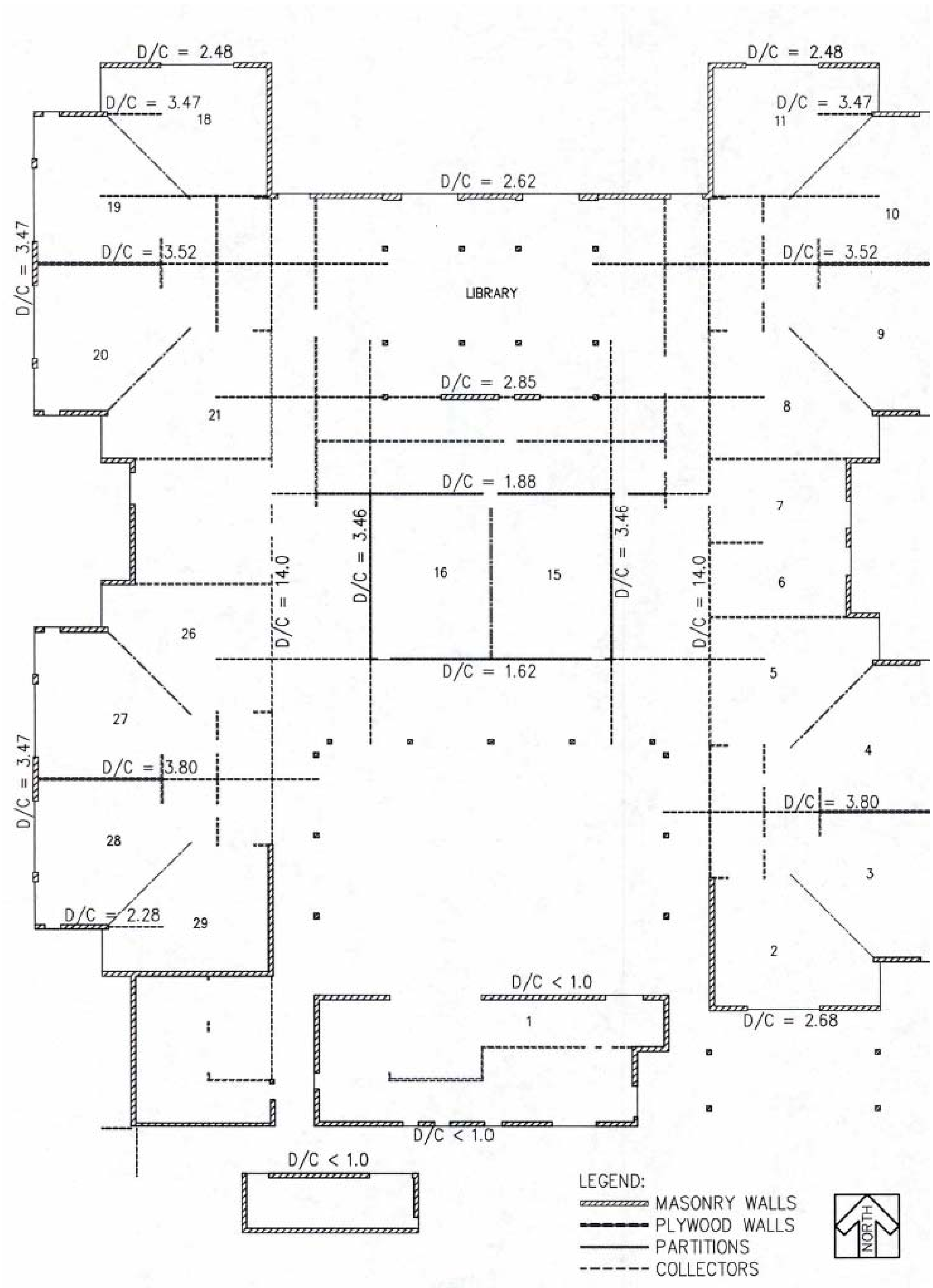

Figure 12 – Building A demand-to-capacity ratios (D/C) for the connection of the roof to the shear walls.

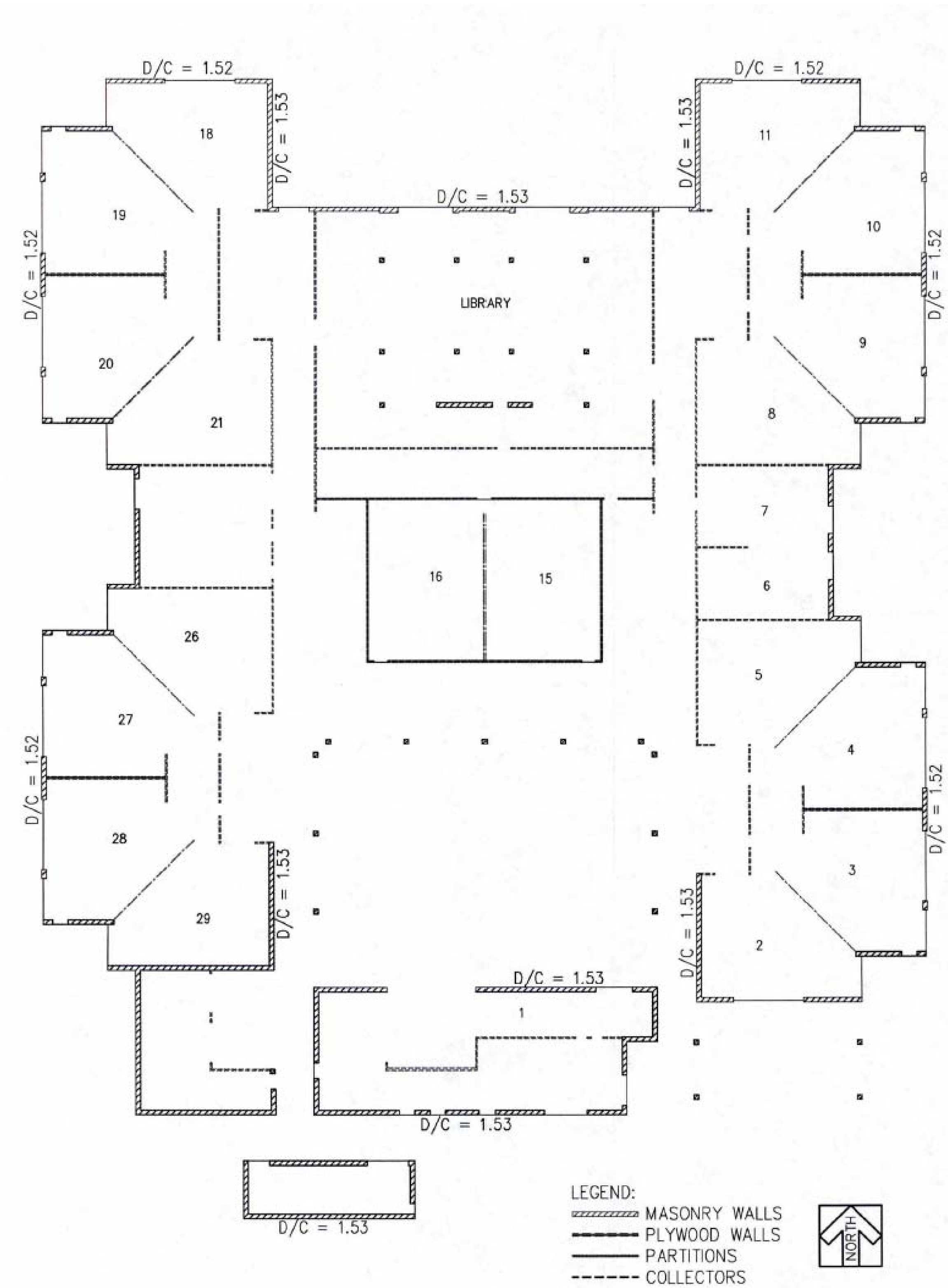

Figure 13 – Building A demand-to-capacity ratios (D/C) for the anchorage of the walls to the roof for out-of-plane seismic forces.

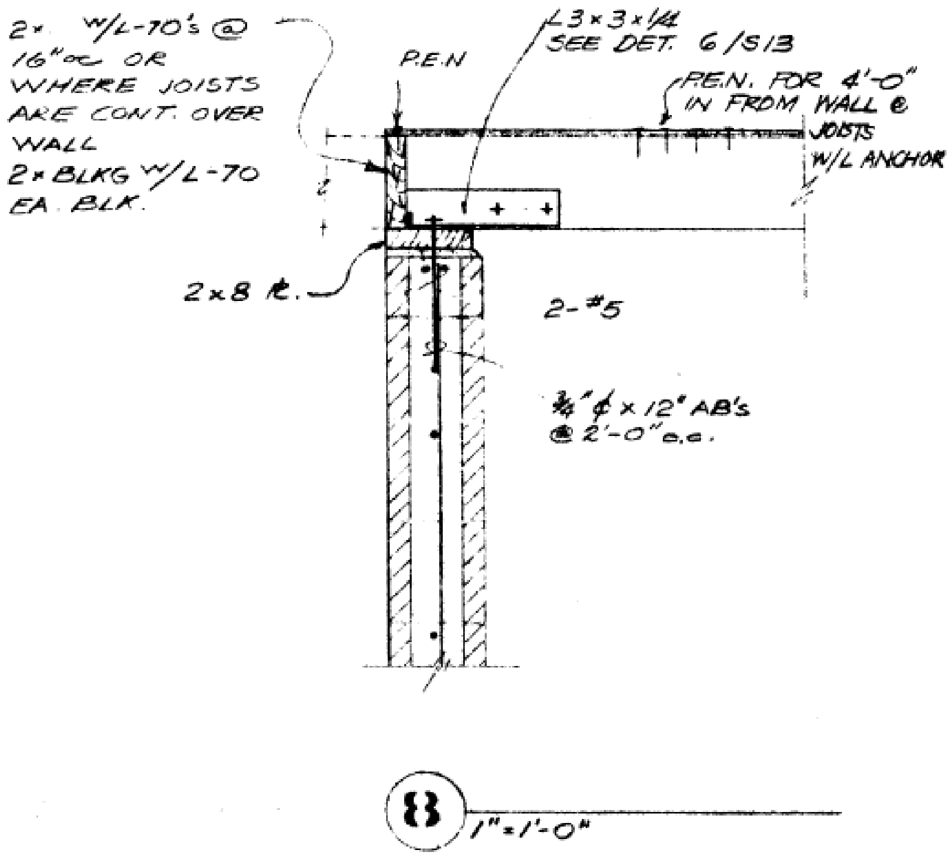

Figure 14 – An example of one of the wall-roof connections used in Buildings A and C. Because the anchor bolts in the masonry lack sufficient side cover, this connection is over-stressed with a D/C of 1.53.

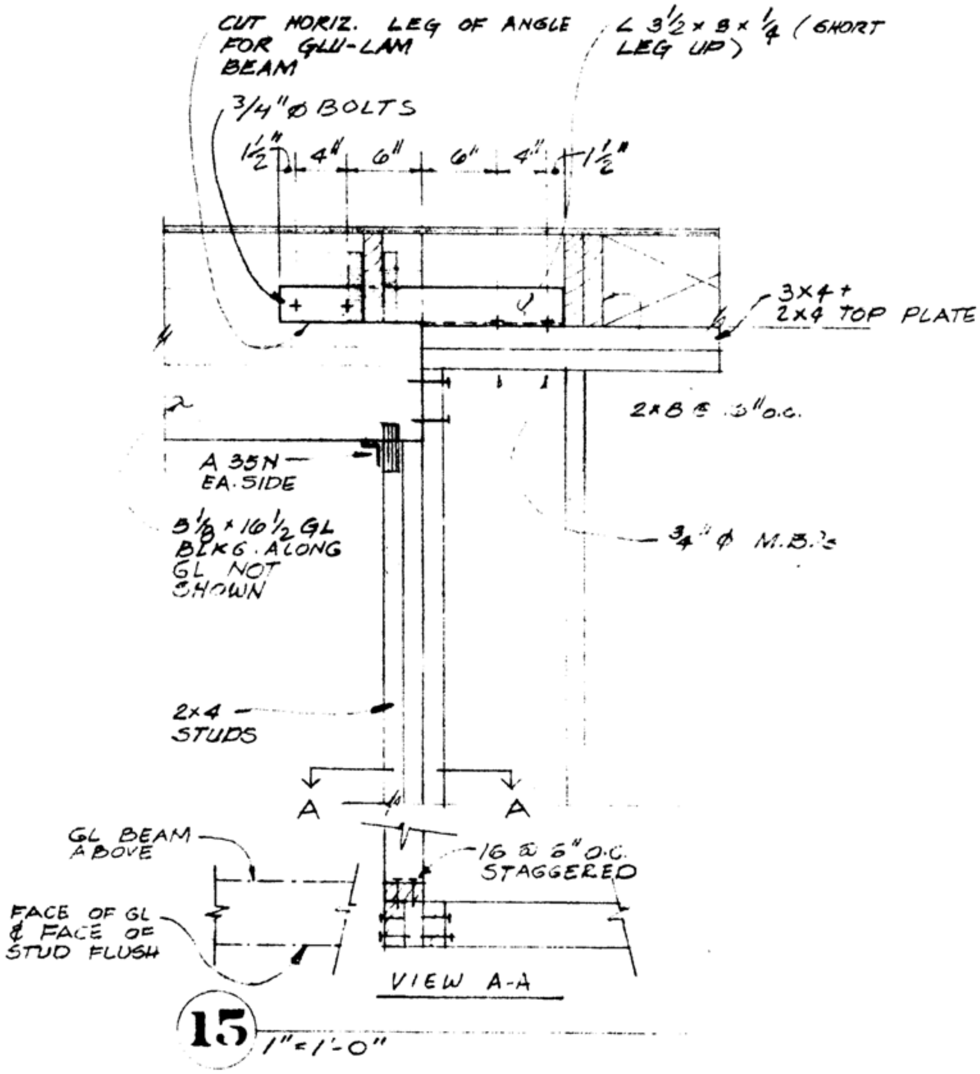

Figure 15 – Typical collector connection in Building A showing the attachment of a glulam beam to a wood wall. The strength of the connection is limited by the ¾" bolts connecting the 3½ x 3 angle to the glulam beam and the wood wall. The D/C ratio is very high 14.0.

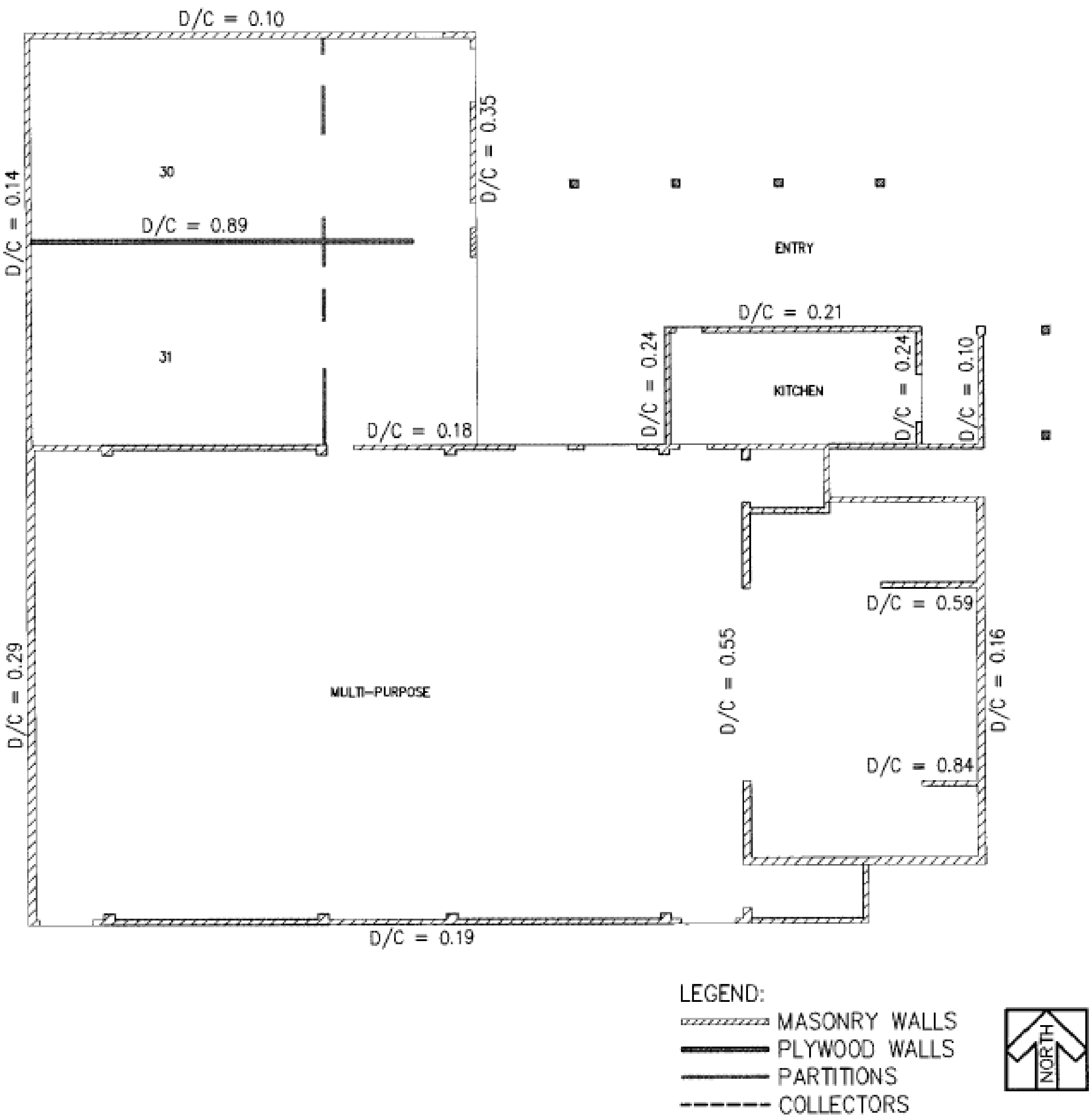

Figure 16 – Building B demand-to-capacity ratios (D/C) for shear wall strength.

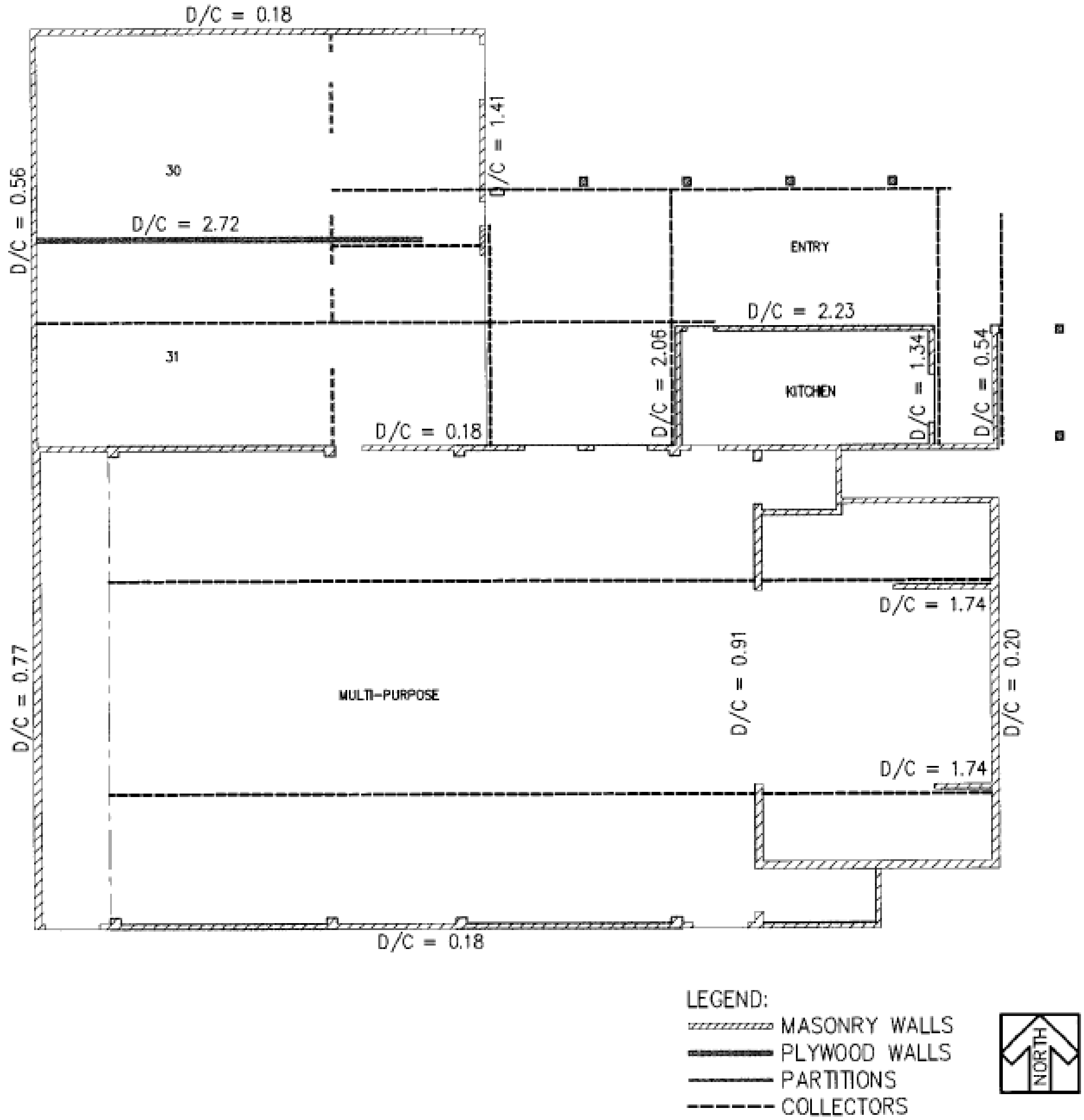

Figure 17 – Building B demand-to-capacity ratios (D/C) for the connection of the roof to the shear walls.

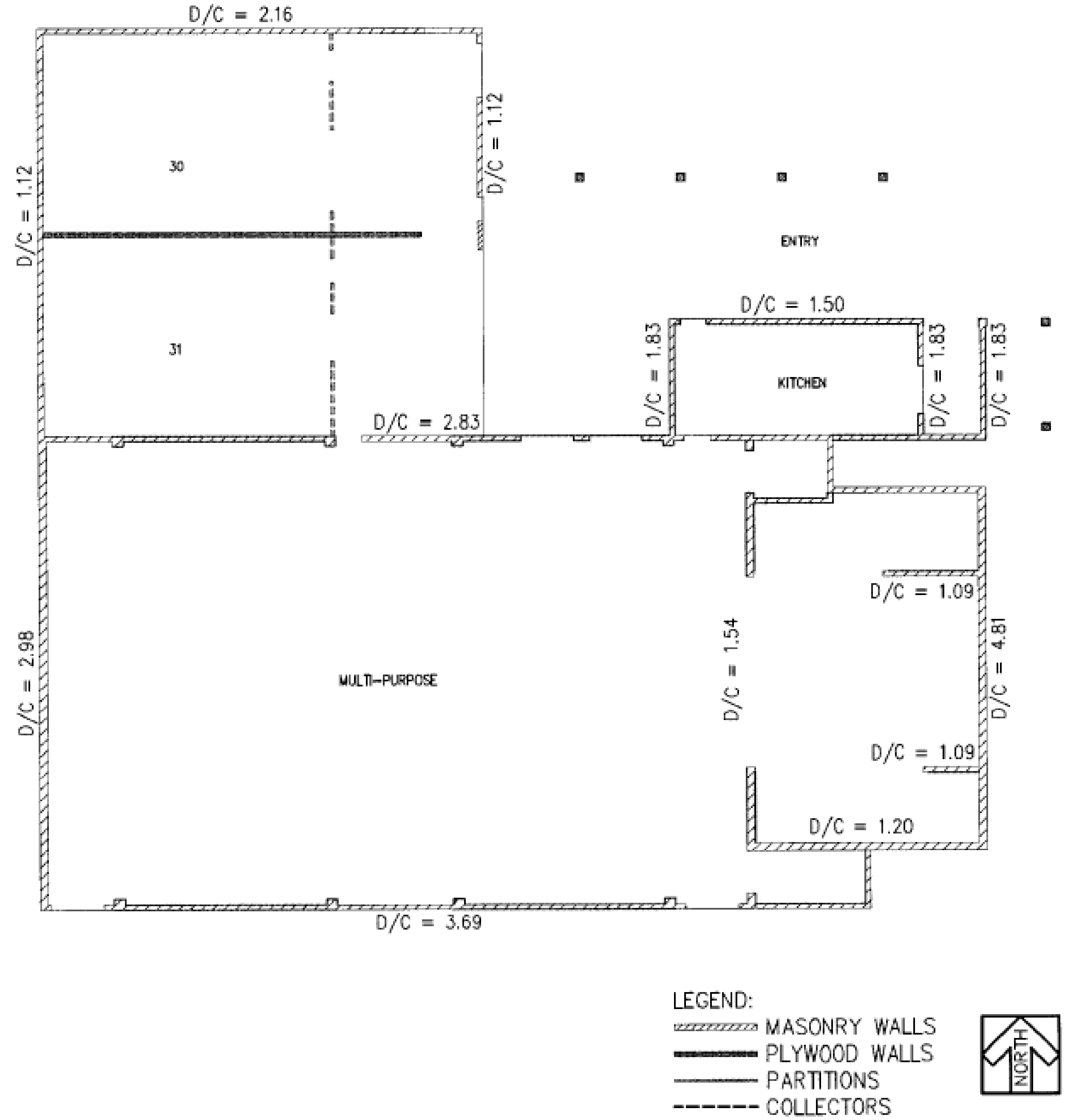

Figure 18 – Building B demand-to-capacity ratios (D/C) for anchorage of the walls to the roof for out-of-plane seismic forces.

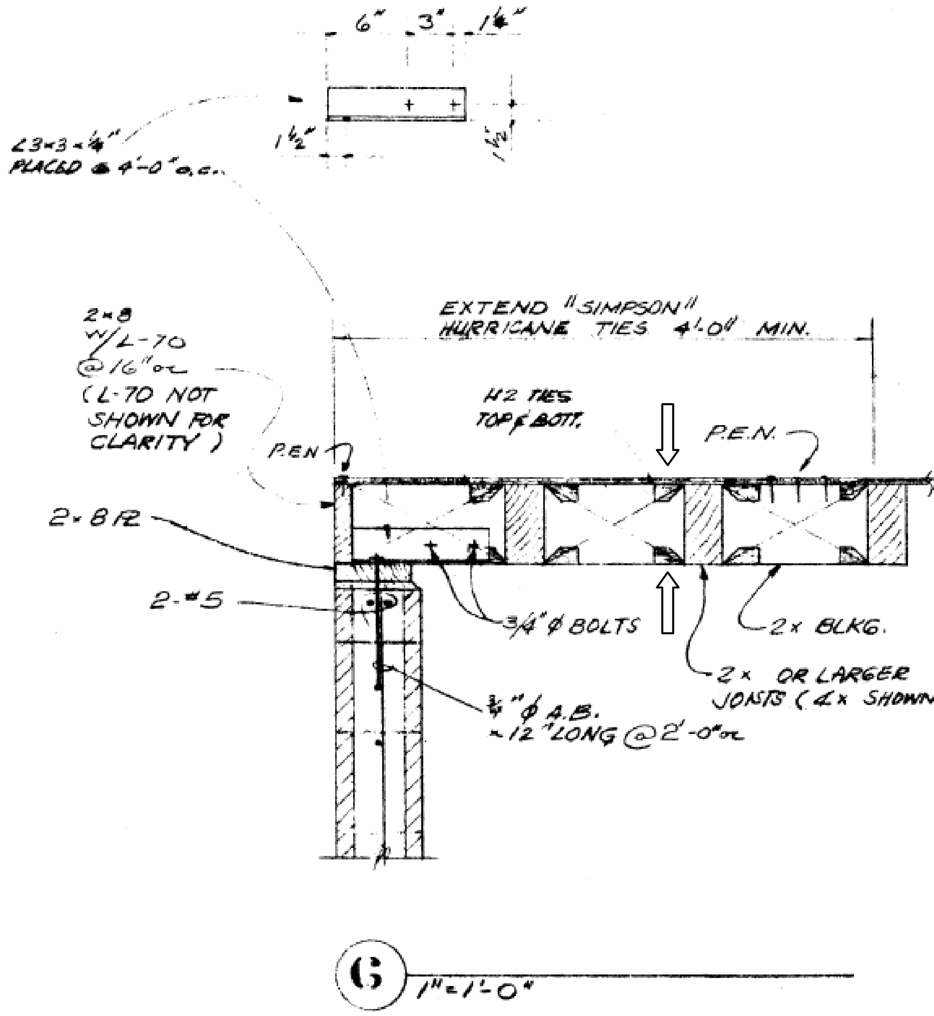

Figure 19 – The wall-roof anchorage connection shown above is used in many places in Building B. In this connection, the weak links are the H2 metal brackets (see arrows). These are greatly overstressed.

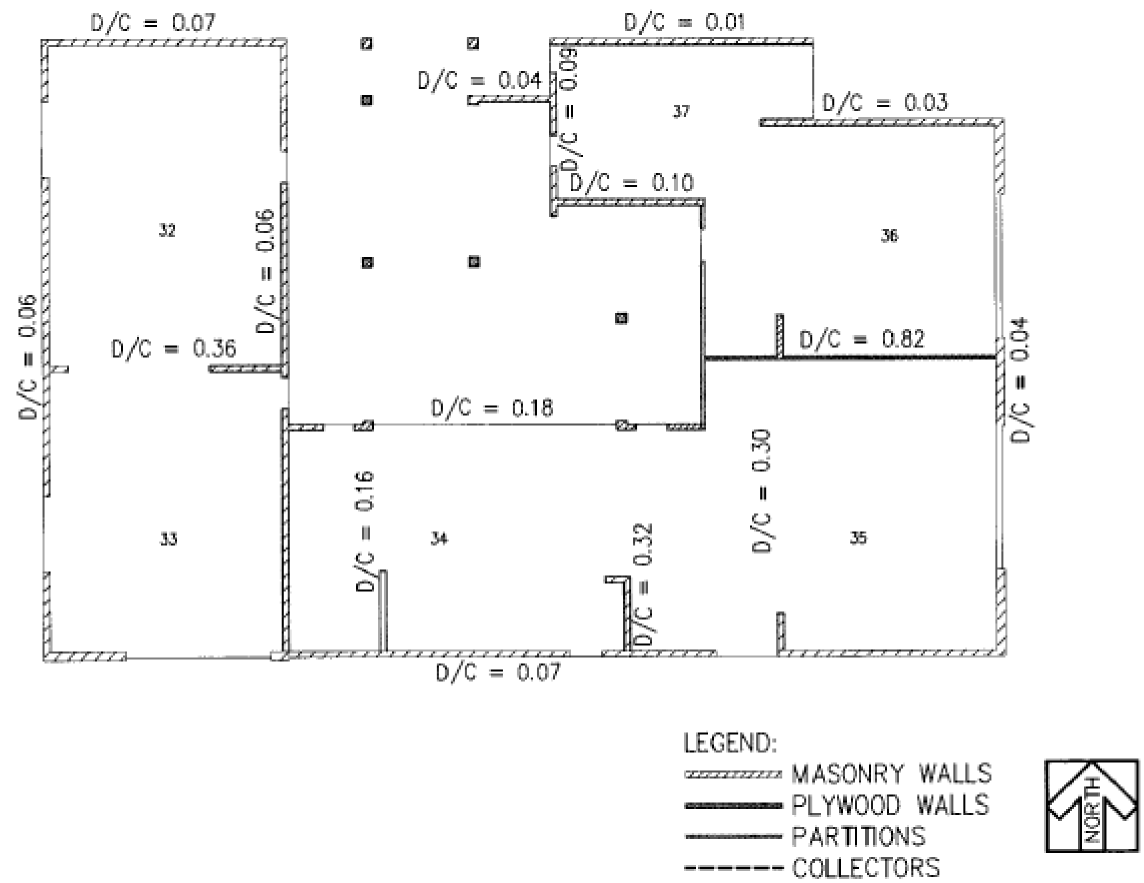

Figure 20 – Building C demand-to-capacity ratios (D/C) for shear wall strength.

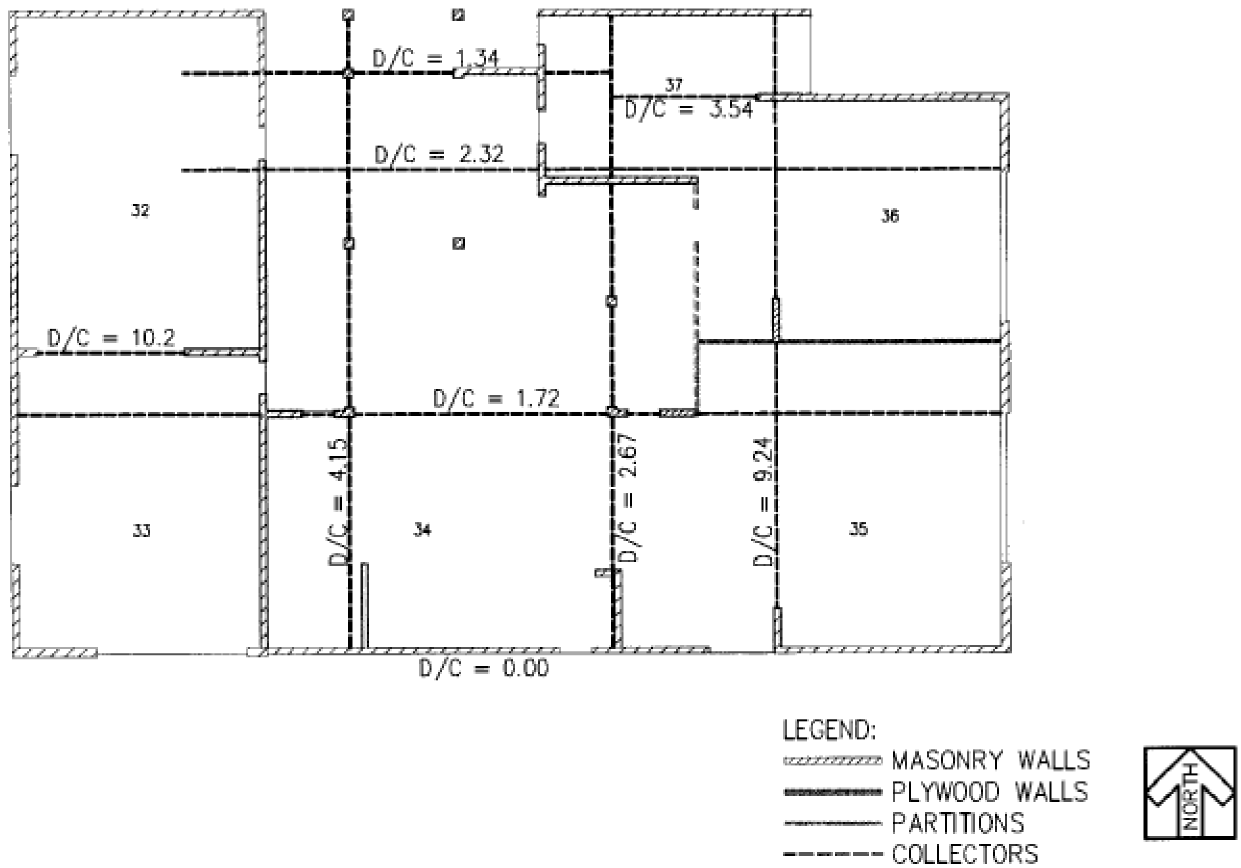

Figure 21 – Building C demand-to-capacity ratios (D/C) for the connection of the roof to the shear walls.

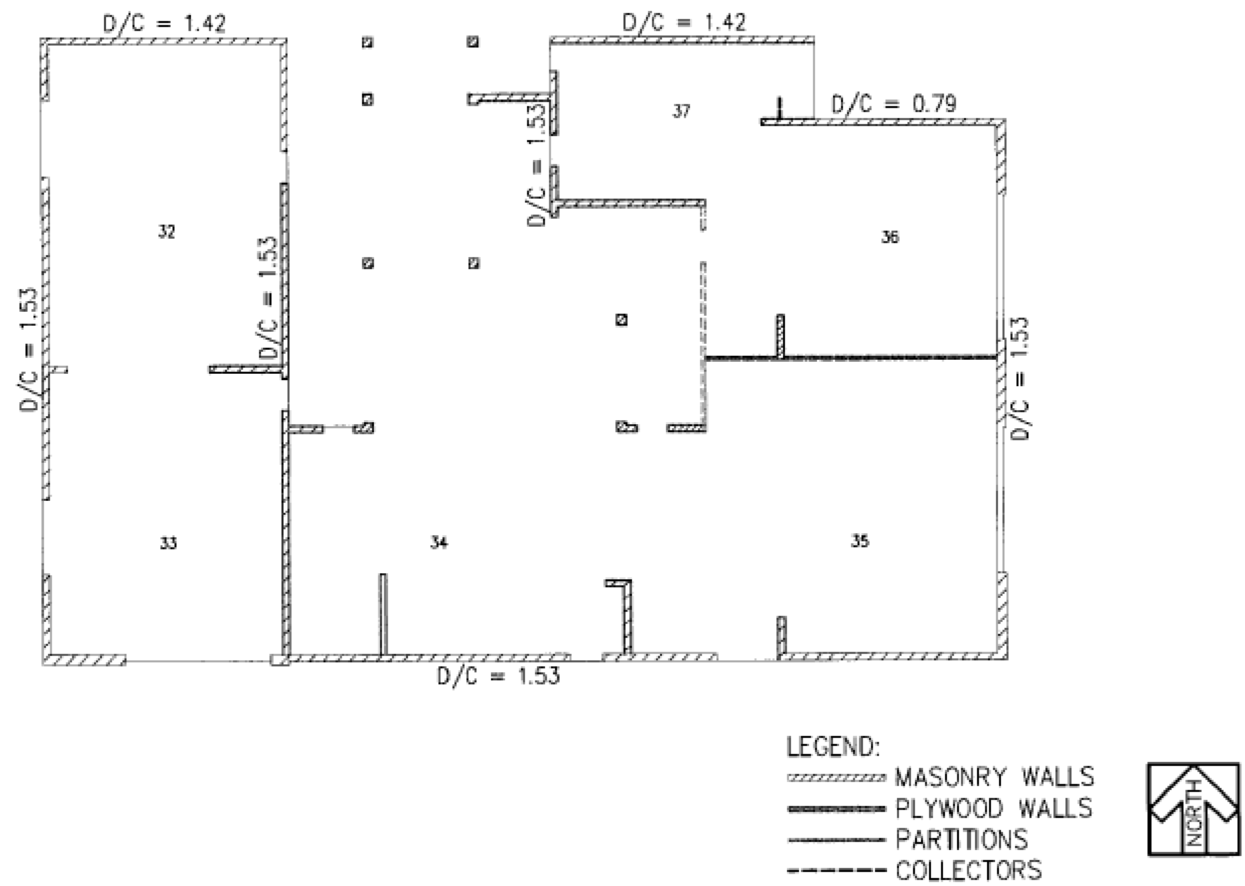

Figure 22 – Building C demand-to-capacity ratios (D/C) for anchorage of the walls to the roof for out-of-plane seismic forces.

4. Summary and Recommendations

4.1 Summary

Three buildings at Ocean View Elementary School were evaluated for seismic safety. The evaluation criteria used were the requirements of ASCE 31 for the Life Safety performance level.

The buildings have concrete block wall construction with wood roofs and were built about 1975. 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 three buildings do not meet the ASCE 31 life safety criteria. The principal findings and deficiencies are described below.

(1) Building A (Classroom/Library/Administration): This is the largest building. The roof diaphragm and masonry shear walls meet criteria, but the wood shear walls do not because of their weak anchorage to the foundation. Sill plate D/C ratios are a high 3.60 to 4.30. The most serious deficiency, however, is the attachment of the roof to the walls. Some of the collectors that drag the roof seismic forces to the shear walls have very high D/C ratios of 14.0. Also, the anchorages of many walls to the roof for out-of-plane forces are overstressed by 50%.

(2) Building B (Multi-Purpose): The shear walls and roof diaphragm of Building B meet the life safety criteria. There are, however, some significant deficiencies in the connection of the roof to the shear walls for both in-plane and out-of-plane seismic forces. The most serious deficiencies are the weak anchorage of the west, south, and east walls of the multi-purpose room for out-of-plane seismic forces. D/C ratios range from 2.98 to 4.81 indicating a significant problem.

(3) Building C (Fifth Grade): While the shear walls and roof diaphragm of Building C meet the ASCE 31 criteria, some significant deficiencies were found. The most serious is the connection of the roof to the shear walls. There are a number of collectors in the roof that “collect” seismic forces and transfer them to the shear walls. These have D/C ratios of 1.34 to 10.2 with six greater than 2.0. The principal weakness is the “connection” of collectors (typically glulam beams) to the shear walls. Connections, consisting of anchor bolts and other devices, are sometimes greatly overstressed while the “collector” is well within criteria.

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.

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. Glazing in the clerestories should be checked for ASCE 31 life safety requirements.

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

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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.

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