Cyclic Comparison Testing
Of
Light Wood Framed Shear Walls

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1999

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1.) Preface:

This document presents the findings of a self-directed, independently funded research project into simplified quantitative testing of the ductile capacity and strength of various light wood framed shear wall sheathing materials. A method for determining the relative ductility of various sheathing materials under reversing-cyclic load was investigated in order to evaluate static Uniform Building Code (ICBO) design capacities for these materials.

We gratefully acknowledge the assistance, support and/or funding provided by: The Department of Civil and Environmental Engineering at San Jose State University, Dr. Bernard Gabrielsen, Mr. Richard Holms, and Dr. Thalia Anagnos.

We also gratefully acknowledge the efforts of students Tim Wann and Randy Buckman who fabricated the test fixtures, built the test walls, set up the instrumentation, ran the tests, summarized their findings in a draft report and analyzed the data.

Malcolm Koch, Raymond Brindos and Erwin Teufel, technicians at the College of Engineering, also provided much appreciated assistance.

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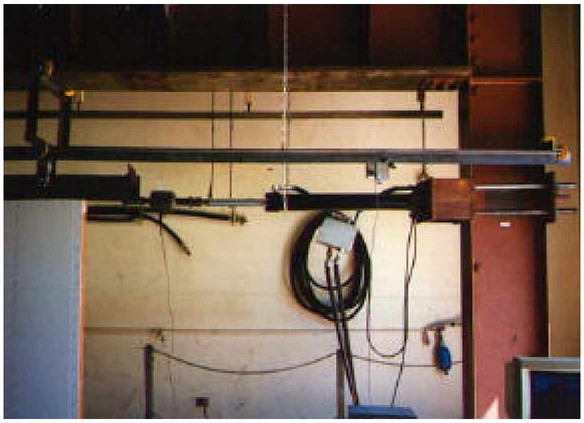

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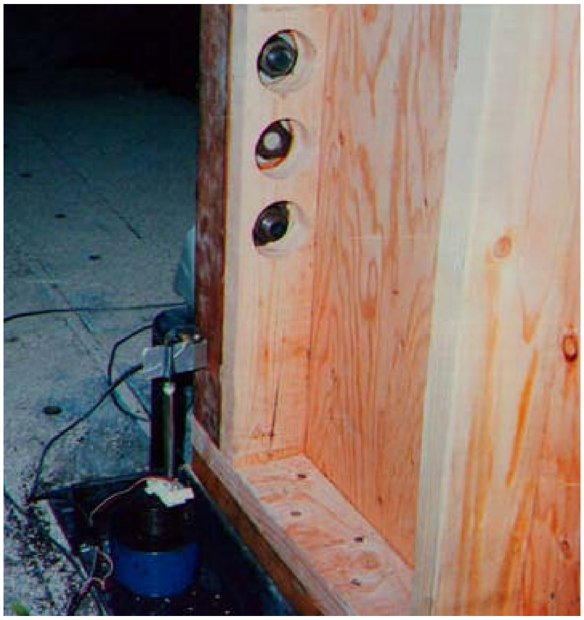

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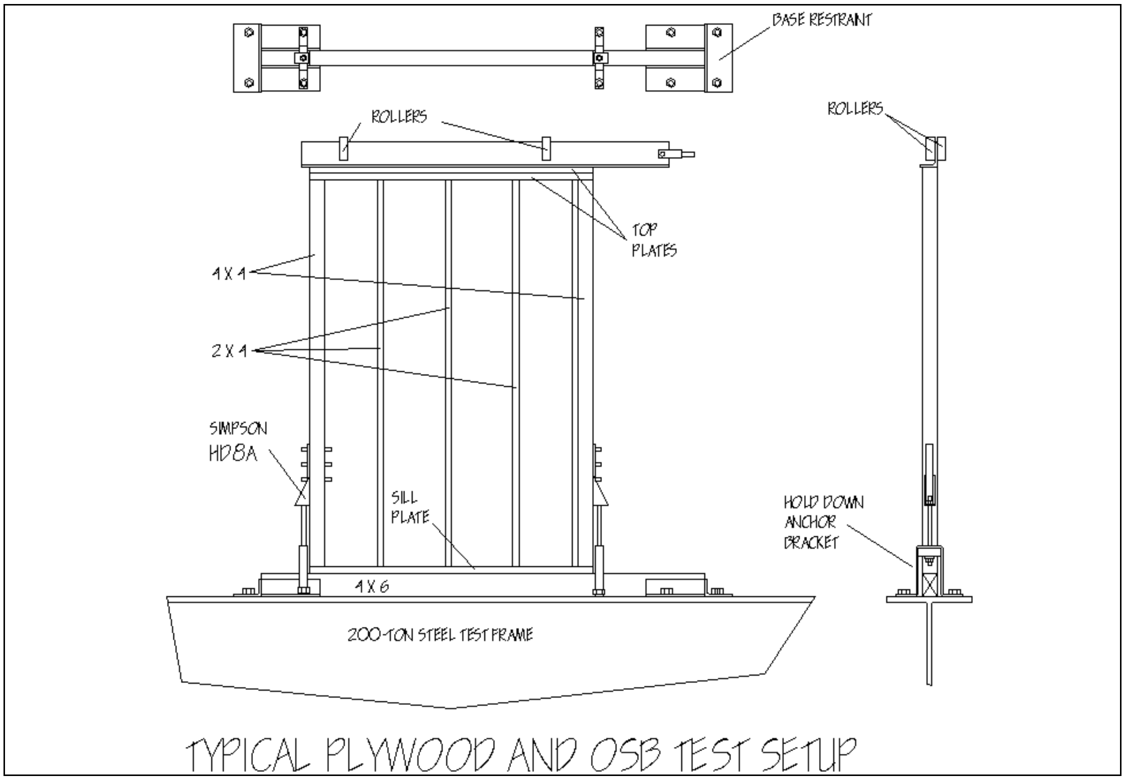

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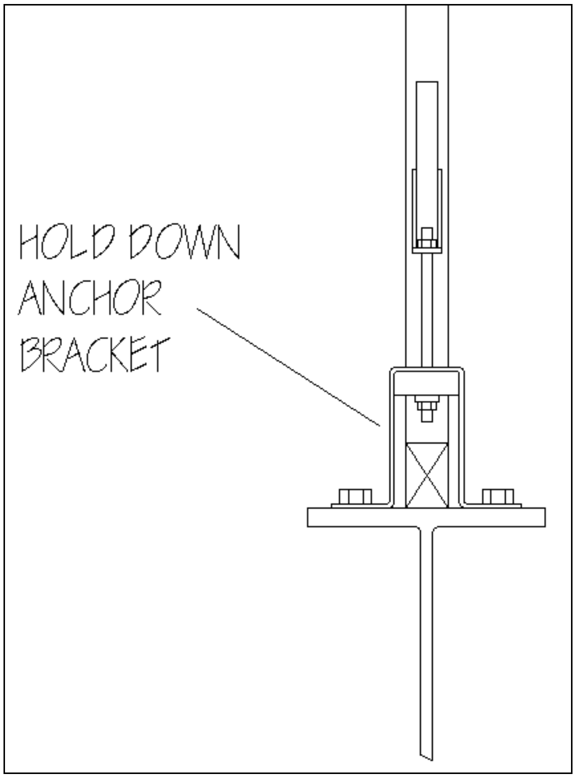

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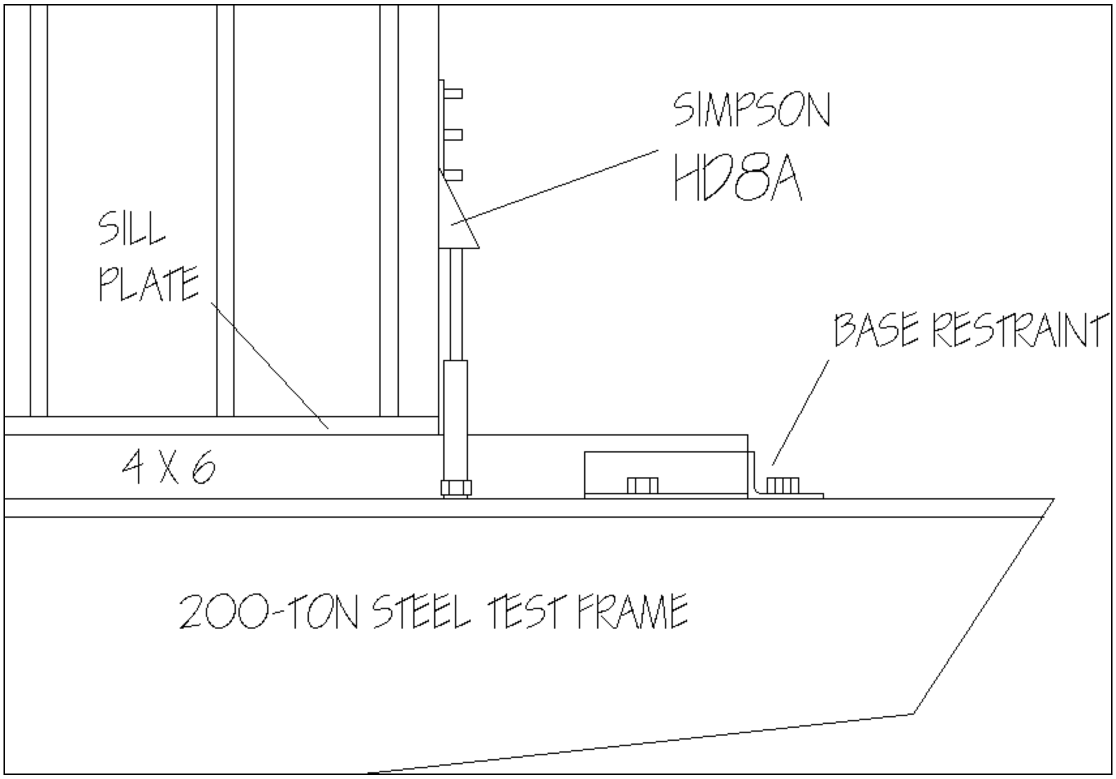

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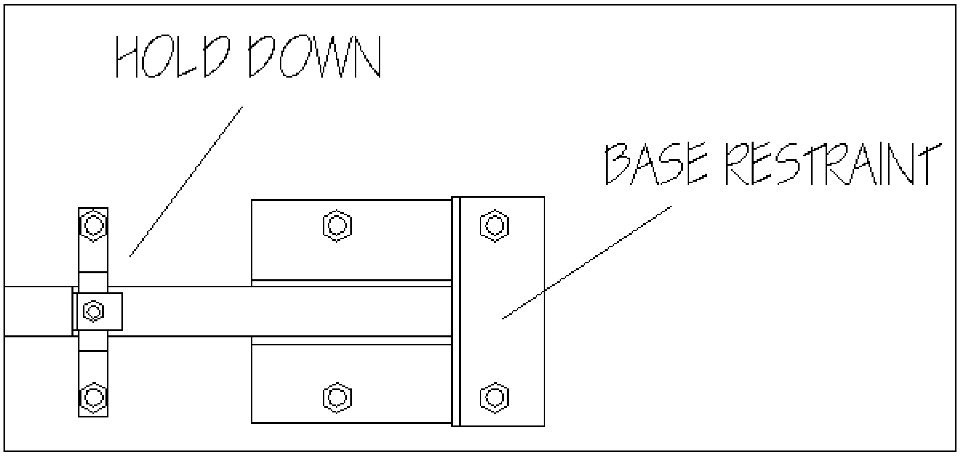

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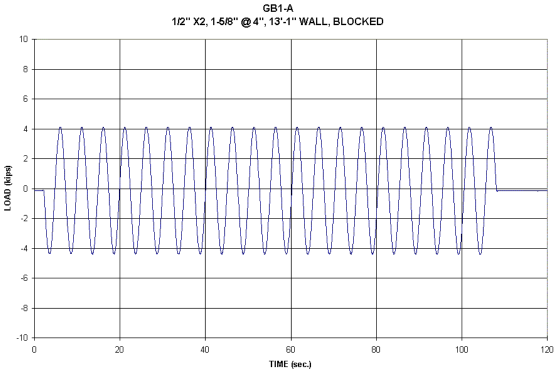

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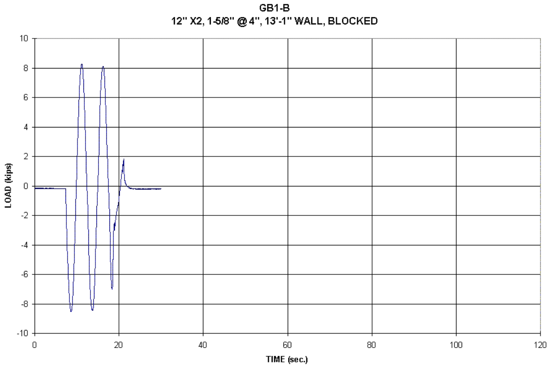

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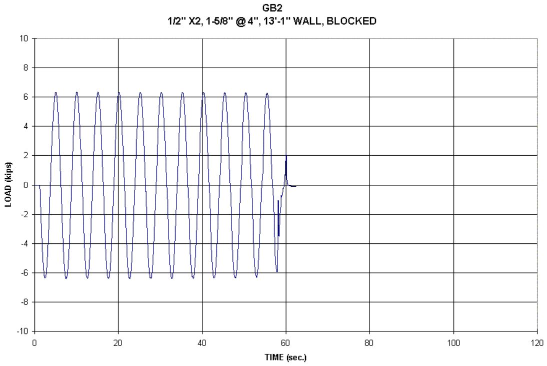

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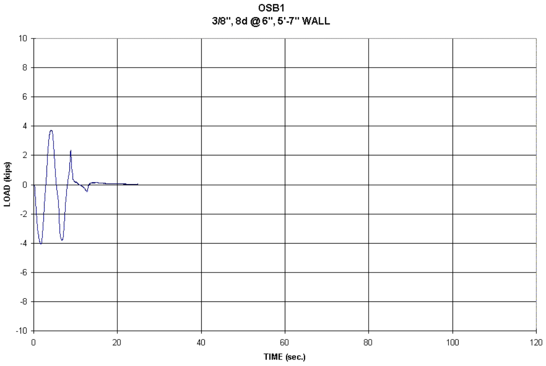

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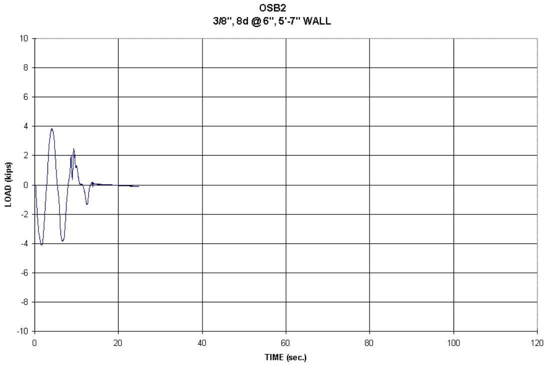

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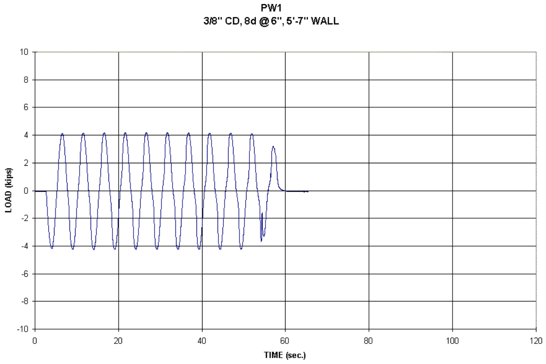

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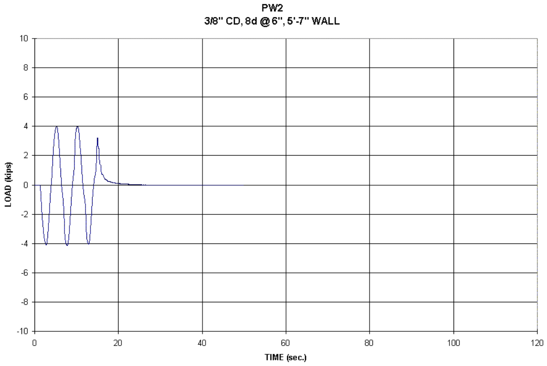

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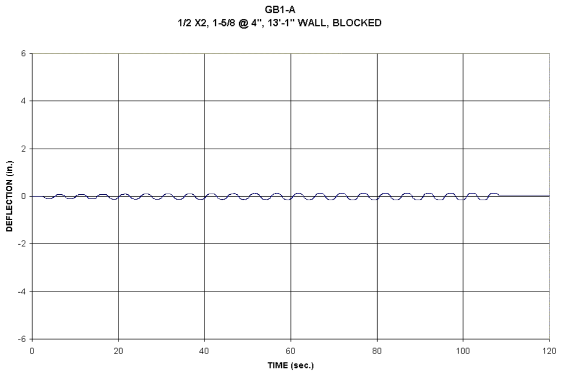

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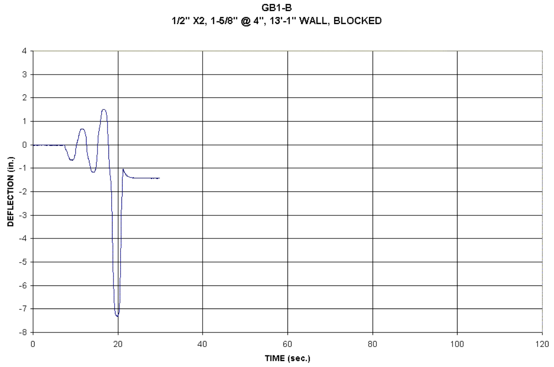

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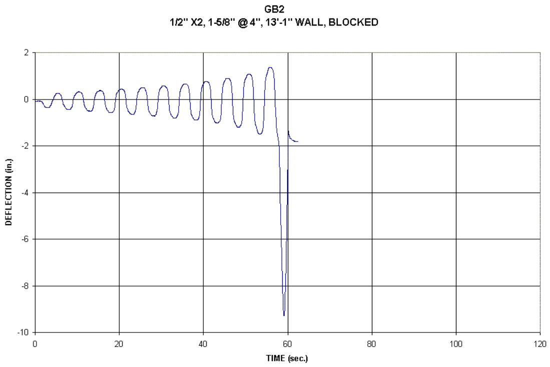

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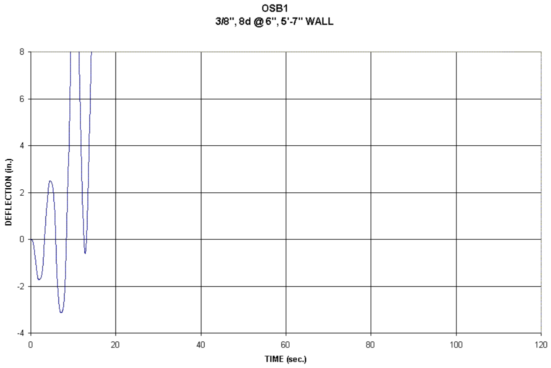

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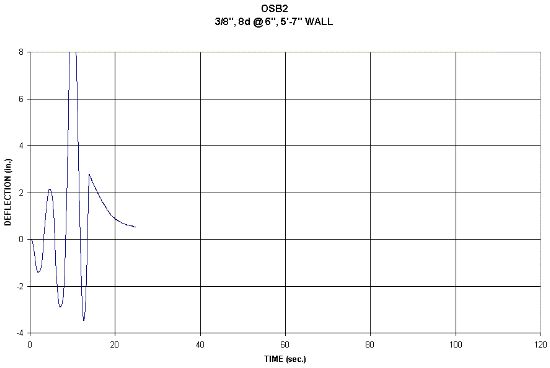

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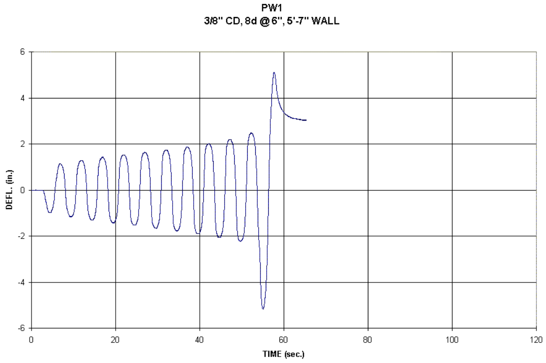

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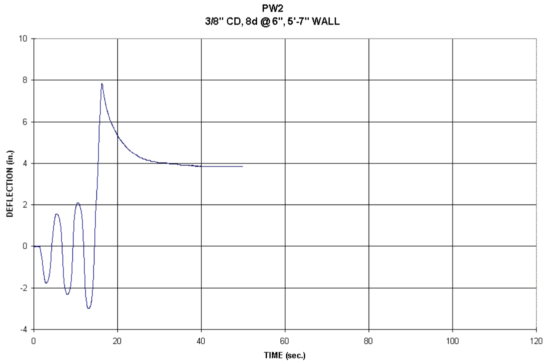

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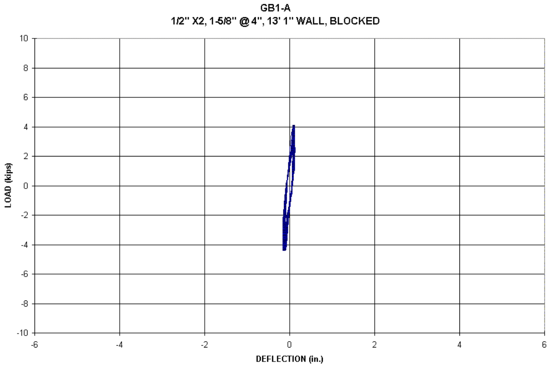

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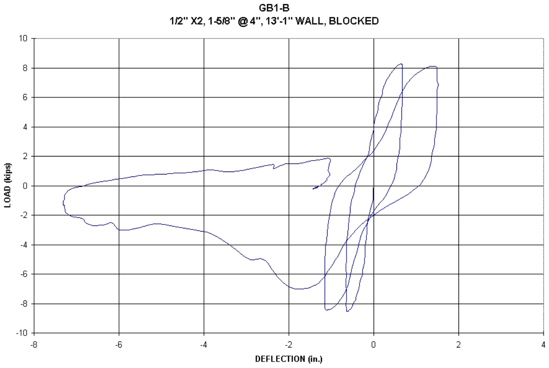

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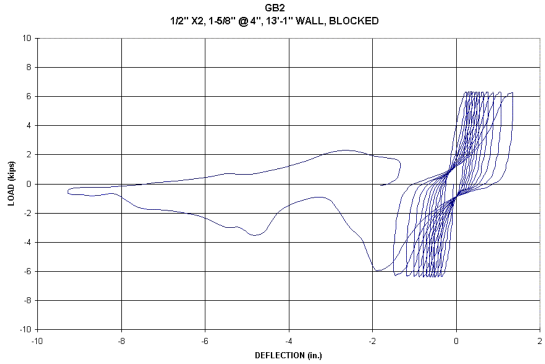

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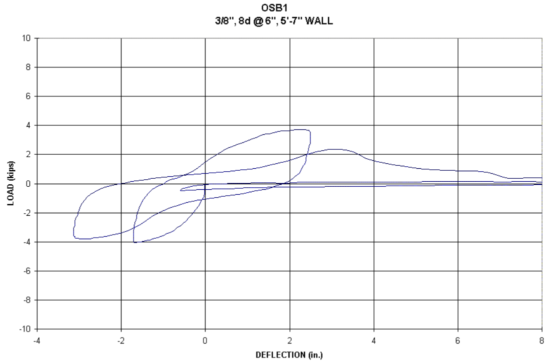

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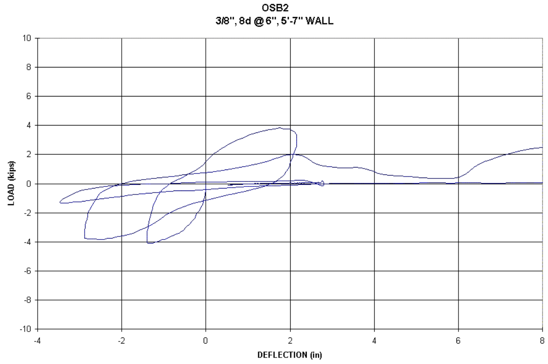

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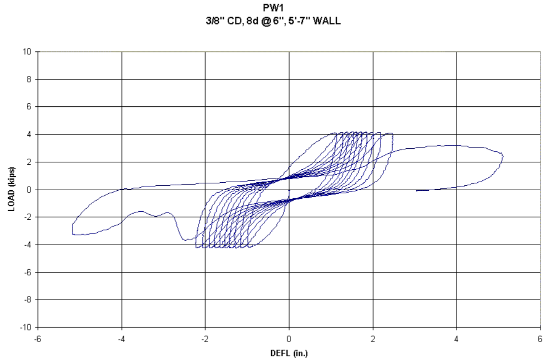

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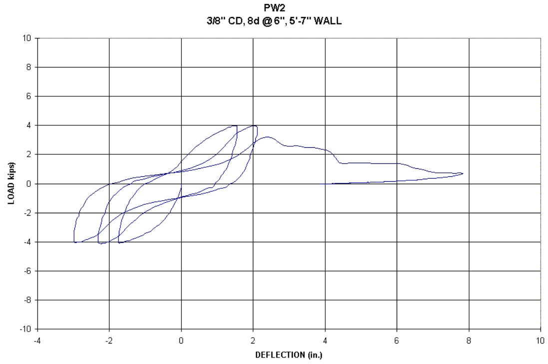

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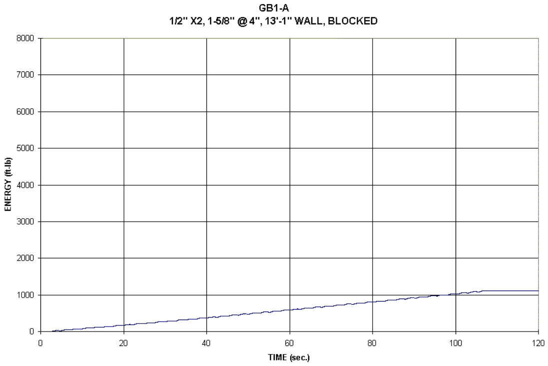

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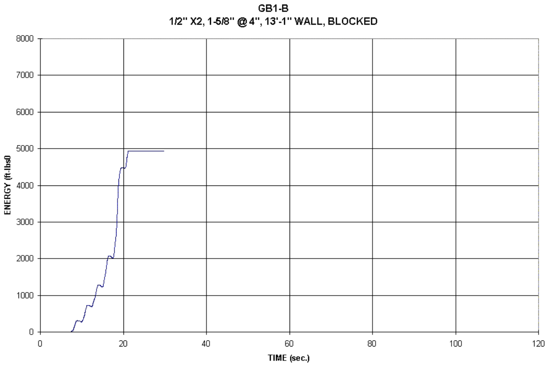

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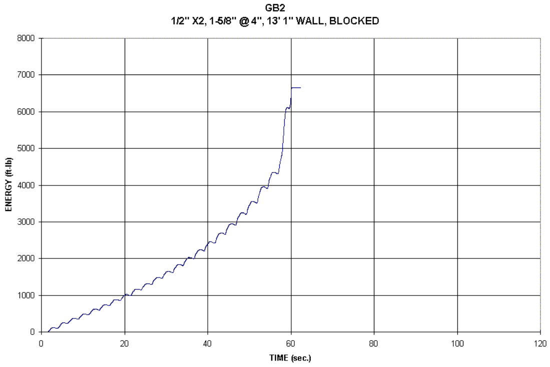

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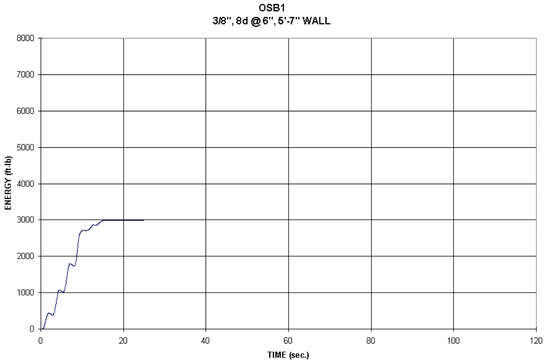

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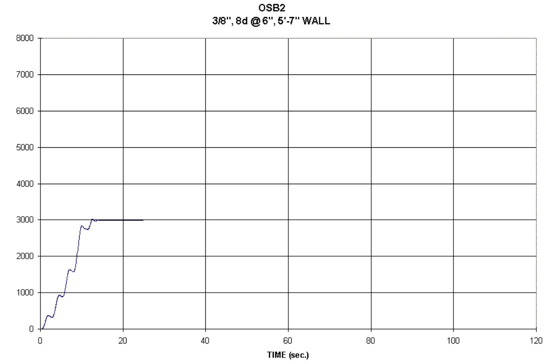

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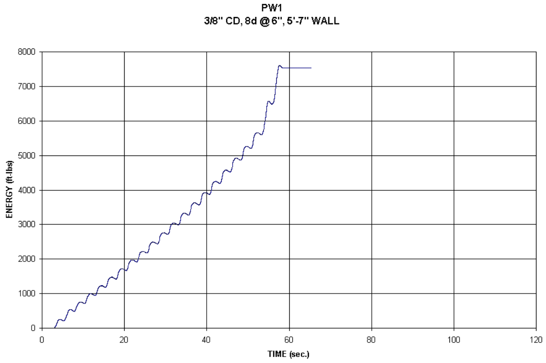

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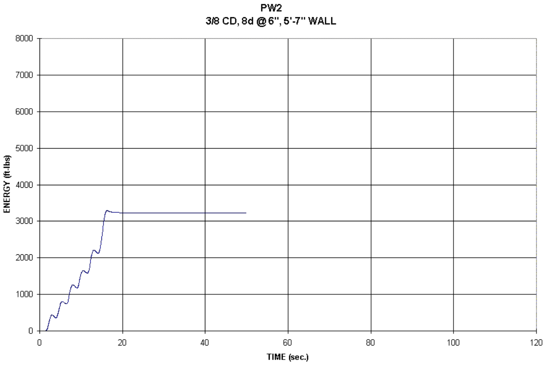

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3.) Introduction:

In light wood framed construction the typical vertical elements in the seismic load path are shear walls. The shear walls are generally framed with vertical wood studs, and horizontal wood top and bottom plates. The wood framing is sheathed, on one or both sides with one of several materials such as plywood, oriented strand board (OSB), gypsum wallboard and/or portland cement plaster (stucco). The sheathing is nailed, stapled or screwed to the wood framing and provides the structural capacity to transfer the horizontal seismic forces from the top of the wall to its base. The sheathing material is usually considered to be loaded in a state of "pure shear", meaning that the sheathing only resists racking. Other elements in the wall are designed to resist any vertical forces that may occur.

Most structures in the western United States are designed according to provisions in the Uniform Building Code (UBC) published by The International Conference of Building Officials (ICBO). The UBC provides the parameters and equations required to calculate a seismic load or demand on any building, or portion of a building such as a shear wall. The UBC also provides allowable strengths or capacities for various structural elements including shear walls. The UBC analysis and design methods commonly used are "static" design methods in that they are not time based although they are intended to represent the dynamic effects of an earthquake. Basically, an equivalent lateral force, representing the dynamic load, is applied to the structural model and the building is designed to resist this static force.

This author has been unable to verify the historic source of the structural capacities listed in the UBC for shear wall sheathing materials but it is believed that the plywood allowable shears were originally calculated from established nail lateral resistance values modified for diaphragms, load duration, framing width, sheathing thickness, etc. and verified by testing. The historic source of the UBC listed capacities for other sheathing materials, such as gypsum wallboard and plaster, is unknown to this author. Testing of shear walls was generally performed to verify the calculated capacities of manufactured sheathing materials, often by industry representatives such as the APA.

Current test specifications such as ASTM E72 and ASTM E564 provide test procedures for shear walls but do not provide for the determination of allowable shears for design purposes. ASTM E72 is intended to provide comparative data for different construction elements or structural details and ASTM E564 provides methods for the determination of shear wall strength and stiffness. The ASTM tests are monotonic in the sense that the load applied to the test wall does not reverse. The test walls were simply subjected to generally increasing load until failure occurs. Tests of this nature performed by the APA indicate that the ratio of ultimate strength to design allowable strength is some value between approximately 3 and 6 for plywood and OSB.

Current thinking is that the monotonic strength of a shear wall system is important, but that the sheathing system's capacity to resist cyclic loading and to dissipate energy (ductility) is also critical in determining the capacity to withstand earthquake loading. Some materials are believed to be more brittle (less ductile) than others are and therefor will not perform as well in an earthquake, even though the monotonic strength is adequate. Many engineers suspect that gypsum wallboard, and possibly OSB, lack adequate ductility. To date no generally accepted method of determining a design capacity from a shear wall ductility testing has been developed completely.

This proposed test method would verify the strength of a shear wall by applying a test load several times the design load. The ductility of a shear wall is measured as total energy dissipated and the durability of a shear wall is measured as number of load cycles survived.

This report proposes a simple method, and preliminary test results, that will provide a comparison of the ductility, strength and deformation capacity of different shear wall sheathing materials. A method is also proposed for determination of baseline values for strength, ductility and deformation capacity, which can be used to determine allowable strengths of sheathing materials and assemblies for design purposes.

At the inception of this project it was determined that the test method must be simple to perform, the data easy to analyze and the method adaptable to a wide range of earthquake resistant structural assemblies. Simply stated, the test method must be practical for the testing laboratory and broadly useful to the engineering community.

4.) Test Program:

4.1.) Determination of Test Load

The load actually applied to the individual test specimen should be related to the design capacity for the material and assembly being tested so that valid comparisons can be easily made. One complication in determining a test load from the UBC allowable strengths is that the seismic demand, or design load, may be different for identical structures at the same site if the shear wall sheathing materials or type of construction are dissimilar. This is due to the expected difference in strength, ductility and stiffness of the various construction materials and methods. For instance, the load specified by the UBC for two identical structures, one constructed with plywood shear walls (expected to be ductile) and the other with gypsum wallboard (expected to be brittle) shear walls, is 30% greater for the gypsum wallboard structure. Another complication is that the design capacities for gypsum wallboard shear walls are reduced by 50% in UBC earthquake zones 3 and 4. So, in determining the test loading as a representation of the UBC design method it is necessary to consider the material being tested, the structure type being represented, and the intended site of the structure.

The simplest way to address the various factors is to design a structure to be tested based on an imagined design seismic mass, or weight to be supported by that structure. For instance, a plywood shear wall and a gypsum wallboard shear wall can be designed to support the same mass, the walls tested in the same way and the results compared. In the preliminary tests described in this report the imaginary design weight utilized was 10,600 pounds. By entering W= 10,600 pounds into the UBC equation for design base shear, a seismic demand or load was calculated. A test shear wall was then designed to resist the calculated demand. In this way a pair of shear walls of dissimilar constriction were tested and the results directly compared.

The design load that is determined by the UBC base shear equation is useful for sizing the test wall but does not represent the full force that is actually expected during the design magnitude seismic event. So, it was decided not to use the UBC base shear value as the test load but to use the effective peak ground acceleration (EPGA) as represented in the UBC by the seismic zone factor Z for the actual test loading.

The 1994 edition of the UBC was referenced in determining the loads for the tests described in this report. For the plywood and OSB specimens the values Z = 0.40 and W = 10,600 pounds were entered into design base shear equation, resulted in a seismic demand of 1460 pounds. The 1997 UBC will provide identical results if the correct near source factors for zone 4 are used.

Plywood and OSB test wall design load

$$V = (ZIC)/Rw * W$$

$$V = (0.4 * 1.0 * 2.75)/8 * 10600$$

$$V = 1460 \text{ pounds}$$

A similar calculation for gypsum wallboard resulted in a seismic demand of 1970 pounds.

Gypsum wallboard test wall design load

$$V = (ZIC)/Rw * W$$

$$V = (0.4 * 1.0 * 2.75)/6 * 10600$$

$$V = 1940 \text{ pounds}$$

Based on a demand of 1460 pounds, a plywood shear wall was designed with Table 23-I-K-1 of the 1994 UBC, which resulted in a wall 5 feet seven inches wide, 8 feet high with 3/8 inch Structural II sheathing on one side with 8d common nails at 6" on center for panel edges and 12" on center in the field. A similar process for the gypsum wallboard, based on Table 25-I, resulted in a wall 13 feet 1 inch wide with blocked 1/2 inch gypsum wallboard on both sides nailed with 5d Parker nails at 4 inches on center to all framing.

Initially, the actual test load for plywood, OSB and gypsum wallboard was determined by (the loading for gypsum wallboard was later modified):

Test load for both plywood and gypsum wallboard

$$P = ZW$$

$$P = 0.40 * 10600$$

$$P = 4240 \text{ pounds}$$

This load was applied to each test specimen as a sinusoidal reversing load at 0.2 Hz

4.2.) Description of Test Apparatus

The test fixtures were designed at working stress levels for the full test load (4240 pounds). The wood sill plate of the test wall was nailed to a 4x6 with 20d common nails. The 4x6 was, in turn, attached to a steel test frame with steel brackets. A steel 6x4x3/8 angle was attached to the top plates with lag bolts and a hydraulic ram was used to apply the test load to the top plate steel angle. Lateral (out of plane) support was provided at the top of the wall by a system of rollers. Hold downs were installed to 3x4 (gypsum wallboard) or 4x4 (plywood and OSB) posts at each end of the test walls and pre-torqued to resisted the calculated uplift without displacement. The connections at both the top and bottom of the walls were arranged so that the test fixtures did not restrain the panel edges and the sheathing was only restrained in plane by the nailing.

The applied load was controlled and monitored by means of a load cell. A signal generator provided the loading function and the hydraulic ram was controlled by a servo-controller.

4.3.) Instrumentation

Horizontal in plane displacements were monitored by means of linear potentiometers at the top and bottom of the wall. Vertical in plane displacements were also monitored by means of linear potentiometers at the hold down posts. All load and displacement data was digitized and stored by a PC type computer.

The sinusoidal lateral load was applied at 0.2 hertz and data for all channels was sampled at 100 hertz.

4.4.) Description of Test Panels

All test walls were constructed with new construction grade Douglas Fir 2x4 studs, top plates and sills. The studs were placed at 16 inches on center. The hold down posts were 3x4 for the gypsum wallboard tests and 4x4 for the plywood and OSB tests. Moisture contents of all framing were measured and below 19%.

GB1& GB2

> Blocked 1/2-inch gypsum wallboard with 1-5/8" drywall nails at 4 inches on center to all framing. The nails used measured 1-5/8 inches long with a 0.29 inch diameter head and a 0.092 inch diameter shank. At the time of the tests, standard 5d dry-tite type nails could not be obtained from local suppliers. The nails used in theses tests were the same length as 5d nails but were about 7% larger in diameter. The boxes of nails tested were not labeled as to penny weight but simply as to length.

PW1

> 3/8 inch plywood with 8d common nails at 6 inches on center along panel edges and 12 inches on center in the field. The panel grade stamp indicated manufacture by Boise Cascade, grade C-D, Exposure 1, and Pittsburgh Testing Laboratory compliance with PS-1-95, span 24/0. The material appeared to be of a good quality and was constructed in four plies.

PW2

> 3/8 inch plywood with 8d common nails at 6 inches on center along panel edges and 12 inches on center in the field. The panel grade stamp indicated manufacture Medply Incorporated, grade C-D, Exposure 1, and Pittsburgh Testing Laboratory compliance with PS-1-95, span 24/0. The material appeared to be of a moderate quality and was constructed in three plies. 1.6 feet of this 5.6 foot specimen was constructed with the material from PW1. It is believed that this oversight did not significantly effect the results of this test.

OSB1 & OSB2

> 3/8 inch OSB with 8d common nails at 6 inches on center along panel edges and 12 inches on center in the field. The panel grade stamp indicated manufacture by Forex St-Michel (Canada), grade Rated Sheathing, Exposure 1, and Pittsburgh Testing Laboratory compliance with PS-1-92, span 24/0. The material appeared to be of normal quality.

Test	*Design capacity lbs.*	*Test loading lbs.*	*Test loading g's*	*Sheathing material*	*Nail size*	*Nailing*
PW1	1460	4240	0.4	3/8" CD	8d com	6" all edges, 12" field
PW2	1460	4240	0.4	3/8" CD	8d com	6" all edges, 12" field
OSB1	1460	4240	0.4	3/8" Rated	8d com	6" all edges, 12" field
OSB2	1460	4240	0.4	3/8" Rated	8d com	6" all edges, 12" field
GB1-a	1970	4240	0.4	1/2" gyp	1-5/8 X 0.092	4" all framing, blocked
GB1-b	1970	8480	0.8	1/2" gyp	1-5/8 X 0.092	4" all framing, blocked
GB2	1970	6360	0.6	1/2" gyp	1-5/8 X 0.092	4" all framing, blocked

4.5.) Procedure

Moisture contents were measured for all materials and zero readings taken for all transducers. The described loading function was applied for 20 full cycles or until failure, whichever occurred first. If the specimen had not failed after 20 cycles, the load was increased and the test restarted.

The preliminary failure criteria are a lateral displacement at the top of the wall in excess of 2 inches.

5.) Test Results

5.1.) General

Although the tests in this series are preliminary and are not adequate to support final conclusions, the results do indicate that some generally believed theories might need to be investigated in more detail. If it is assumed that properly designed and constructed shear walls of good quality plywood perform well in design magnitude earthquakes, the good quality plywood test data from PW1 can be used as a baseline for comparison to the other materials. The good quality plywood used in test PW1 provided significantly more ductile capacity than the lower quality plywood of

PW2 and the OSB of tests OSB1 and OSB2. The gypsum wallboard tests provided higher strength (for zone 4) and energy dissipation comparable to the good quality plywood. Earlier, unpublished data from similar plywood shear wall tests at San Jose State University resulted in energy dissipation very close to that measured in PW1 and further verify this preliminary conclusion.

The number of cycles that the specimen survived is also an important measure of the performance of the shear wall since significant ground motion generally occurs for several cycles during a design magnitude earthquake. The test loading, which was based on the EPGA expected by the UBC, represents a ground motion intensity that will probably last more that one cycle during a major earthquake. It seems reasonable to require a shear wall assembly to survive several cycles of ground motion at the level of the EPGA. It is not clear how many cycles but an informal survey of engineers and geologists seems to indicate that the minimum number of cycle expected is about 3 to 6.

If the results of PW1 are accepted as a baseline for determining an acceptance criteria, then the gypsum wallboard samples provided adequate strength, ductility and durability as represented by the number of load cycles resisted. The low quality plywood and the OSB did not provide adequate ductility and durability.

5.2.) Observations and Data

All the tests in this series were performed between June 10 and June 24, 1997.

5.2.1) Plywood Specimens

PW1 was the baseline test and the specimen performed very well. The specimen survived 7 full cycles of 0.4 g loading and dissipated about 4650 foot-pounds of energy.

PW2 was constructed of lower quality plywood than PW1 and did not perform well in comparison to the baseline test. PW2 failed after about 1 full cycle of 0.4 g load and dissipated 17% of the baseline test energy.

5.2.2.) Gypsum Wallboard Specimens

Specimen GB1 was subjected to two tests. In the first loading (GB1-a) a full 20 cycles of 0.4 g loading was applied and no failure occurred. It was then decided to subject the specimen to 0.8 g loading (GB1-b) to represent non zone 4 UBC design capacity. Since the 1988 edition, the UBC has required the design capacity of gypsum wallboard shear walls be reduced by 50% when used to resist earthquake forces in seismic zones 3 and 4. The wall failed very quickly under this high loading. However, the total energy dissipated during the two tests was 134% of the energy dissipated in the baseline PW1 test.

For specimen GB2 it was decided to apply a 0.6 g loading because the 0.4 g loading of GB1-a was too low and the 0.8 g loading of GB1-b was too severe. The wall performed very well and dissipated 94% of the baseline test energy while surviving 11 full load cycles.

5.2.3) Oriented Strand Board Specimens

The OSB specimens performed poorly. Their performance was comparable to the low quality plywood. Both OSB1 and OSB2 failed after about 0.75 cycles of loading and dissipated less than 50% of the baseline test energy.

5.3 Comparison of test results

Test	*Load*	*Cycles to failure*	*% baseline cycles*	*Energy* *ft-lbs.*	*% baseline* *energy*	*Result of Test*
PW1	0.4 g	7 1/4	100	4560	100	Nails sheared off
PW2	0.4 g	1 1/4	17	1170	26	Nails pulled through
OSB1	0.4 g	3/4	3	2020	44	Nails pulled through
OSB2	0.4 g	3/4	3	890	20	Nails pulled through
GB1-a	0.4 g	21		1100	24	No failure
GB1-b	0.8 g	2 1/4		2970	65	Nails pulled through
GB1-a+b sum				4070	89	
GB2	0.6 g	11 1/4	155	6090	134	Nails pulled through

6.) Conclusions

The small number of tests and the small number of material samples prevent reaching firm conclusions about the relative performance of general categories of sheathing materials. However, preliminary indications are that the quality of wood sheathing materials is very important and that OSB may not perform as well as plywood. Gypsum wallboard seems to perform quite well with the 50% design capacity reduction for zones 3 and 4 introduced in the 1988 UBC. The current design values for gypsum wallboard seems to be appropriate and further reduction, as suggested after the 1994 Northridge earthquake does not seem justified.

7.) Recommendations

Baselines for both ductility and strength of shear walls must be established carefully before current design values can be confidently evaluated. Ground motion time histories and/or a statistically sound number of tests could provide a basis for the amount of energy that a typical structure should be able to dissipate and the number of cycles of loading that the structure should survive during a design magnitude event.

Post earthquake evaluation combined with ground motion time histories could provide further input but is hampered by incomplete construction and design data for individual structures. Analysis of actual structure performance in an earthquake along with complete data on the structure, including quality of design, materials and construction, could be utilized to establish a baseline for minimum performance testing of assemblies. Post-earthquake investigations typically do not, or cannot, completely evaluate the quality of design, construction, materials or compliance with drawings. It is not unusual in California to find shear wall construction with too few or undersize nails, etc.

Although there are several established test methods for shear walls, there is currently no method for determining the design capacity of a shear wall assembly from test data. A test method that will result in design capacities for innovative shear wall construction and materials must be developed. This test method should account for ductility, strength and stiffness of the assembly if acceptance and failure criteria can be established.

8.) References

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