LOW COST SEISMIC DESIGN AND CONSTRUCTION

PREISWERTE SEISMISCHE WANDKONSTRUKTION

Thomas S. Tarpy, Jr.
Research Associate Professor
Vanderbilt University
Nashville, Tennessee, U.S.A.
Structural Engineer
Stanley D. Lindsey and Associates, Limited
Nashville, Tennessee, U.S.A.

Cynthia S. McCreless
Associate Engineer
EXXON Corporation
Los Angeles, California, U.S.A.
Former Graduate Student
Vanderbilt University
Nashville, Tennessee, U.S.A.

Stephen F. Hauenstein
Graduate Student
Vanderbilt University
Nashville, Tennessee, U.S.A.

This paper presents the results of a full scale test program for determining the shear resistance and acceptable deflection level for composite light gauge steel stud and gypsum wall panels under lateral loads. Special emphasis is placed on the wall attachment and anchorage details as they apply to seismic conditions. Application of the results for the design of low cost seismic design and construction is presented. General observations are made on the ability of the wall panel to effectively function as a lateral load or shear resisting element in building design.

In diesem Vortrag werden die Ergebnisse eines Versuchsprogrammes zur Bestimmung der Schubwiderstandes und annehmbarer Verformungen von Vollwandpanelen beschrieben. Die Panele bestehen aus dünnwandigen Stahlstützen mit Gipskartonplatten in Verbundskonstruktion, welche horizontal in der Wandebene belastet werden. Besonderer Nachdruck wurde auf die Befestigungs- und Verankerungsdetaillierung mit Hinblick auf die seismische Belastung gelegt. Anwendungen des Ergebnisse für den seismischen Entwurf von preiswerten Wandkonstruktionen werden presentiert. Auch allgemeine Schlussfolgerungen, die sich auf die Schubfähigkeit der Wandpanele in Bauwerken beziehen, sind dargelegt.

1. INTRODUCTION

The three basic framing systems commonly used in building design for resisting lateral loads caused by seismic action, wind loads, etc. are the unbraced frame, the braced frame, and the vertical diaphragm. The relative advantages of one of these framing systems over another depends to a large degree on the allowable lateral drift, the ductility requirements, and potential problems with uplift or overturning. That is, any of these framing systems can be used economically for certain classes of problems provided adequate design recommendations and precautions are followed.

The design of low rise structures of four stories or less presents a special challenge to the structural engineer as to the proper selection of an economical framing system. For this particular application, the writers wish to present the use of the vertical diaphragm system or wall system composed of gypsum wallboard for the diaphragm and light gage steel studs for the framing members. This framing system corresponds to wood diaphragms currently used in many areas of construction. When lateral loads are applied to the diaphragm, they are resisted primarily by shear stresses generated in the plane of the diaphragm. Due to the brittleness of the gypsum and the ductility of the steel stud, the resulting composite wall system possesses a limited amount of ductility, the exact amount being dependent upon the degree of attachment of the gypsum to the studs and the resulting anchorage of the wall system to the rest of the structure. Its resistance to overturning depends largely on its height to width ratio which for most wall configurations is usually not a problem.

From a dynamic load viewpoint, the composite wall system offers considerable savings in weight over conventional systems in that the lateral forces exerted are directly proportional to the mass of the structure. The mass of the composite gypsum-steel stud wall system is approximately 24 kg/m^2. Hence, due to the lighter wall weight over that of other materials, the resulting structure has a better chance of surviving an earthquake than a heavier structure. The primary caution is to keep the failure out of the diaphragm and the connections and to adequately tie the structure together.

Several building codes permit the use of wall panels composed of wood studs and gypsum as vertical shear diaphragms provided the height to width ratio does not exceed unity and the deflection between supports does not exceed L/240. The gypsum panel attachment to the wood studs is restricted to a maximum spacing of 178 mm for an allowable shear value of 1095 N/m. The option of using steel studs in lieu of wood studs is not covered in the codes due primarily to the lack of supportive performance data.

While the economic advantages of using composite steel stud-gypsum wallboard partitions appear numerous, very little design information is available on the shear strength and stiffness of the panels or damage threshold load level of the gypsum. These values are best determined experimentally due to the complexity of trying to model the composite system constructed of both steel and gypsum. The availability of this information permits the use of this system in building design.

The earliest known research project involving composite shear wall partitions was conducted by URS/John A. Blume and Associates beginning in the mid-sixties. They developed and conducted a testing program for composite wall panels subjected to racking loads (1,2,3,4). Several 2.44 m x 2.44 m wall panels with both wood and drywall studs were tested. The majority of the panels were constructed of gypsum wallboard, but plaster, plywood, concrete block and combination plywood and gypsum wallboards were also tested. Pop-rivets and friction connections were used to attach the steel studs to the track. Both static loading and cyclic load reversals were used in testing.

Additional small scale tests involving composite steel stud-gypsum wallboard partitions were performed at Cornell University to study the behavior of steel stud wall diaphragms (6). Results of these tests indicate that commonly used gypsum wallboard significantly increases the load carrying capacity of steel studs.

While the research to date has provided many valuable results on the behavior of composite wall systems very little structural design information is available to assist in the design of the wall panels for possible usage to resist lateral loads. The purpose of this paper is to present the results of a test program aimed at establishing design information for typical interior steel stud gypsum wallboard partitions commonly encountered in building construction.

The objective of the test program is two-fold. The first is to determine the effect of various construction techniques on the shear strength and shear resistance of composite steel stud-gypsum wallboard partitions. The second is to determine the degree of panel distortion possible before major wall panel damage of the gypsum occurs for asthetic as well as structural purposes.

The experimental test program consists of testing several full size wall panels of varying wallboard attachment and wall panel anchorage details. Displacements are measured at critical locations on the wall for varying load levels and load displacement curves are plotted. Shear strength and shear stiffness are calculated from the test results.

2. EXPERIMENTAL TEST PROGRAM AND PROCEDURE

The shear strength and stiffness of the panels are determined by racking a panel from a rectangle to a parallelogram. This is accomplished by fixing the base of the wall and applying a force along the top of the wall parallel to the plane of the wall. The forces required to rack the wall and the corresponding displacements at increasing load intervals are measured. The shear strength and stiffness of the panels are then calculated from the load deflection curves.

Testing is performed in accordance with ASTM # 564 - 76. This method is a static load procedure designed to evaluate the shear resistance of framed walls for buildings. The recommended test assembly is shown in Figure 1. Specifications are not made regarding the type of connection system used except to duplicate as nearly as possible the system intended for use in actual building construction. The wall may be tested vertically or horizontally and the panel size should not be less than 2.44 m high by 2.44 m wide.

The shear strength and shear stiffness are obtained from the test results. The ultimate shear strength (N/m) is determined by dividing the ultimate load (i.e. the last load that gage deflections were recorded) by the length of the wall panel parallel to the application of the load. The shear stiffness (KN/m) is determined as one-third the ultimate load divided by the total deflection including shear deflection and that contributed by bending of the panel at that load level times the aspect ratio of the wall panel.

For this investigation a series of interior wall panels with various construction details as shown in Table 1 were tested. The variables considered were the wallboard attachment centers and the type of wall panel anchorage to the base. Based on previous research (5,7), these conditions were felt to

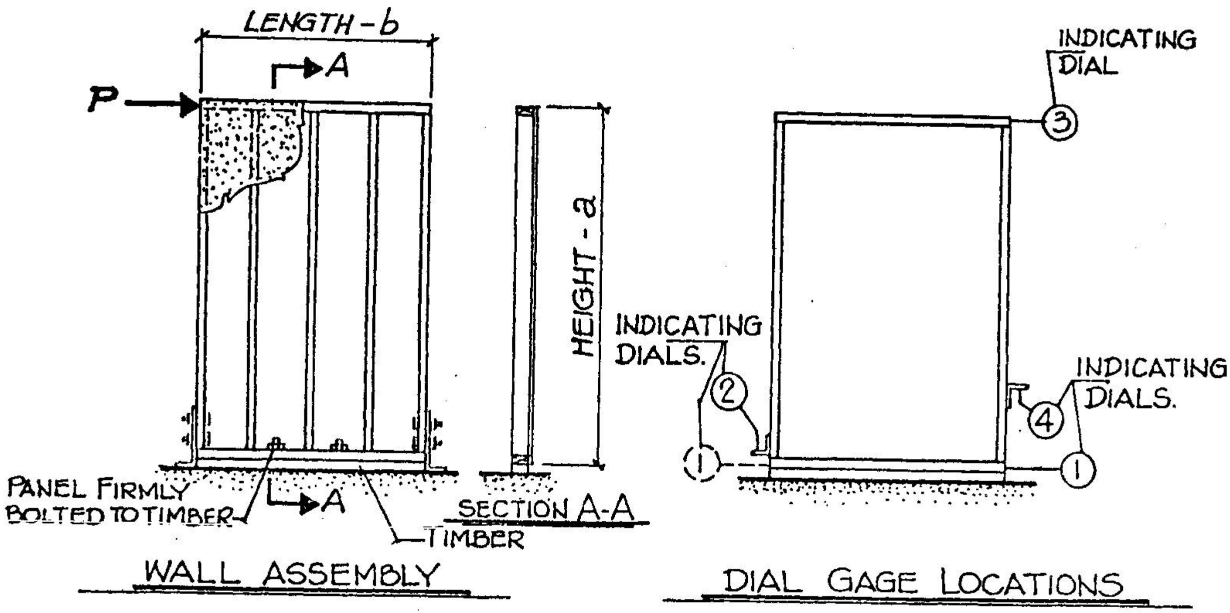


Figure 1. Racking Load Assembly ASTM E 564 - 76.

TABLE 1

WALL ASSEMBLY

WALL TYPE	WALL HEIGHT (m)	WALL WIDTH (m)	TYPE WALLBOARD	STUD SPACING	WALL FASTENER SPACING	WALL ATTACHMENT	STUD ATTACHMENT	WALLBOARD ATTACHMENT
A	2.44	2.44	12.7 mm Gypsum Each Face	610 mm-o.c. Steel	305 m-o.c.	Clips at 1.22 m-o.c.	#10x12.7 mm Low Profile Head Screws	#6x25.4 mm Bugle Head Screws
B	2.44	2.44	"	"	153 mm-o.c. perimeter Balance @ 305 m-o.c.	"	"	"
C	2.44	2.44	"	"	5 at 153 mm-o.c. at corners Balance @ 305 m-o.c.	"	"	"
D	2.44	2.44	"	"	305 mm-o.c.	Bolt & Washer @ 1.22 m-o.c.	"	"
E	2.44	3.66	"	"	"	Clips at 1.22 m-o.c.	"	"
F	2.44	3.66	"	"	"	Clips at Ends Bolt & Washer @ 1.22 m-o.c.	"	"

have the greatest influnece on the wall performance. The panels were tested horizontally in a steel load frame assembly designed especially for the series of tests. The connections used to attach the wall panel to the frame and prevent overturning of the wall were located at 1.22 m o.c. For the clip angle detail, one face of the angle was bolted to the stud and the other face of the angle was bolted through the track to the load frame. A digital strain indicator in combination with a linear load cell was used to apply the load.

Each wall panel was constructed of 89 mm by 1 mm thick structural "C" studs spread 610 mm o.c. The steel studs were attached to 92 mm web by 38 mm flange by 1 mm thick structural track with #10 x 12.7 mm long low profile head screws. Care was taken to avoid gaps between the studs and track. The studs were attached by screws to both flanges of the track.

The use of screws provides a permanent means of attachment of the steel frame. This eliminates the collapse failure that occurs with friction connections or the breaking of pop rivets.

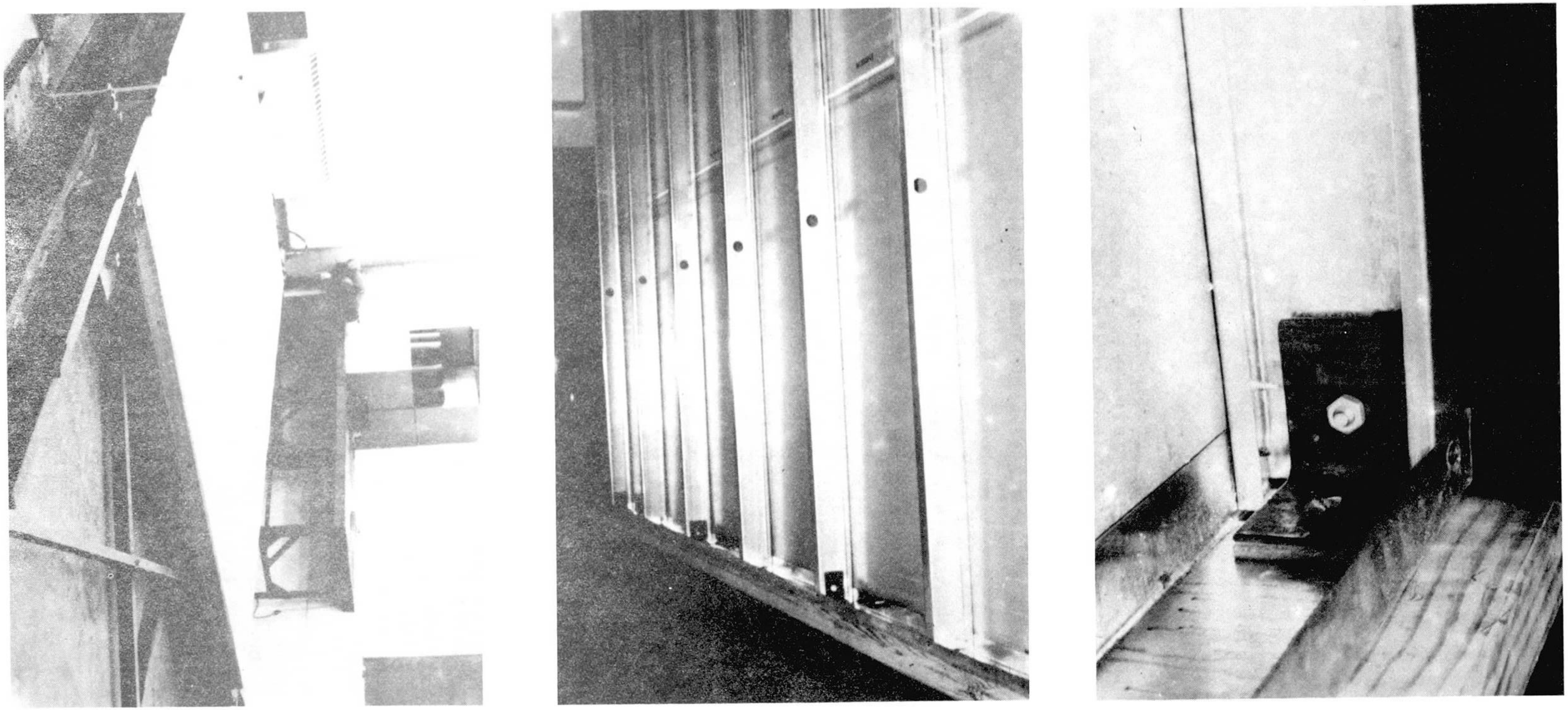
Gypsum wallboard 12.7 mm thick, was positioned horizontally and attached to one side of the stud panels with #6 x 25.4 mm long Bugle head self-drilling screws. The standard spacing for the fasteners was 305 mm o.c. over the entire face of the panel along both studs and runner tracks for all wall types except B and C. Wall type C had fasteners spaced 153 mm around the perimeter, while wall type C has fasteners spaced 153 mm o.c. within 610 mm of the corners along the perimeter with the balance of the fasteners spaced 305 mm o.c. The gypsum wallboard seams were then caulked and taped to complete the construction of one face of the wall panel. A minimum curing time of 24 hours was maintained before the wall panel was moved to allow the joint compound to harden properly.

Once the wall panel had cured it was mounted horizontally in the load frame by either clip angles or bolts and washers. Wall types A, B, C and E were anchored to the test frame assembly by clip angles located 1.22 m o.c. Wall type D was anchored by bolts and washers located at 1.22 m o.c., and wall type F had clip angles locat-d at the corners of the wall panel and bolts and washers at the two interior attachment points. A bearing block and structural steel joist was then attached at the top of the steel stud panel to uniformly distribute the load along thelength of the wall.

After the connections were completed the remaining face was covered with gypsum and taped as described before. It was felt that by constructing the wall panel in this manner the laboratory construction would represent as closely as possible actual field installation. The only exception being the jack bearing block and steel joist assembly. In actual construction, this assembly simulates the support furnished by the gravity supporting frame systems. The completed wall assembly located in the load frame and interior wall panel details are shown in Figures 2.

Displacement indicating dials were located on the test frame assembly at points shown in Figure 1. The horizontal dial gage at the lower right measures the slippage of the panel in the test frame. The two vertical dial gages measure panel rotation and the dial at the upper right measures the same readings as the other dial gages plus the lateral deformation of the panel.

Prior to starting a test the ultimate load was estimated and loading increments determined to guarantee a minimum of ten readings. A preload of ten percent of the estimated ultimate load was initially applied to the wall panel for five minutes to set all connections. The load was then removed and all the dial gages set to zero. The load was then applied incrementally to the wall and



a) Completed Wall Assembly　　b) Interior of Wall Assembly　　c) Clip Angle

Figure 2. Completed Wall Assembly and Typical Details.

displacement measurements recorded after a two minute hold to allow the wall to stabilize. At load levels of one-third and two-thirds of the estimated ultimate load, the load was fully removed and the wall recovery recorded after a five minute duration. The load was then re-applied to the next increment above the back-off load. Loading continued in this manner until the panel was no longer capable of holding additional load. The last load held for two minutes with displacement measurements recorded is defined as the ultimate load.

As discussed earlier the information obtained from the test results are load-deflection curves, ultimate shear strength, ultimate shear stiffness, and damage threshold levels. The load-deflection curve is a plot of the applied load versus the corresponding wall deflection. The ultimate shear strentth is determined from the ultimate load and the ultimate shear stiffness is determined from the load-deflection curves. The damage threshold is a visual observation and is defined as the level of loading which causes critical and major damage to the gypsum wall panel; that is, the gypsum is no longer structurally effective.

ASTM recommends that the total deflection or a combination of shear and bending deflection be used in all computations. The total deflection of the wall panels or drift is determined by subtracting the base slippage from the total lateral deflection.

The ultimate shear strength of the wall is defined as the highest load level held long enough to record gage measurements divided by the length of the wall panel.

The shear stiffness is obtained from the corresponding load-deflection curve. A reference load in the elastic range of the load-deflection curve at one-third ultimate is recommended by ASTM and that load and corresponding deflection used in the calculations. The shear stiffness computed from the total deflection is defined as the load at the one-third reference point divided by the corresponding total deflection times the aspect ratio of the wall.

3. DISCUSSION OF RESULTS

Table 2 shows the gypsum damage thresholds observed during testing. The first noticeable damage is the point where the first hairline cracks in the wallboard materila were observed and furnishes an indication of the effect of shearing of the brittle gypsum and paper material. Major damage is defined as the point where the damage to the wall was extensive and unrepairable. That is, the gypsum tore through the sheet. Human judgement is a primary factor in the determination of these values and varies from one observer to another. As such, the values reported are based on the general observations of several individuals involved in the testing.

The visible signs of yielding for all wall types followed the same general pattern. The first sign was one of the wall base track deforming around the exterior corner tension uplift anchorage point. As the load was increased cracking of the gypsum wallboard occurred at the same corner screw location. This process continued with increased deformation in the track and increased cracking of the wallboard until yielding due to excessive rotation of the panel occurred. For structural purposes the load level and corresponding deflection at first cracking of the gypsum wallboard is the controlling design factor. For this case, it is noted from Table 2 for wall type C that for a slight increase in the number of fasteners in the corners the load level doubles and by adding the fasteners at 143 mm around the perimeter in wall type B increases

TABLE 2

GYPSUM DAMAGE THRESHOLDS

WALL TYPE	WALL HEIGHT (m)	WALL WIDTH (m)	INITIAL CRACKING LOAD LEVEL (KN)	INITIAL CRACKING TOTAL DEFLECTION (mm)	REAL DAMAGE LOAD LEVEL (KN)	REAL DAMAGE TOTAL DEFLECTION (mm)
A	2.44	2.44	7.6	7.6	11.1	10.2
B	2.44	2.44	18.2	17.6	20.5	22.9
C	2.44	2.44	14.7	12.7	16.9	17.8
D	2.44	2.44	8.9	17.8	9.8	22.9
E	2.44	3.66	14.7	10.2	18.7	17.8
F	2.44	3.66	16.9	10.2	18.7	12.7

TABLE 3

TEST RESULTS

WALL TYPE	WALL HEIGHT (m)	WALL WIDTH (m)	ULT. SHEAR STRENGTH (N/m)	MAX. TOTAL DEFLECTION (mm)	SHEAR STIFFNESS (KN/m)
A	2.44	2.44	5983	24.9	1699
B	2.44	2.44	9778	36.6	1681
C	2.44	2.44	8756	34.5	1856
D	2.44	2.44	4524	30.5	718
E	2.44	3.66	5838	16.8	1891
F	2.44	3.66	5473	16.3	2452

the load level one hundred and forty percent. This increase in wall panel load capacity and corresponding deflection is significant from a seismic viewpoint as all connections must be designed for 1.25 times the allowable design loads for a braced system.

The effect of eliminating the clip angles on the damage threshold appear to be minimal. However, it is the writers opinion that the two end angles should be maintained to reduce the potential of track deformation that occurs around the bolt and washer.

The calculated shear strength, total deflection and shear stiffness are summarized in Table 3 for the different wall panel sizes considered. The calculated shear strength of the wall panels indicates that the shear strength is essentially independent of aspect ratio. The total deflection, on the other hand, is a function of the anchorage details. This is reasonable in that the wall behaves as a cantilever system with larger deflection for the walls without the corner clips or with closer wallboard fastener spacings.

It can be noted from Table 3 that shear strength is highly dependent upon the construction details of the wall systems. Basically, an increase in the number of wall fasteners or a decrease in fastener spacing causes an increase in shear strength, while the replacement of clip angles with bolts and washers lead to a decrease in strength. The total shear stiffness was also found to be dependent upon wall assembly anchorage, but was almont entirely independent of wall fastener spacing. The complete replacement of clips with bolts and washers lead to a pronounced decrease in total shear stiffness, while a decrease in the wall fastener spacing had no noticeable effect on this stiffness value. This effect was not as pronounced when the end clip angles were maintained.

4. CONCLUSIONS

The results of the test program indicate that composite steel stud-gypsum wallboard partitions can offer an economical framing system for resisting lateral loads in building construciton for seismic and hurricane forces provided appropriate factors of safety and anchorage details are maintained. This conclusion is based on the ultimate shear strength of the panels as well as the level of loading at first cracking of the gypsum wallboard. Based on these test results theoptimum installation details would be wall type B with fasteners at 153 mm around the perimeter and with clip angles at the ends. This offers the ideal maximum load and deflection for the gypsum and the wall panel.

Previous tests (5,7) run by the writers on wall type A with different aspect ratios indicated that the performance of steel stud wall panels is dependent on the panel aspect ratio. From the results of these tests design curves for total shear stiffness, shear strength, and load level at initial damage of the gypsum wallboard for walls of varying aspect ratios were developed. While it is expected that walls using different types of construction details with varying aspect ratios would produce design curves similar to those produced from the previous tests, it is the opinion of the writers that the extension may not necessarily be straight-forward. Therefore, additional tests should be run on wall type B with the anchorage details modified as discussed herein.

5. ACKNOWLEDGMENT

The research reported herein was sponsored at Vanderbilt University, Nashville, Tennessee by the American Iron and Steel Institute and the United States Steel Corporation. For their sponsorship and the assistance of the advisory task group chaired by Karl Klippstein for AISI and George Ratliff for U.S.S. Corp. the writers are extremely grateful. The steel studs, joists and track used in the tests were furnished by the U.S.Steel Corporation.

REFERENCES

1. BLUME, J.A., "First Progress Report on Racking Tests of Wall Panels," NVO-99-15, John A. Blume and Associates Research Division, San Francisco, August 1966.

2. BLUME, J.A., "Second Progress Report on Racking Tests of Wall Panels," JAB-99-34, John A. Blume and Associates Research Division, San Francisco, July 1968.

3. FREEMAN, S.A., "Third Progress Report on Racking Tests of Wall Panels," JAB-99-54, John A. Blume and Associates Research Division, San Francisco, December 1971.

4. FREEMAN, S.A., "Fourth Progress Report on Racking Tests of Wall Panels," JAB-99-55, John A. Blume and Associates Research Division, San Francisco, September 1974.

5. MCCRELESS, C.S., "Shear Resistance Tests on Steel Stud Wall Panels," Masters Thesis, Vanderbilt University, May 1977.

6. SIMAAN, A., and PEKÖZ, T., "Diaphragm Braced Members and Design of Wall Studs," Proceedings ASCE, Vol. 102, ST1, January 1976.

7. TARPY, T.S. and MCCRELESS, C.S., "Shear Resistance Tests on Steel Stud Wall Panels," CE-USS-1, Report submitted to the United States Steel Corporation, December 1976.

8. TARPY, T.S., and HAUENSTEIN, S.F., "Effect of Construction Details on Shear Resistance of Steel Stud Wall Panels," CE-AISI-1, Report submitted to the American Iron and Steel Institute, November 1977.