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DEVELOPMENT AND VERIFICATION OF A STRUCTURAL SYSTEM  
USING COLD-FORMED STEEL WALL STUDS

E. R. diGirolamo<sup>1</sup>, T. Pekoz<sup>2</sup> and T. Bond<sup>3</sup>

The Stud-Plank Building System takes two highly accepted building methods; light steel framing and prestressed concrete slabs, and integrates them into a very cost effective method of building. The Stud-Plank Building System combines the most cost effective component of the steel framing system (the "C" stud) with the most cost effective component of the prestressed concrete system (the hollow core plank). The Stud-Plank Building System uses panelized light weight steel framing for bearing walls and exterior walls, and prestressed hollow core concrete planks for floors and roof slabs as shown in Fig. 1. The structural characteristics of the building system are undergoing extensive testing at the Winter Laboratory of Structural Engineering, Cornell University.

The Stud-Plank Building System is patent pending in the United States and many foreign countries. Patent pending status of the Stud-Plank Building System includes the design, method of fabrication and method of erection. Prefabricated Integrated Construction, Inc. strictly prohibits the use of the Stud-Plank Building System by other than authorized entities qualified by P.I.C.

STRUCTURAL SYSTEM

Walls

The structural building system uses cold-form steel C section studs in the load bearing and non-load bearing walls. As typical in bearing wall construction, the stud transfers all dead and live loads, axially through all levels down to the foundation of the building. Axial loads are transferred through the concrete slab of the floor system at each level.

The load bearing steel frame wall is designed considering steel products only and does not consider any additional increase in load carrying capacity due to the attachment of gypsum sheathing. All walls accept gypsum sheathing without additional furring or framing.

All light steel framing products conform to ASTM A446 Grade E steel and are designed in accordance with the AISI cold formed steel specification (1986).

Exterior non-load bearing steel frame curtain walls are used to support a wide variety of finishes. Although the exterior curtain wall is considered non-load bearing, axial loads induced by the accumulated dead loads from the curtain wall above as well as the flexural loads, induced by wind loading are considered in design in accordance with the A.I.S.I. specifications.

A wall system using light weight steel framing and gypsum wall board is usually less than 15 lbs per square ft. For 24 ft slab spans, the system developed results in a 40% reduction in the dead load of the building compared to a block and plank system. The 40% dead load reduction will equate to an overall total load reduction of approximately 15%, reducing the required foundation structure. Foundations are similar to the types used bearing wall construction today.

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## Floors

A prestressed hollow core slab, 8" in depth can achieve clear spans of up to 30 feet between bearing walls which typically replace interior partitions, eliminating an extensive amount of dry-wall framing. Additional savings at the foundation are gained by the relatively light weight of the Stud-Plank structure, for an overall dead load reduction of up to 40% when compared to other conventional building methods. The time of construction is reduced significantly over conventional methods by the prefabrication of interior bearing walls, concrete plank floors and finished exterior walls.

The span length between bearing walls is the primary consideration in designing a framing scheme for the floor system using hollow core slabs. Hollow core slabs are designed in accordance with ACI (318-83) and the PCI Manual for the Design of Hollow Core Slabs which recommends limits for span/depth ratios for the hollow core slabs. For roof slabs, a span depth ratio limit of 50 is recommended and for floor slabs, a limit of 40 is recommended. When considering the typical depth of the slabs to be 8", the maximum recommended span of 26 ft. is allowed at the typical floor slab. The load capacity for hollow core slabs is a function of the slab thickness, the amount of prestressed steel strands provided and the effective depth of the prestressed steel strands.

The floor system acts as a beam created by the combination of light weight steel frame channels above and below the slab, combined with the grouted hollow core slab butt joint and various mechanical connections. The composite beam above each wall distributes loading through the floor system, allowing the studs below to receive a near concentric axial load. Additional distribution of loading from the stud wall into the slab is obtained by the placement of a bearing plate between each stud and track. Welded connections provided at the ends of each stud to the continuous top and bottom channel complete the typical bearing wall panel.

## Bracing

Narrow sheet steel strapping is attached horizontally at the mid point or third points of each stud to provide lateral stability of the C-section against flexural buckling about the weak axis and torsional-flexural buckling. Loads transmitted into the strapping are taken out at the end of each wall by a fabricated tube section, a double stud "C" to "C" member which is welded together.

The wind loads are transferred from the exterior curtain wall into the floor slab. The floor slab acts as a diaphragm transferring lateral loads to shear walls (X-bracing attached to bearing walls) within the structure. Hollow core slabs can be used effectively to produce a diaphragm, although certain local building codes may require the addition of composite structural topping. Consideration is given to the frequency and location of shear walls. The diaphragm must have structural integrity in shear and flexure to span as a horizontal beam between lines of support. Diaphragm design requires calculating the forces to be resisted by the diaphragm and providing a connection to transfer forces out of the diaphragm. For the distribution of forces to vertical bracing elements, the diaphragm is normally assumed to be infinitely rigid, thus equilibrium can then be determined for the system. Forces are transferred from the floor system into the "X" bracing by a series of connections through the slab, which are attached to the steel frame walls above and below the floor system. X-bracing in the steel frame wall transfers all lateral loading, for wind and seismic conditions, down to the foundation.

## Fabrication and Construction

Each prefabricated component is designed, fabricated, delivered and erected in sequence. Each floor of the Stud-Plank Building provides a working platform

for the following floor, eliminating the use of scaffolding. Exterior walls arrive on the job complete with sheathing, a variety of finishes, and windows installed, allowing erection of a fully enclosed building. The time and cost associated with debris removal is minimized with prefabrication.

The installation of electrical and mechanical items is simplified by the design of perforations in the studs and prefabricated penetrations in the concrete plank. With the Stud-Plank Building System, less on-site, construction work is required, thereby saving on labor costs, carrying costs and weather related down time.

All prefabricated wall panels are welded under the supervision of a quality control inspector. All welds are cold galvanized to further assure protection against corrosion. Light weight steel frames are fabricated on close tolerance jig tables to assure consistent quality. All prefabricated exterior walls are sheathed and finished in a controlled environment, which creates a consistently superior product. Windows may be installed in the panel shop, providing additional cost savings and superior water proofing. Prefabricated exterior panels are completed without scaffolding, or the detrimental effects of glaring sun, blowing wind, snow, wet and cold. After final inspection, all prefabricated wall panels are loaded in sequence onto trailers for shipment.

Using prefabricated construction, a minimum amount of welded and mechanical connections are required in the field, allowing greater control of quality. All light weight steel frame walls are connected at the bottom track into the floor slab with either powder actuated fasteners or expansion anchors. Field welded connections are provided at intersecting wall panels, butt joints between wall panels and for heads that are installed in the field to provide continuity of a load bearing wall.

#### **Fire Resistance**

Fire ratings of light weight steel frame wall assemblies and hollow core slab floor assemblies are available in the Underwriters Laboratories Fire Resistance Directory. Interior walls are insulated, and with two layers of fire rated gypsum sheathing to each side have a two hour fire rating and a minimum sound transmission classification of 50. Non-combustible walls can also be designed to meet other specific project requirements. Hollow core slabs are non-combustible and provide excellent fire resistance.

#### **Sound Transmission**

Sound ratings are designed to meet specific project requirements. (STC) Sound Transmission Class and (IIC) Impact Insulation Class for various wall and floor assemblies were tested in accordance with ASTM specification E-90 and E-492 are available through various available testing facilities.

#### **Energy Efficiency**

Stud-Plank Buildings are well insulated and designed to retard air and moisture penetration. Insulation of the light steel framed exterior is accomplished by placing batts of insulation between studs. R values can be designed to optimize heat consumption by adjusting the depth of wall studs or using an exterior finish system which incorporates EPS board.

#### **Durability and Maintenance**

Steel framing exhibits no shrinking, rotting, creep, or insect related problems and the hot-dipped galvanized coating assures corrosion resistance for the life of the building. Hollow core concrete slabs are permanently resistant to corrosion, rot, rust, water, weather and insect related problems.

## Quality Assurance Program

Prefabricated Integrated Construction, Inc. offers a wide range of quality assurance services for the design, fabrication, and erection of each project. Licensed contractors are audited on a regular basis to assure implementation of the quality assurance program.

### PROJECTS COMPLETED AS OF JULY 1990

The Stud-Plank Building System has produced a seven-story residential apartment building in The Bronx, N.Y. Phase I (the seven-story building) consists of 121 apartments, totaling over 105,000 square feet and features a combination of exterior finishes, thin brick on the ground floor for durability, and acrylic stucco on the upper floors for economy. Phase II of the Gerard Avenue Apartments will be two ten-story buildings consisting of 600 apartments totaling over 520,000 square ft.

At Spring Creek Gardens, Brooklyn, N.Y., four, five and six story buildings were constructed in phases creating 760 units for a planned community of affordable housing. A view from this development is shown in Fig. 2. The first phase of the project was a classic example of fast tracking, 285 units were fabricated and erected in 15 weeks allowing completion of the buildings for occupancy in less than six (6) months from the pouring of the foundations.

### TEST OBJECTIVES

The primary objective of the test program is to verify the load carrying capacities calculated for various wall configurations. Various parameters influence the load carrying capacity and are being investigated in the test program. These include the performance of lateral bracing using flat straps and the effect of perforations in the studs. Valuable information is also obtained on the eccentricities of the axial loading in the studs due to the rotation of the floor slabs.

The behavior of various connections such as between the tracks and the floor slabs and between the slabs over walls influence the overall performance. There is no test evidence on the influence of track characteristics on the overall behavior. These can be studied best in full scale tests as the ones conducted in this project. The testing is also intended to give guidance for specifying tolerances for optimum performance. The determination of the behavior and ultimate load of X-bracing is also an objective of the test program.

### TEST SETUP

#### Loading Frame

Plans for testing began in August of 1989. Shortly after determining a specific series of tests, that would meet the test objectives, a schedule and a budget were formulated. The initial task was to design and build a versatile test frame that could be used to test one or two story high structures having single or double bays. For each case, the frame enables the application of loads coming from the stories above the ones being tested.

The test frame built towers 24 feet in height, 13 feet in width and 38 feet in length. The frame is designed for a maximum internal loading capacity of 750,000 lbs distributed over three (3) sub-frames. Each sub-frame provides the necessary structure to apply loading over a typical bearing wall. Overall views of the test frame with a two story test specimen are shown in Figs. 3 and 4.

The overall height of a single bearing wall is limited to 22'-0" during full scale tests. Bearing walls tested are 8' - 0" high and consist of a group of five studs in each wall. The test frame is provided with X-bracing along the

top and sides for rigidity. The X-bracing was designed to support the frame if it racked 6" at the maximum loading capacity.

#### Data Acquisition System

Each test assembly is rather complex and time consuming. A tremendous amount of data is collected during each test. The data acquisition system provided a means of measuring the loads applied to the stud walls and floors, 35 displacements (3 on each of the 3 center studs on the three first floor walls and 8 on the first floor planks) and 288 strains (8 on each stud and 2 on each strap) for the two-story test.

The system consists of an IBM/AT compatible computer communicating with four measurement systems via the General Purpose Interface Bus. Each measurement system includes a multiplexer and a measuring device. The multiplexers allow the computer to select one of many input devices to be connected to each measuring device. The computer tells the measurement device when to make a measurement, then reads the measurement from the device, displays and stores all the acquired data.

Loads are applied to the stud walls and floors with groups of 5 hydraulic jacks for the walls, one over each stud as shown in Fig. 5 and 4 jacks for the floors. Three displacement measurements are made on a given section of several studs, 2 on the web and 1 on the flange, in order to determine deflections in the two principal axis directions and rotation. The deflections and the end rotations of the planks are also measured at several locations.

Strains are measured in both flanges and at the ends of the web near the top and bottom of several studs. The gages are oriented to measure strains along the length of the stud. At stresses below yield, the measured strains are used to help understand the stress distribution in the studs. Strain gages are also mounted on the straps connecting the midpoints of the studs in each wall together and to the test frame.

The measured displacements and strains are processed through the use of a spread sheet. The measurements can be combined to give a good understanding of the forces in the structure. Plots of the data collected will be useful in understanding the behavior of the test specimen and allow us to organize the hundreds of thousands of measurements recorded. Information gathered from the DCDTs are typically plotted as shown in Fig. 6.

#### TEST PROGRAM

##### Test performed to date

The following is a summary of tests performed at Cornell prior to July 1, 1990.

1. A full scale test was conducted on a one-story structure made up of three 18 gage steel framed walls 8 ft. high and 19 ft. apart and four 8 in. deep hollow core slabs attached above, as typically used for the roof of any building. Loads were applied to the slabs at their mid-point until failure occurred.
2. A full scale test was concluded on a multi-story/one-story structure with three 12-gage steel framed walls supporting a typical floor system as described in the first test. In addition, 1 foot long stub columns were located above each 1st floor wall to simulate multi-story loading. Loads were applied to the slabs and fixed at 1.25 times the design load and loads were applied to the stub columns until the failure occurred in the first floor studs.

3. A full scale test was conducted on a multi-story/two-story structure with the first floor consisting of three 12-gage steel framed walls supporting the typical floor system and the second floor consisting of three 12-gage steel framed walls supporting a typical floor system. As in Test 2, 1 foot long columns were located above each second floor wall stud to simulate multi-story loading above the second floor. Loads were applied to the slabs and fixed at 1.25 times the design load and loads were applied to the short columns until failure occurred in the stud walls.

After initial testing one of the end walls was covered with gypsum sheathing, attached to both sides and tested.

#### Future Testing

Testing is expected to continue through the summer of 1990 with the following tests scheduled.

1. A two-story X-braced shear wall will be tested to failure.
2. Two-story, two-bay full scale test incorporating worst case tolerances to establish stud-plank tolerances will be carried out.
3. A two-story wall with gypsum sheathing will be tested.
4. Various connections will be tested.
5. Stub columns and tensile coupons from each stud will be tested.

#### SUMMARY OF TEST RESULTS TO DATE

Preliminary findings based on the results of tests conducted on the stud-plank building system clearly show that the final factors of safety will exceed those of the current 1986 A.I.S.I. specifications. The extensive of instrumentation used on the structural wall and floor components helped discover several facts about the behavior of the structural system that can only be discovered on the basis of full scale testing. Testing completed at Cornell University was extremely valuable and greatly influenced the ability of P.I.C. to successfully fabricate and erect a complete structure.

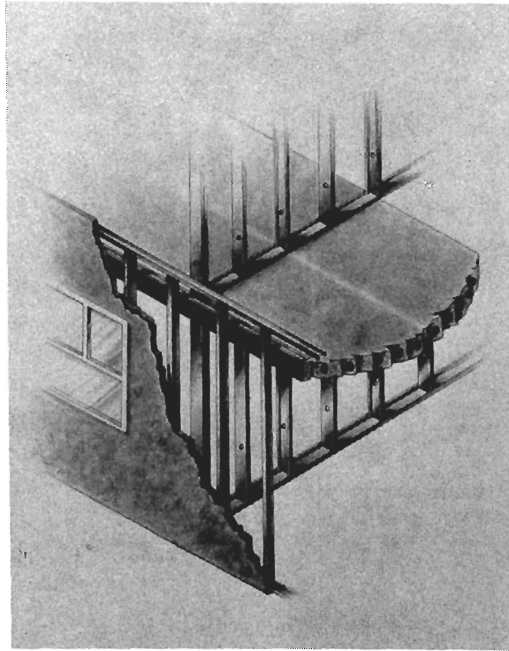


Fig. 1 Stud-Plank Building System





Fig. 2 A View of a Spring Creek Gardens 6-Story Building

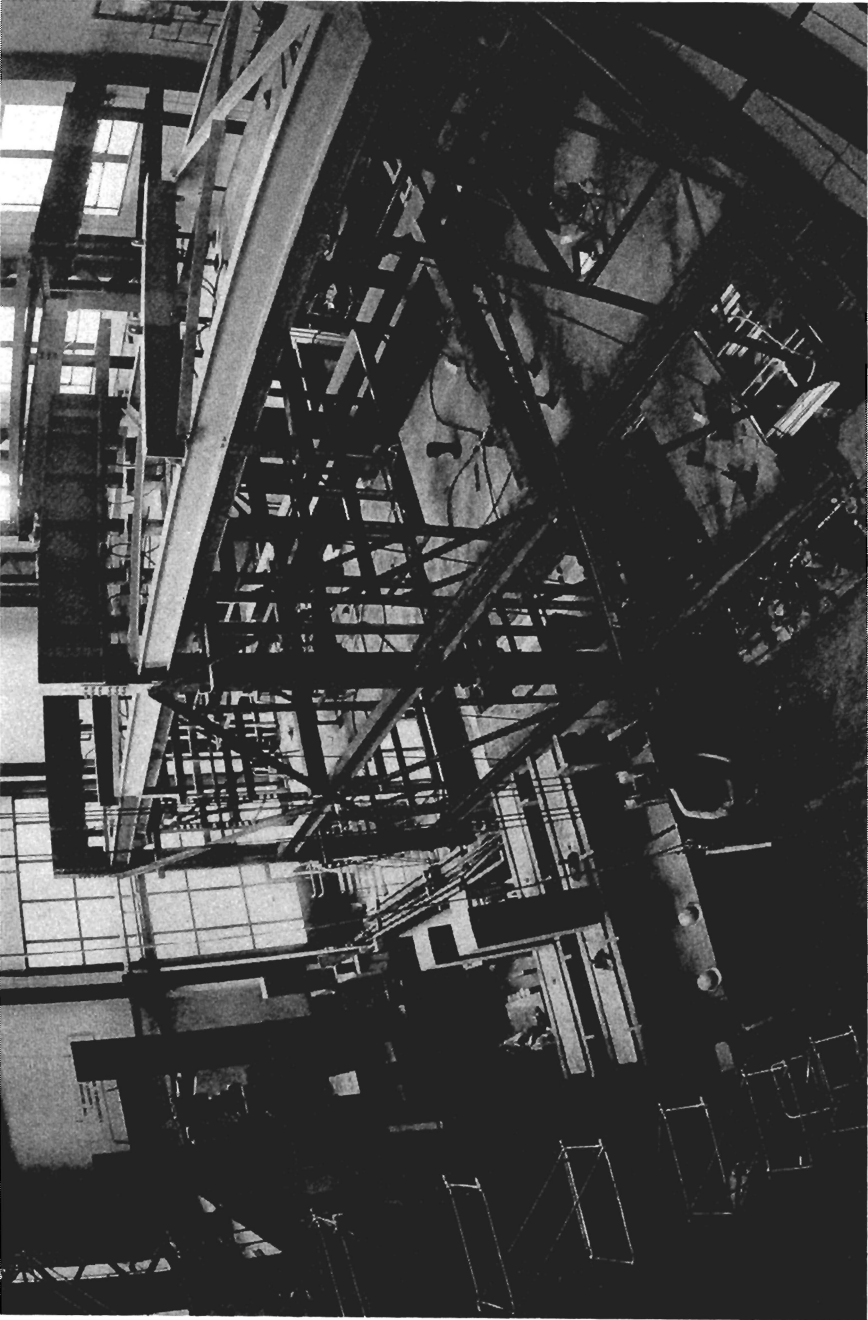


Fig. 3 An Overall View of the Test Setup

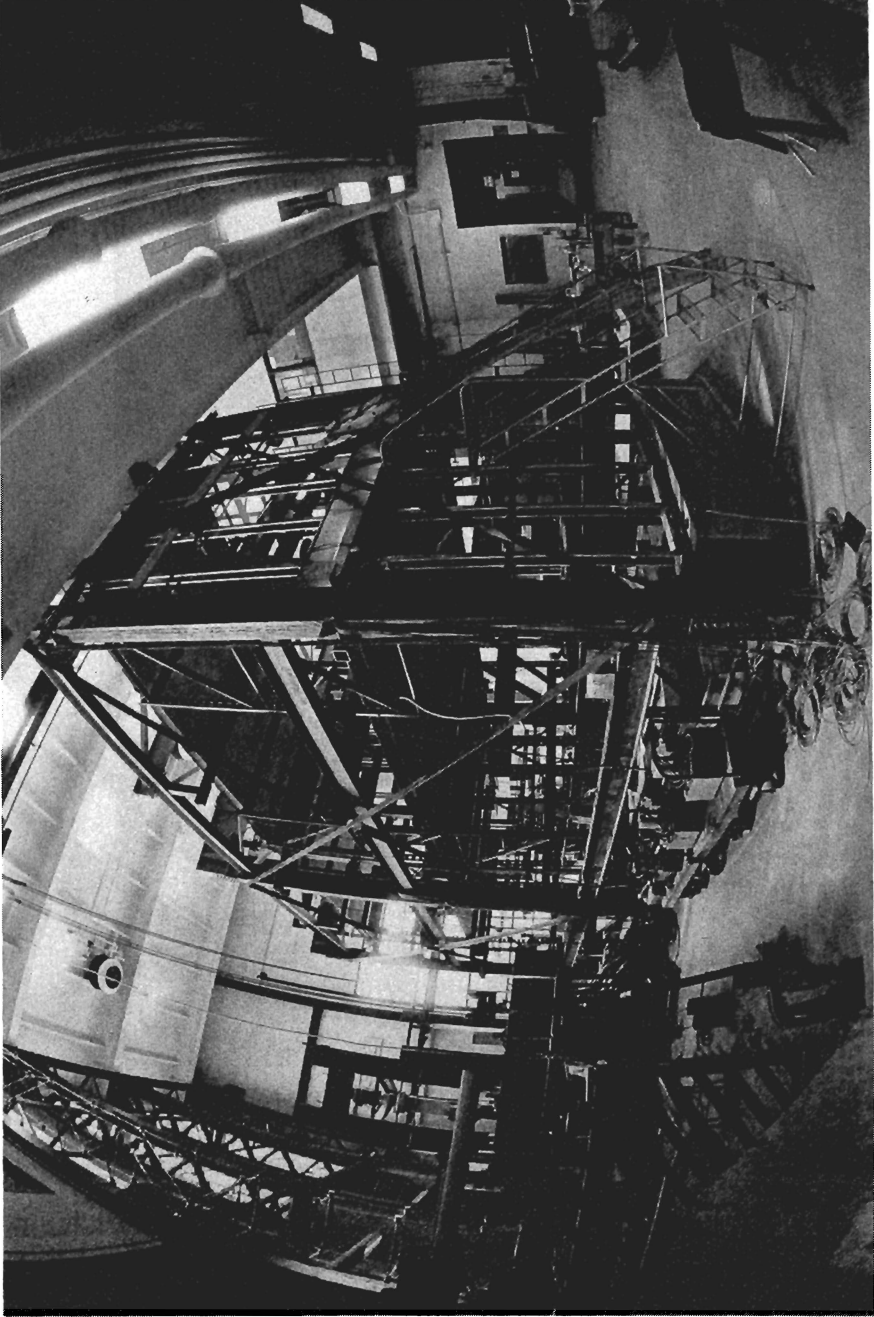


Fig. 4 An Overall View of the Test Setup

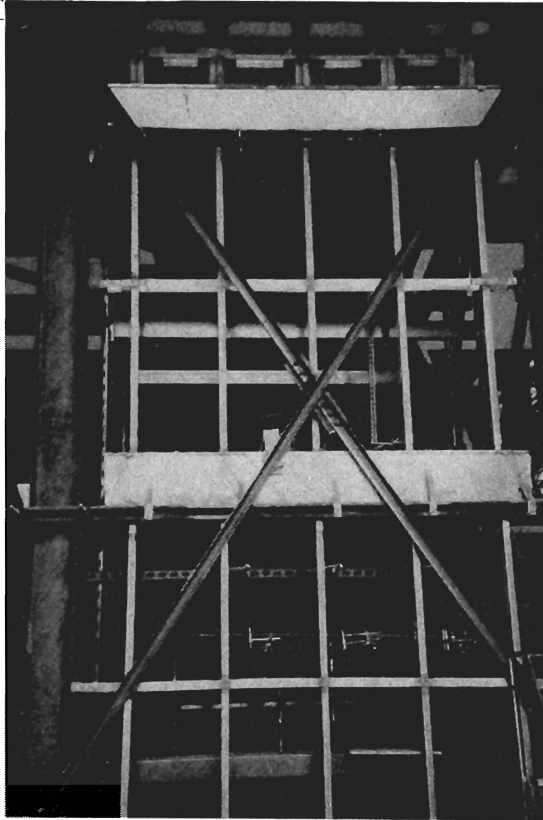


Fig. 5 End wall of a 2-Story test showing jacks at the top for applying axial loads and the frame for loading, instrument mounting and safety.

Load, lbs

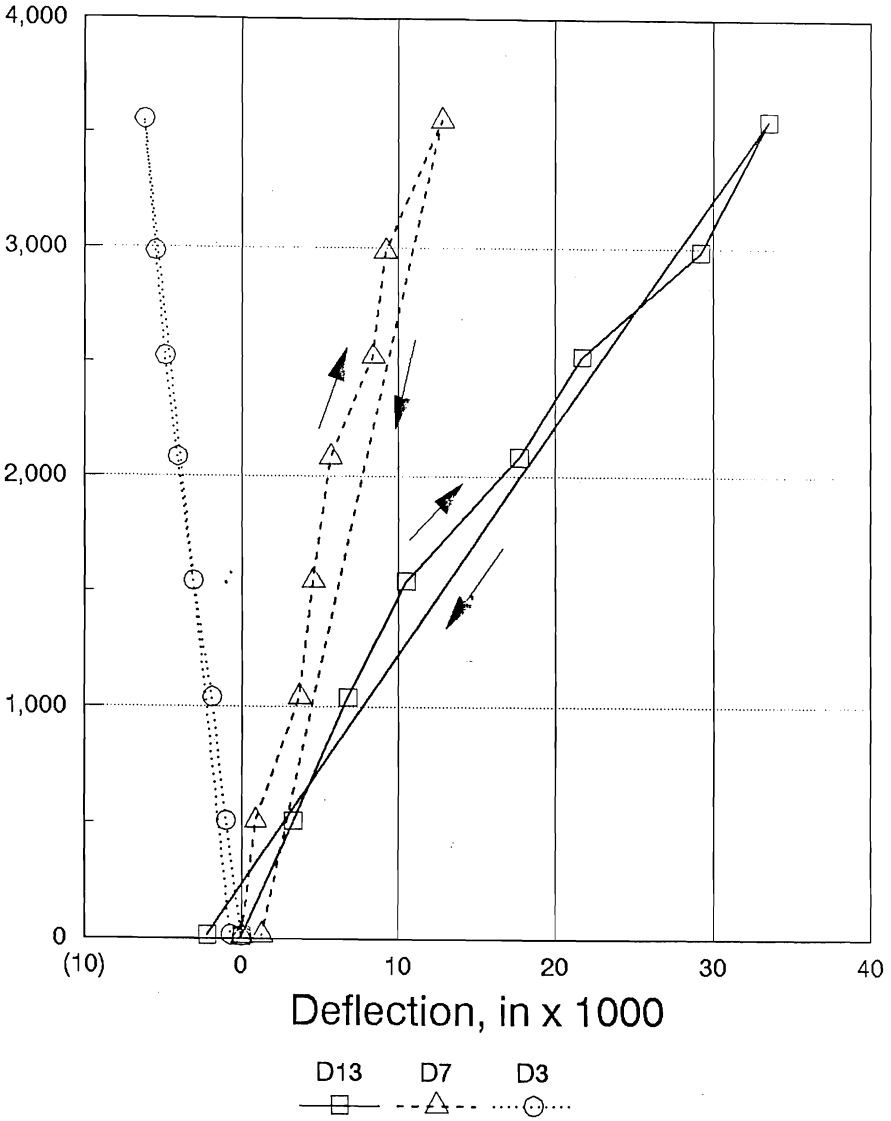


Fig. 6 Plot of DCDT attached to mid-point of floor slabs in Test (2).