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# SEISMIC TESTING AND DESIGN OF RAISED COMPUTER FLOORS

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## SUMMARY

The behavior of raised access floor systems when subjected to seismic loading is not very well understood. Until recently, the U.S. building codes did not address the design of these floors. A laboratory test program was conducted in order to evaluate the behavior of typical raised floor systems under lateral loading. Many current raised floors were found to be inadequate to resist the expected earthquake motions. Several strengthening schemes were also tested. The results and design criteria presented herein may be used in a rational seismic design of raised access floor systems.

## INTRODUCTION

Raised access flooring is finding increasing use in industrial and commercial facilities such as data processing centers and high technology production and testing facilities. Due to the relatively recent use of raised access floors, there is little data available on the performance of these structural systems when subjected to strong ground shaking. Isolated instances of reported performance of these floors point to the need for careful consideration of seismic behavior of these elements.

Building codes in the U.S. did not address the seismic design of raised access floors until recently. Most existing floors have been installed without proper consideration for seismic performance. The 1985 Uniform Building Code (UBC) specifies lateral load coefficients for raised access floors, but does not address stiffness requirements. The determination of seismic capacity of raised floor elements cannot be based solely on analytical procedures, due to uncertainties in estimating material properties and specialized connection details. Prototype testing is the appropriate method to evaluate the behavior of these elements.

The objectives of this study were to test and evaluate the lateral load-carrying ability of existing raised access floors, and to test and evaluate schemes for seismically strengthening existing floor systems.

## STRUCTURAL SYSTEMS

The structural system of raised access floors consists of 2-foot square removable floor panels which are supported by pedestals at the corners. Pedestals are made of steel or aluminum with base plates which, in most floor systems, are glued to the structural floor by a mastic compound.

The pedestal, which is considered fixed at the structural floor level, carries the seismic lateral load by cantilever action. This requires development of shear and bending stresses in the mastic compound which is considered unreliable for resisting earthquake loads, due to long-term deterioration and questionable quality control during installation. Pedestal bases, therefore, should be anchored to the subfloor by a reliable anchorage. The tests reported herein are based on anchorage of pedestal using expanded wedge anchors.

## TEST PROCEDURES

The raised access floor test program was conducted at Dames & Moore's Whittier laboratory facilities. The test setup employed a steel test frame using C-clamps (as a substitute for anchor bolts) to fasten the pedestal base to the supporting test frame. The loading mechanism consisted of a double-acting compression/tension hydraulic jack which allowed complete load reversal for cyclic loading. The cyclic force-displacement relationship was automatically plotted on an X-Y recorder. The displacement of the test specimen in the direction perpendicular to the applied load was prevented in all tests. This allowed more accurate assessment of cantilever pedestal strength when the pedestal base is anchored at two diagonal corners only.

The cyclic load tests allowed an evaluation of stiffness degradation with repeated cycles of loading. A typical force-displacement relationship for a cyclic load test is shown in Fig. 2. The ultimate strength, displacement, and initial stiffness, were determined from the force-displacement plots. The following tests were performed:

<u>Cantilever Pedestal Test</u> Several pedestal types as shown in Fig. 1 were loaded as a cantilever. Description of these pedestals is given in Table I.

<u>Braced Pedestal Test</u> Several methods of laterally bracing floor pedestals were tested to determine the increase in lateral strength and stiffness due to the added bracing. The bracing schemes consisted of steel tubes connected to one or both sides of the pedestal with a split-ring or bent plate clamp, and connected to the subfloor with wedge anchor. Typical pedestal bracing scheme is shown on Fig. 3. For the double brace scheme bracing elements were at a 45-degree slope.

<u>Cruciform Panel Test</u> This bracing scheme is highly efficient and requires a minimum of field installation. The system consists of a standard steel floor panel with two bent tubular steel diagonal bracing members, each welded to the panel at diagonally opposite corners. The two members are connected at a point just above the floor slab level, where a wedge anchor rigidly attaches the assembly to the structural floor. Cruciform panel bracing scheme is shown on Fig. 4.

## TEST RESULTS

<u>Cantilever Pedestal</u> Table I shows the cantilever pedestal test results. The larger values of design capacity are associated with tests using four anchor bolts. The following observations were made regarding the behavior of the pedestals tested:

a. Type B pedestal, which employs circular cast metal base plate, has a relatively higher initial stiffness, but exhibits a brittle failure mode.

b. In other pedestals, the ultimate strength and stiffness were found to be controlled by base plate weld failure or inelastic bending of the base plate. Thus, the strength of the pedestal is inversely proportional to the height and the initial stiffness is inversely proportional to the square of the height. These relationships can be used to determine the approximate strength and stiffness of floors with various heights using the test results provided here.

Table I. Cantilever Pedestal

| Type | Base | Lower Stem | Upper Stem | No. of Tests | No. of Bolts | Pedestal Height(in) | Design Capacity(lb) |
|---|---|---|---|---|---|---|---|
| A | Steel, 4" square, 0.06" thick | Threaded rod | Steel tube | 4 | 2,4 | 10-12 | 22-45 |
| B | Round, cast metal, 4.5" diameter | Threaded cast metal stud | Aluminum tube | 4 | 3 | 10 | 70 |
| C | Steel, 4" square, 0.19" thick | Threaded rod | Steel tube | 2 | 2,4 | 10 | 80-115 |
| D | Steel, 4" square, 0.13" thick | Steel tube | Threaded rod | 2 | 2 | 10 | 70 |
| E | Steel, 6" square, 0.18" thick | Steel tube | Threaded rod | 2 | 2,4 | 22 | 80-105 |
| F | Steel, 4" square, 0.13" thick | Threaded rod | Square or hexagonal steel tube | 1 | 2 | 13 | 35 |

Braced Pedestal Preliminary tests indicated that the stiffness of a single-braced pedestal is highly dependent on deformations in connections of the pedestal to the bracing element. In order to reduce these deformations, it was found that the connecting clamp should closely fit the shape of the pedestal tube. Also, a cotter pin should be installed which extends through the clamp connection at 45 degrees to the brace. Table II indicates the test results for braced pedestals with connections detailed as indicated above. The failure modes were either shearing of bolt or cotter pin or yielding of brace tube at its connections.

Cruciform Panel Table III shows the results of the cruciform panel tests. The basic mode of failure was found to be local distortion of the panel near the welded brace connections. However, for the 25-inch-high floor, the panel slipped through the supporting stringers due to large displacement and distortion.

Table II. Braced Pedestal

| Pedestal Type | Pedestal Height (inches) | Bracing | Design Capacity (lb) |
|---|---|---|---|
| A | 10 | Double | 1100 |
| A | 10 | Single | 1250 |
| E | 21.5 | Single | 1000 |
| F | 14.5 | Single | 1275 |

Table III. Cruciform Panel

| Floor Height (inches) | Panel Metal Thickness (Gage) | Design Capacity (lb) |
|---|---|---|
| 12 | 18 | 2700 |
| 25 | 18 | 1875 |
| 13 | 20 | 2680 |
| 16 | 20 | 2550 |

## DESIGN CAPACITY

The design capacity is defined here as the reliable strength which can be used for design purposes. It is an ultimate value (not allowable) and is used to compare to the actual anticipated level of earthquake force (not code force). The following strength and displacement criteria was used.

a. Strength Criteria The strength was chosen to be the smaller of:

- o The minimum value of ultimate strength obtained from various tests;
- o 0.85 times the average ultimate strength.

b. Displacement Criteria A lateral displacement or drift limit was imposed in order to prevent the raised floor from excessive deformation and damage due to pounding against structural walls and partitions during an earthquake. The maximum lateral displacement at the pedestal head was assumed to be 0.025 times the pedastal height. The choice of this limit was based on engineering judgment (this criteria controls the design in many cases and should be modified depending on the level of acceptable damage).

The design capacity is the minimum of the two values obtained based on the above strength and displacement criteria. These values are calculated for samples tested and are shown in Tables I to III. Figure 5 shows the the authors' recommended design capacity for various retrofit solutions based on test results.

## EVALUATION OF COMMON FLOOR SYSTEMS

The design of raised access floors for noncritical facilities may be based on minimum code requirements. However, for computer facilities in which continuous operation or limited downtime after a major earthquake is required, the design should consider the actual anticipated earthquake motions of the raised floor at the particular level in the building.

The period of vibration of a fully loaded raised floor system is in the range of 0.15 to 0.3 seconds. This period range coincides with the peak acceleration response of most ground (and building floor) earthquake spectra. Considering the high equipment load supported by raised floors, one can analytically demonstrate that none of the common floor systems tested in this study have a sufficiently high design capacity to satisfy the earthquake demand. Therefore, retrofit strengthening of these floor systems is appropriate.

## RETROFIT DESIGN

Figure 5 indicates that the recommended design capacity of two braced pedestals is equal to one cruciform panel, and thus a pedestal-braced bay with 2 braces in each direction is equivalent to one cruciform panel. Due to the lack of diaphragm action in raised floor systems, every line of pedestal in each direction should have a seismic resisting element. However, the bracing elements or cruciform panels should be located so as to provide maximum freedom in the use of the subfloor area. Various arrangement of brace locations should be considered that meet the above demand while satisfying design force requirements. As an example, a checkerboard arrangement of 24-inch high cruciform panels (or braced bays each having two braces in each direction) may be used if the desired ultimate lateral load per pedestal is less than 400 pounds.

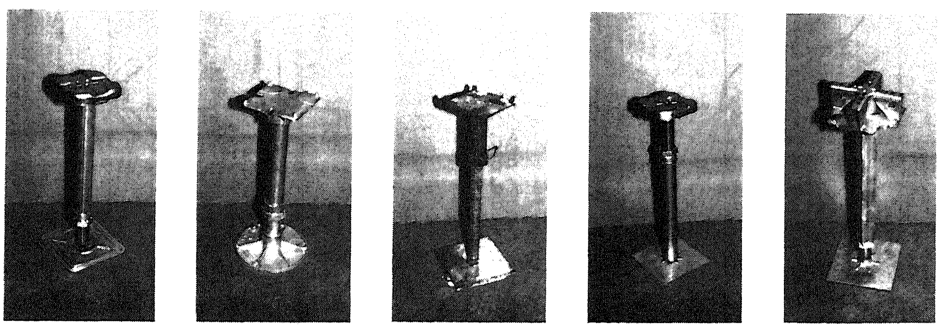
In most floor designs the stringers act as collectors between vertical resisting elements. Stringers and their connections to pedestal heads should have sufficient capacity to resist the collector loads.

The design capacities presented here are based on the specifics of samples tested, and may serve for the preliminary design of retrofit bracing. A program of job specific laboratory and field verification testing is recommended.

## SUMMARY AND CONCLUSIONS

Based on the results of the test program described in this paper, the following conclusions can be drawn:

- Even when anchored securely to the subfloor, most commonly available raised floor systems do not have the necessary strength and stiffness to survive a major earthquake without damage.
- Specially designed seismic pedestals or retrofit bracing can be used to reduce earthquake vulnerability.
- Design criteria and test results reported here can be used for preliminary seismic design of raised access floors.



Type A Type B Type C Type D,E Type F

Fig. 1 Cantilever Pedestals Tested

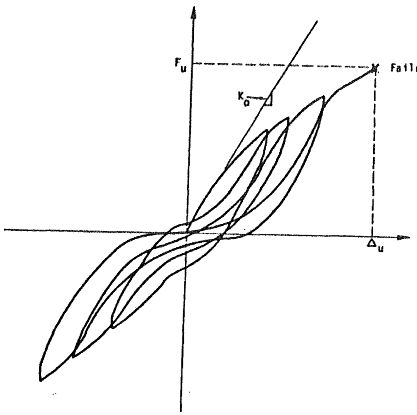



FIGURE 2 FORCE - DISPLACEMENT PLOT FOR A TYPICAL CYCLIC LOAD TEST

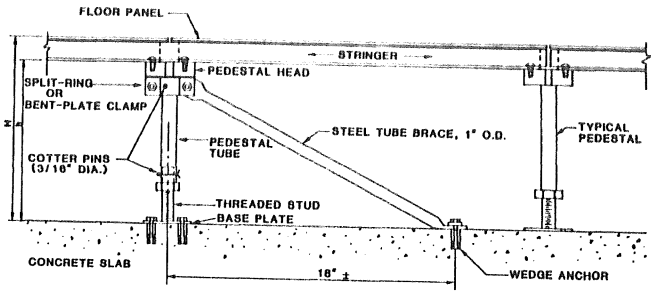



FIGURE 3 PEDESTAL BRACING SCHEME

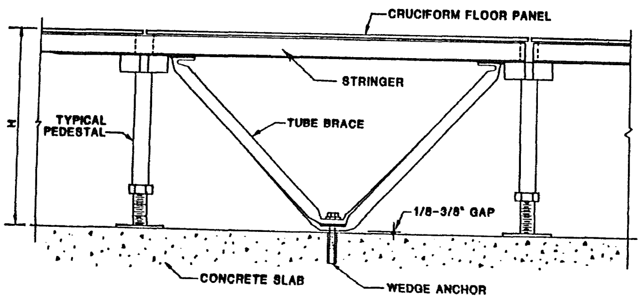



FIGURE 4 BRACED PANEL SCHEME WITH CRUCIFORM FLOOR PANEL

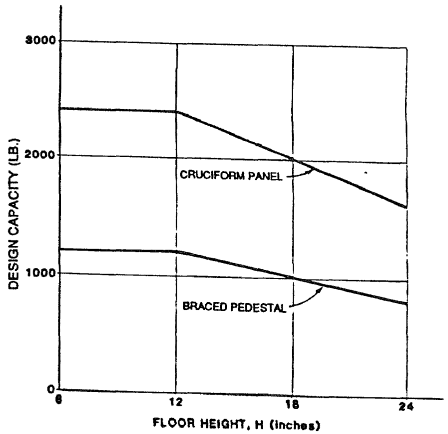



FIGURE 5 RECOMMENDED DESIGN CAPACITY