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STRENGTH TESTING OF SUSPENDED CEILING SYSTEMS AND CONSTRUCTION DEFECTS IN TAIWAN

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SUMMARY

systems. Different ceiling configurations were tested to understand their ultimate strength under incremental shock spectrum excitation. Numerical model and experimental tests were first conducted to understand the vibration characteristics of DHS ceilings. It was confirmed that the natural frequency of a DHS ceiling system could be calculated as that of a pendulum system. From this finding, the possibility of resonance between a DHS ceiling and the residing building can be easily determined.
Different ceiling configurations were tested in the laboratory at NCKU to understand their ultimate strength under incremental shock spectrum excitation. It was discovered that the 45-degree sway wire method prescribed by CISCA does not increase the seismic capacity of the entire system. Also discovered was that a DHS ceiling system, with edge hanging wires located within 20 cm from the edge molding, could exhibit high Seismic capacity up to 0.9 g.
Based on recent field observations of DHS ceiling earthquake damage in Taiwan, it was found that pop rivets at the molding would increase the seismic capacity of a DHS system. It was also discovered that a constraint transverse to the excitation direction would greatly influence the behavior of the DHS syste

INTRODUCTION

systems are generally composed of runners and lay-in panels. Both the main and cross-runners are made of light gage metal sections with an inverted “T” section whose flange provides a support ledge for the acoustical lay-in tile. Mechanics of each runner is statically determinant with little redundancy. Perimeter supports are provided by light gage metal angles that are attached to partitions or walls**.** DHS ceiling damage was widespread in several earthquakes where ground acceleration was only moderate. However, in some cases building structures suffered severe damage while the DHS system inside suffered little damage [Yao and Lien, 1998].

In developing a performance based design approach to reduce earthquake loss, people have begun to realize the importance of maintaining the strength of nonstructural elements in a building. For most of the nonstructural elements, Seismic capacity can be simplified into a static problem and easily evaluated. But the strength of a DHS ceiling system is difficult to estimate because its swaying behavior is dynamic in nature and is further complicated by modifications of floor vibrations of the building. Based upon the above reasons, the author attempted to investigate the behavior of DHS ceiling systems and their strength in earthquakes using vibration analysis and experimental verification

EARTHQUAKE EXPERIENCE AND RELATED RESEARCH WORKS

the perimeter of a room at the intersections of walls and ceilings where runners would easily buckle or detach from the wall angle [ANCO, 1983]. In response to this problem, CISCA in the USA proposed a seismic restraint requirement to improve the performance of DHS system in 1972 [CISCA, 1992]. CISCA proposed the installation of 45-degree sway bracing wires in each direction at 4 m (12 ft) o.c. These wires are to provide a

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positive means of resistance for the horizontal component of the earthquake force. In addition, to reduce ceiling perimeter damage, hanger wires are required within 20 cm (8 in.) of a wall for all runners abutting the walls, as shown in Fig. 1. These seismic measures were later adopted by various organizations, such as ICBO and ASTM, with slight modifications such as adding vertical struts at the center of the sway wires and pop rivets at the wall edge. However, the original concept of sway wires is based upon engineering judgement rather than rigorous investigation.

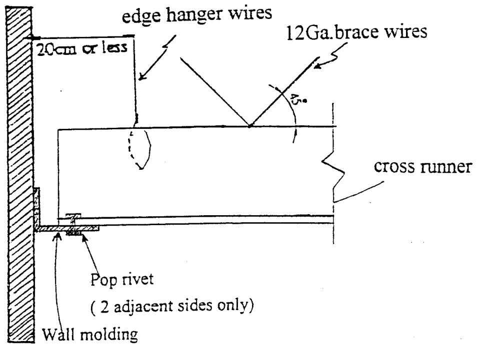

Fig.1 CISCA Recommended Seismic Provision

In the USA, two shaking table experimental studies were performed on the strength of suspended ceilings. One was conducted by ANCO Engineers Inc. [ANCO, 1983] and the other by Rihal and Granneman [Rihal and Granneman, 1984]. Major findings of the former were the ineffectiveness of vertical struts, and that pop rivet installation may be more effective than sway wires. Major findings of the later were the effectiveness of sway wires on partial-height partitions, and the reduced uplift when a vertical strut was installed. Both reports indicated some improvement in seismic capacity, but conclusive results on the requirements and parameters for DHS Seismic capacity are non-existent. [FEMA, 1997].

The vibration behavior of a DHS ceiling system in small amplitude was studied by Yao [Yao,1999]. Numerical model of a 1.2 m X 4 m DHS ceiling system with suspension height of 1 m was built to investigate the modal parameters of the system. Vibration experiments on the same model was conducted to verify the analytical results. A shaking table [Yao,1996] was used to provide an uniaxial excitation. It was discovered that the natural frequency of a DHS ceiling can be approximated by that of a pendulum model and be expressed as:

$$f = \frac{1}{2\pi}\sqrt{\frac{g}{L}}$$

Where f is frequency in cycles per second, g is the gravity constant, and L is the suspension length.

This paper continues the research work on the previous DHS ceiling model and presents an investigation into the seismic capacity of a DHS system with lay-in panels. The shock spectrum approach was chosen as the excitation method to identify the strength of the DHS systems. The main purpose of the strength test was to distinguish the effects of installing sway wires in the suspended ceiling system

SEISMIC CAPACITY USING FRAGILITY TESTING

with and without sway bracing wires. Each type was further divided into two groups, one with transverse supports and the other without transverse supports. Therefore there were four types of test samples. Transverse supports, shown in Fig. 2, refer to short cross runners perpendicular to the longitudinal excitation direction. Transverse supports provide lateral resistance to the runner grids during excitation so that the inserted connections would not fail due to the lateral spread of the runner grids and can increase the strength of DHS ceiling systems. Edge hanger wires and end walls were installed but pop rivets were not included in the test specimen. The direction of excitation is also shown in Fig. 2.

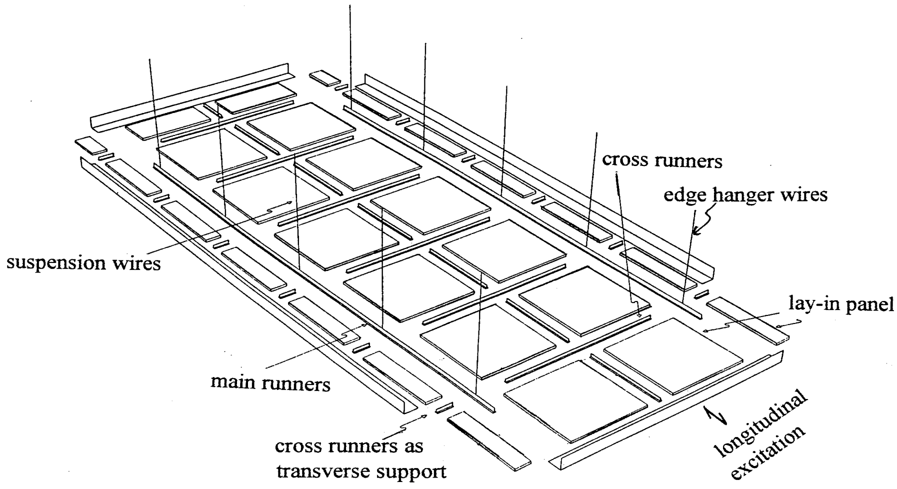

Fig.2 Test Sample Configuration

The test excitation is a time history generated from the building design spectrum for the hard rock foundation in the Taiwanese design code with peak spectrum platform ranging from 3.0 to 6.7 Hz, as shown in Fig. 3. Excitation levels are gradually increased until failure occurs. Failures are defined as separation of the runners or the falling of panels. The peak acceleration is then recorded as the seismic capacity. Test samples were realigned before each excitation increase to ensure no accumulated deformation was present. Three sets of samples were tested for every test type to ensure the consistency of the test results. Test results are shown in Table 1 for the group without transverse support and Table 2 with transverse support.

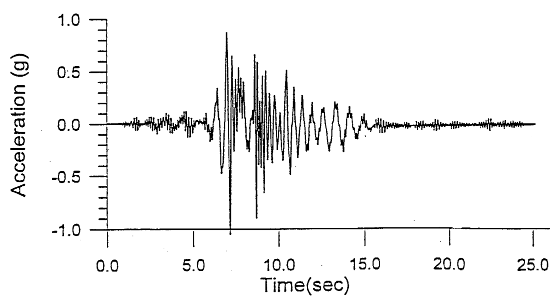

Fig.3 Time History from Design Spectrum

It can be seen from Table 1 and Table 2 that the performance of the DHS ceiling under earthquake excitation was very different. For systems with transverse supports, the fragility accelerations were high and could generally be grouped in the Operational category according to FEMA 273 [FEMA, 1997, p.2-15] for nonstructural elements. Systems without transverse supports exhibited lower fragility accelerations around 0.9 g. According to test observations, the main reason for the differences in performance was that the lateral supports provided lateral constraints to limit the lateral spread of the runner grids and therefore could maintain the integrity of the entire system. With appropriate lateral constraints, the seismic capacity can almost be doubled. This could be an important factor to the Seismic capacity of large area DHS ceiling systems One thing of particular interest from Table 1 and 2 is that the installation of sway bracing did not make any differences in the fragility acceleration.

Table 1. Fragility Acceleration of the DHS Ceiling Without Transverse Supports (g)

No Sway Bracing		With Sway Bracing	
Sample A1	0.92	Sample B1	0.93
Sample A2	0.91	Sample B2	0.96
Sample A3	0.90	Sample B3	0.87
Average	0.91	Average	0.92

Table 2. Fragility Acceleration of the DHS Ceiling With Transverse Supports (g)

No Sway Bracing		With Sway Bracing	
Sample C1	2.6	Sample D1	2.5
Sample C2	2.9	Sample D2	2.5
Sample C3	2.5	Sample D3	2.6
Average	2.7	Average	2.6

Observation of damage patterns for systems without transverse support revealed the following features:

1. Most of the failure patterns were local instead of total collapse. Only a few runners or panels separated from the original position.
2. The most frequently observed damage pattern was the separation of runners at connection points near the edge as shown in Fig. 4.
3. Observation of the test video indicated slight side sway in the main runners, which increased the spacing between runners and enabled the panels to fall down.
4. Connection failure in runners occurred together with falling panels.

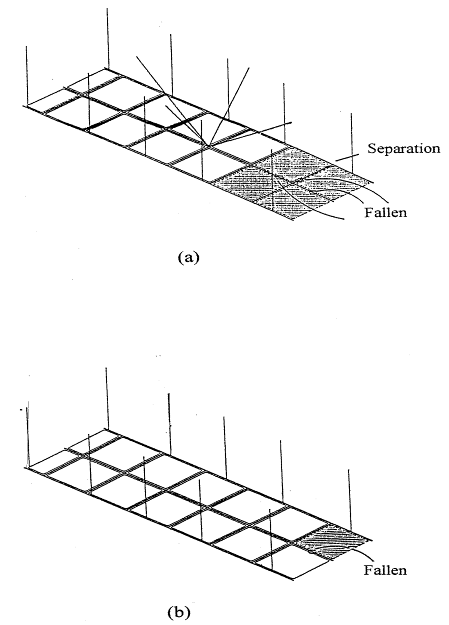

Fig.4 Damage Patterns for Systems Without Transverse Supports

Damage patterns for the system with transverse supports had the following features:

1. Most of the damage was caused by the deformation of runner members. Less separation of runners took place, indicating a more rigid in-plane system.
2. Panel jumping was observed, creating fallen or dislocated panels, as seen in Fig. 5.

Runner connection distortion could be observed.

CEILING DAMAGE OBSERVED IN TAIWANESE EARTHQUAKES

provisions [CISCA, 1971] except that sway wires, edge hanger wires, and wall molding pop rivets are not installed because of the increased labor involved. Sometimes, at the request of architects, pop rivets are installed as a safety procedure against earthquakes, and they are always installed on the four sides of the wall in a room instead of the CISCA-recommended two adjacent walls only.

In July 17, 1998 a magnitude 6.2 earthquake in southern Taiwan severely damaged eight school buildings. Among the four buildings whose columns were severely deteriorated, all had DHS ceilings installed on various floors. Post-earthquake field trips revealed that little damage to any of these DHS systems took place [Yao and

Lien, 1998]. One of the schools had strong motion accelerometers installed and recorded a PGA of 0.7 g in horizontal motion. Close examination of these DHS ceilings was conducted. It was found that all of the DHS ceiling systems included the pop rivet procedure and therefore retained their integrity in the strong shaking that damaged the structural systems. However, neither edge hanger wires nor sway bracing were include

CONCLUSIONS

idea of including sway wires to increase lateral resistance against earthquake motion does not show any distinguishable difference in the laboratory tests. Tests reveal that when hanger wires were installed within 20 cm to a wall, a DHS ceiling system is adequate to provide a seismic capacity up to 2.5 g when excited laterally. This strength does not increase by adding sway wires.

Data from field trip damage surveys in many buildings, whose structural systems were badly damaged from strong motion, indicated that DHS systems with adequate edge connectivity, such as added pop rivets, can provide a lot of Seismic capacity. This finding is consistent with the ANCO experiments. Also observed is that the edge hanger wire seems to provide significant seismic capacity already and works similarly to pop rivets. It was suggested to the local industry that edge wires and pop rivets should always be installed to guarantee the seismic capacity of a DHS ceiling system. The effect of sway wires is to be investigated in the future research work.

Transverse supports, which could prevent the lateral spread of the DHS runners, made the test results very different. It is the author's opinion that in a large DHS ceiling area system, such as under a long span stadium roof system, the lateral spread of the DHS ceiling can take place and results in the reduction of seismic capacity of DHS ceiling systems. Further analysis and experiment to investigate this issue are neede

ACKNOWLEDGEMENTS

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