Suspended Components Study at University at Buffalo
August-September-October 2011
Test Preparation:

1 Overview

A series of testing are planned in order to experimentally investigate the seismic behavior of a suspended ceiling system installed on a steel testing frame - new design and construction (20ft by 50ft., 10ft high) at UB-SEESL.

2 Objectives

The main objectives of the tests are as follows:

1. Identify failure modes describing functionality (limit states). The previously named limit states (Badillo, Whittaker and Reinhron, 2003) are:
   a. dislocation of panels
   b. grid failure
   c. total collapse of a system
2. Measure engineering demands (i.e. forces) through accelerometers and load cells associated with the newly defined limit states.
3. Determine the effects/efficiency of various protective systems (i.e. bracing, compression struts, perimeter angles/clips, etc.) to improve limit states.
4. Investigate the influence of ceilings, lighting and other nonstructural installation conditions (i.e. plenum heights, panel weights, panel sizes, expansion joints)
5. Investigate the influence of input motions (i.e. uni-axial, biaxial and tri-axial, and AC156 RRS matched using random motions and/or sine sweep motions)
6. Investigate the influence of suspending roofs-floors' motions (i.e.in plane and out of plane for various boundary conditions)

3 Practice committee providing input to this project

Bill Holmes,
Robert Bachmann,
Dennis Alvarez (manufacturers and CISCA coordinator),
John Gillengerten,
Andre Filiatrault (liaison)
Manos Maragakis (PI - NEESGC)

4 Researchers

Reinhorn (project coordinator), Ryu (leading researcher, operator), Filiatrault (PI), student assistant (TBA)

5 Manufacturers(alphabetically):

Armstrong, Inc
Chicago Metallic, Inc
Marshall Corp
USG, Corporation
others

6 Test configurations

See **Frame Configuration**, **Construction details** **&** **Grid Layout** (modified in agreement with rep of practice committee D. Alvarez (9/02/2011)
Additional **Grid Layout for 2x4** Lights was prepared 10/10/11 with input from practice committee)
All the installations follow the **INSTALLATION GUIDE** (Draft) and the **ASTM-E580** which has details of the connections and materials

7 Instrumentation layout and list

See **Instrumentation Plans** & **Instrumentation List**
Summary of Instrumentation

List	Permanent	Temporary*	Sum
Accelerometer	44	61	105
String Potentiometer	15	-	15
Displacement Potentiometer	-	16	16
Load Cells	-	20	20
Video	0	5	5
Total: 161 channels	59	102	161

* Temporary instruments (on ceiling systems) shall be prepared for easy removal and reinstallation on subsequent series (see details).
** Permanent instruments will be installed on the shake tables and test frames.

8 Test protocol -sequences of occurrence

See **Test Protocol-Schedule**

- Frequency searching - white noise testing, and/or sine sweep at low level
- Compensated motions at top corners of the test frame for AC156 RRS matched using *Random motions* (traditional) and Sine sweep (new development) motions (RRS Levels Ss=1.00g)
- Addition test input motions may be used to investigate the response of the system; UB-NCS protocol and simulated floor motions (Retamales et al ,2008), and recorded floor motions (CSMIP, 2005) (see **test input motions**)
- Incremental AC156 RRS matched using *Random motions* and *Sine sweep* motions - alternating - (RRS Levels Ss=1.50g and increments by 50 or 25 %)
- Various vertical input motions (for one configuration and nondestructive testing)

Details of motion input histories are still in preparation before verification with the shaking system

9 Data structure design on local repository-using Reinhorn's Data Structure

All data is recorded in the (private) repository at University at Buffalo before transfer to the NEEShub repository, using an original **data structure** developed for projects directed by Andrei M Reinhorn

10 Other preparatory issues:

- Modification of frames to fit fails safe requirements and testing - completed successfully
- Align and coordinate manufacturer's supplies and assistance - completed

11 References:

Mosqueda G., Retamales R, Filiatrault A and Reinhorn, A.M. (2011), "Testing Protocol for Experimental Seismic Qualification of Distributed Nonstructural Systems", in *Earthquake Spectra*, 27(3), 835-856

Maddaloni G., Ryu K.P. and Reinhorn, A.M. (2011), "Shake Table Simulation of Floor Response Spectra" in *Int. Journal of Earthquake Engineering and Structural Dynamics,* 40(6), 591-604

Reinhorn, A.M. Ryu K.P. and Maddaloni G., (2010), "Modeling and Seismic Evaluation of Nonstructural Components: Testing Frame for Experimental Evaluation of Suspended Ceiling Systems", *MCEER Technical Report –MCEER-10-0004*, University at Buffalo – the State University of New York

Retamales, R., Mosqueda, G., Filiatrault, A., and Reinhorn, A.M. (2008), "New Experimental Capabilities and Loading Protocols for Seismic Qualification and Fragility Assessment of Nonstructural Components", Technical Report MCEER-08-0026, MCEER, University at Buffalo-the State University of New York, Buffalo, NY

CSMIP (2005). "Instrumented Building Response Analysis and 3-D Visualization System", John A. Martin & Associates, Inc., Los Angeles, CA.

Note 1: The installation of test frame, instrumentation, test planning and operations, data collection and management, processing and reporting is designed and scheduled by the NEESR project investigators. The supply and installation of ceilings is provided by the participating manufacturers, with assistance of lab personnel

12 Testing Schedule - Completed

Activity / Testing	Duration	Tentative Schedule Start	End
Calibration & Set up: assembly of two frames, instrumentation (permanent channels), and metal adjustments **(COMPLETED)**	5 days	15-Aug	19-Aug
Bare Frame Testing - Instrumentation check and input motion preparation **(COMPLETED)**	3 days	22-Aug	26-Aug
#1 (#3 old designation): Test 3D + Instrumentation (removable and reinstall-able channels) + input motion check + redesign and correction of layout **Video-T1-Sep 9-S=1.50**	10 days	29-Aug	9-Sep
#2 Test - 2D effects **Video-T2-Sep 20-S=2.75**	5 days	12-Sep	20-Sep
#3 - (#1 old designation) Test 1D to failure **Video-T3-Sep 22-S=2.75**	3 days	21-Sep	22-Sep
#4 - (Repeat test #1) with 3D **(Video-T4-Sep 27-S=2.25)**	3 days	23-Sep	27-Sep
#5 - (Same as 1-4 without restrains - posts) with 3D -No Post **(Video-T5-Sep 30-S=2.00)**	3 days	28-Sep	30-Sep
- (Same as 5 with heavy tiles 3 psf) with 3D **(SKIPPED)**	2-1/2 days		
#6 - (Same as 6 with heavier tiles 4 psf) with 3D **(Video-T6-Oct 5-S=1.50)**	2-1/2 days	3- Oct	5-Oct
#7 - (Same as 4 with 7/8 angle and clips, no post) **(Video-T7-Oct 7 S=2.25)**	2 days	6-Oct	7-Oct
#8- (NonSeismicdesign-IntermediateWeightGrid SDC C) **(Video-T8-Oct 11 S=1.75)**) **(Video-T8-Oct 11 S=2.00)**	2 days	10-Oct	11-Oct
#9 (Same as #4 with 2x4 lights) **(Video-T9-Oct 13 S=2.75)**)	2 days	12-Oct	13-Oct
#10- (Same as 1-4 with larger plenum) with 3D **(Video-T10-Oct 18 S=2.50)**)	2 days	14-Oct	18-Oct

*Please see attached the test description Table 2 – Test description was prepared by the Practice Committee - in next page (modified A.M.Reinhorn, 10/18/2011)

13 Preliminary Results of Testing

The tests were completed on October 18, 2011
A table showing the peak accelerations during testing at various locations is included in
For each test a series of observations were prepared and marked on INSPECTION SKETCHES after each episode of progressively increasing intensity testing.
For each test a video of the failure was recorded (besides other intermediary videos)
The information is presented below along with the initial comments of the researchers:

TEST #1:

#1 (#3 old designation): Test 3D + Instrumentation (removable and removable channels check + input motion check + redesign and correction of layout	29-Aug	9-Sep
Video-T1-Sep 9-S=1.50		

Comments: This test was prepared for the calibration of the equipment, tuning the motions in the ceilings, testing the influence of variation of vertical input, learning how to do inspection and take notes, and fail the ceiling with increasing intensities with 3D motions, initially scheduled as Test #3. Due to early failure, probably caused by failure of rivets in the early preparation tests and previous vertical vibrations, this test will not be considered in the further evaluations of failure modes

TEST #2:

#2 - with 2D	12-Sep	20-Sep
Video-T2-Sep 20-S=2.75 **Inspection Sketches**		

Comments: This test using the 2D-vertical and longitudinal motions as specified by AC156, showed early failure of the rivets on the east side (short side) gradually appearing at the end of the main runners, first in the unrestrained, then in the restrained ones. Total failure started near the side of the failed rivets.
It appears that the dynamic loads are collected by the main runners from a tributary area of 4 ft and transferred at the end of the runner or to the horizontal restrainers.

TEST #3:

#3 - (#1 old designation) with 1D	21-Sep	22-Sep
Video-T3-Sep 22-S=2.75 **Inspection Sketches**		

Comments: This test using the 1D-longitudinal motion as specified by AC156, showed early failure of the rivets on the east side (fixed, short side) gradually appearing at the end of the main runners, first in the unrestrained, then in the restrained ones (as similar failure of Test#2). Total failure started near the east side of the failed rivets.

TEST #4:

#4 - (Repeat test #1) with 3D 23-Sep 27-Sep
(Video-T4-Sep 27-S=2.25) **Inspection Sketches**

Comments: This test using the 3D-longitudinal, lateral, and vertical motions as specified by AC156, showed the effects of multi-directional input motions. The system collapsed at the slightly lower level than ones of Test #1 and Test #2. The initial failure occurred at the rivets on the east side (fixed, short side) gradually appearing at the end of the main runners, first in the unrestrained, then in the restrained ones (as similar failure of Test#2 and #3). Under the combined movements in the longitudinal and lateral directions, total failure occurred near the north side (fixed, long side).

TEST #5:

#5 - (Same as 1-4 without restrains - posts) with 3D -No Post 28-Sep 30-Sep
(Video-T5-Sep 30-S=2.00) **Inspection Sketches**

Comments: This test using the 3D-longitudinal, lateral, and vertical motions as specified by AC156, was conducted without lateral restrainers (i.e. compression posts and splay wires). The initial failure occurred at the rivets of all the longitudinal main runners (grid) on the east side (fixed, short side). Total failure started near the north side (fixed, long side).

TEST #6:

#6 - (Same as 6 with heavier tiles 4 psf) with 3D 3- Oct 5-Oct
(Video-T6-Oct 5-S=1.50) **Inspection Sketches**

Comments: This test using the 3D-longitudinal, lateral, and vertical motions as specified by AC156, showed the effects of heavy tiles. The initial failure occurred at the rivets on the east side (fixed, short side) at the lower level than the ones of any other testing and some of main runner splices were twisted. Total failure started in the middle of the ceiling system with severe damage to some of the cross T-ees (bent tabs).

TEST #7:

#7 - (Same as 4 with 7/8 angle and clips, no post) with 3D 6-Oct 7-Oct
(Video-T7-Oct 7 S=2.25) **Inspection Sketches**

Comments: This test using the 3D-longitudinal, lateral, and vertical motions as specified by AC156, was conducted with the installation of 7/8" wall angles and seismic clips. The initial failure occurred at the grid joints (end of cross tees) on the east side (fixed, short side). Cross tee ends on the South side (floating side) were unseated from wall angles. Total failure started near the north-east corner (fixed-fixed-sides).

TEST #8:

#8- (NonSeismicdesign-IntermediateWeightGrid SDC C) with 3D 10-Oct 11-Oct
(Video-T8-Oct 11 S=1.75)) **(Video-T8-Oct 11 S=2.00)**
Inspection Sketches

Comments: This test using the 3D-longitudinal, lateral, and vertical motions as specified by AC156, was conducted with the setup of the Non-Seismic design-Intermediate Weight Grid for SDC C. The early failure occurred at the end of main runners on the east and west sides (short sides) first, which were unseated from wall angles, then ones on the South and north sides.
Total failure started near the perimeters of the middle north and south sides.

TEST #9:

#9 (Same as #4 with 2×4 lights) with 3D **(Video-T9-Oct 13 S=2.75))** **Inspection Sketches**	12-Oct	13-Oct

Comments: This test using the 3D-longitudinal, lateral, and vertical motions as specified by AC156, was conducted with the installation of 2×4 light fixtures in the short direction (north-south). The initial failure occurred at the rivets on the east side (fixed, short side) gradually appearing at the end of the main runners, first in the unrestrained, then in the restrained ones (as similar failure of Test#2 and #3). At the level of S_s=2.25g RRS, the center main runner splice broke and local vertical vibration in the center area of the system was observed during testing. Total failure started in the middle area and at the west and east sides independently but at the almost same time.

TEST #10:

#10- (Same as 1-4 with larger plenum) with 3D **(Video-T10-Oct 18 S=2.50**) **Inspection Sketches**	14-Oct	18-Oct

Comments: This test using the 3D-longitudinal, lateral, and vertical motions as specified by AC156, was conducted with the setup of deep plenum (≈ 65" from the bottom of joists). 7/8 wall angles and seismic clips were installed. The early failure occurred at the end of main runners on the west side (floating side), which were unseated from wall angles. Vertical sagging between compression posts on the main runners were observed.

Total failure started near the perimeters of the middle south side (floating, long side).

Table 1 - Test description (original)

	Ceiling Dimenstions										
Test Number	**x, ft.**	**y, ft.**	**ht, z in.**	**Duty rating**	***fixtures/ weight**	**bracing**	**comp. strut?**	**peri. angle condition**	****Shaking Direction**	****Design Condition**	**Comment**
1	20	50	36	heavy	2x2 distributed	yes	yes	2" angle	y	SDC D	one D motion; mains in 20' direction Typ unless noted
2	20	50	36	heavy	2x2 distributed	yes	yes	2" angle	yz	SDC D	Add vertical
3	20	50	36	heavy	2x2 distributed	yes	yes	2" angle	xyz	SDC D	Investigate effedt of 3D motion
4	20	50	36	heavy	2x2 distributed	no	no	2" angle	xyz	SDC D	Investigate 1000 sf limit
5	20	50	36	heavy	2x2 distributed	no	no	7/8 angle/clips	xyz	SDC D	investigate effect of clips
6	20	50	36	heavy	2x4 linear	yes	yes	2" angle	xyz	SDC D	Investigate fixture pattern; Main in 50 ' direction 2 lines of fixtures in 20' direction
7	20	50	36	heavy	2x2 distributed	yes	no	2" angle	xyz	SDC D	investigate compression strut
8	20	50	72	heavy	2x2 distributed	yes	yes	7/8 angle/clips	xyz	SDC D	investigate deep plenum
9	20	50	36	intermediate	2x2 distributed	no	no	7/8 angle	xyz	SDC C	investigate typical SDC C conditions
10	20	50	36	intermediate	2x2 distributed	yes	yes	7/8 angel/clips	xyz	SDC D	investigate intermediate duty at SDC D

* fixtures, diffusers, and return air grills to be included to an average weight of 2.5 psf

** Shaking to be taken to max damage state. Intermediate damage states noted for purposes of establishing fragilities. Damage state also noted at appropriate SDC intensity

Shaking protocol to be determined.

Direction of shaking for tests 4-10 to be determined. XYZ assumed.

Table 2- Test description (updated list October, 2011) - [highlighted yellow:-completed]

		Ceiling Dimenstions											
Initial Planned Test Number	**Actual / Revised Test Number**	**x, ft.**	**y, ft.**	**ht, z in.**	**Duty rating**	**TileWeight**	***fixtures/ weight**	**bracing**	**comp. strut?**	**peri. angle condition**	****Shaking Direction**	****Design Condition**	**Comment**
3	1	20	50	29	heavy	1.05	2x2 distributed	yes	yes	2" angle	**xyz**	SDC D	Investigate effedt of 3D motion
2	2	20	50	29	heavy	1.05	2x2 distributed	yes	yes	2" angle	**yz**	SDC D	Add vertical
1	3	20	50	29	heavy	1.05	2x2 distributed	yes	yes	2" angle	**y**	SDC D	One D motion; mains in 50' direction Typ unless noted
3 (Repeat)	4	20	50	29	heavy	1.05	2x2 distributed	yes	yes	2" angle	**xyz**	SDC D	Investigate effedt of 3D motion
4	5	20	50	29	heavy	1.05	2x2 distributed	**no**	**no**	2" angle	xyz	SDC D	Investigate 1000 sf limit
7	skipped	20	50	29	heavy	**3.00**	2x2 distributed	**no**	**no**	2" angle	xyz	SDC D	investigate compression strut
10	6	20	50	29	heavy	**4.00**	2x2 distributed	yes	yes	2" angle	xyz	SDC D	investigate heavy tiles at SDC D
5	7	20	50	29	heavy	1.05	2x2 distributed	**no**	**no**	**7/8 angle/clips**	xyz	SDC D	investigate effect of clips
9	8	20	50	29	**intermediate**	1.05	2x2 distributed	**no**	**no**	**7/8 angle**	xyz	SDC C	investigate typical SDC C conditions
6	9	20	50	29	heavy	1.05	**2x4 linear**	yes	yes	2" angle	xyz	SDC D	Investigate fixture pattern; Main in 50 ' direction 2 lines of fixtures in 20' direction
8	10	20	50	**65**	heavy	1.05	2x2 distributed	yes	yes	**7/8 angle/clips**	xyz	SDC D	investigate deep plenum

Table 3 - Future tests on smaller frames (original plan) to be executed at latter time

Single Table Tests												
S1		12	12	36	heavy		2x2 distributed	none	yes	7/8 angle/clips	xyz	SDC D
S2		16	16	36	heavy		2x2 distributed	none	yes	7/8 angle/clips	xyz	SDC D
S3		20	20	36	heavy		2x2 distributed	none	yes	7/8 angle/clips	xyz	SDC D
S4		16	16	20	heavy		2x2 distributed	yes	yes	7/8 angle/clips	xyz	SDC D
ASTM E 580												
SDC C		Moderate EQ										
SDC D		Sever EQ										
defined by ASCE7 and IBC. Seismic Design Category.												
SDC C												
1. Grid, T&C >= 60lb												
2. Wall Angle >= 7/8in.												
3. End wire <= 8in distance from perimeters												
4. wire #12 spaced @ 4ft.												
5. No fixed ends.(?)												
SDC D												
1. Grid, T&C >= 180lb												
2. Wall Angle >= 2in.												
3. End wire <= 8in distance from perimeters												
4. wire #12 spaced @ 4ft.												
5. Lateral force bracing > 1000 ft2												
6. Seismic seperation joist > 2500 ft2												