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"ENGINEERING ON DISPLAY" AT THE NEW ENGINEERING INDUSTRIAL BUILDING, UNIVERSITY OF ALASKA - ANCHORAGE

D.A. Skolnik(1), M. Ciudad-Real(2), D. Swanson(3), E. Bishop(4), U. Dutta(5)

(1) *Project Manager, Kinemetrics, Inc., das@kmi.com*
(2) *Program Manager, Kinemetrics, Inc., mcr@kmi.com*
(3) *Principal, Director, Structural Group, Reid Middleton, Inc., dswanson@reidmiddleton.com*
(4) *Project Engineer, Reid Middleton, Inc., ebishop@reidmiddleton.com*
(5) *Professor, University of Alaska – Anchorage, udutta2@uaa.alaska.edu*

Abstract

Anchorage is the largest population center in the State of Alaska and located in the highly active North Pacific seismic zone and overlies a deep sedimentary basin. The area witnessed several widespread destruction including liquefaction and clay failure during the Great 1964 Prince William Sound Earthquake (Mw=9.2). The University of Alaska - Anchorage (UAA) campus in the midtown area of Anchorage, Alaska is located on a seismic site class C ($360 < \beta 30 \leq 760$ m/s) and having a prominent Site Response (SR) of 2.0 at short period (0.2 sec) compared to the rock site located on the foothills of Chugach Mountains in the eastern part of the basin.

Besides the University buildings, the campus and its adjoining area house several medical facilities which are highly occupied during normal working days. With the sustained growth of the area as observed during last several decades, the seismic hazard has become one of the more important issues.

To understand the structural response of a typical building (3 to 4 stories) in the campus area, the newly constructed 81,000 square-foot four-story College of Engineering building, commonly known as Engineering Industrial Building (EIB) at the University of Alaska - Anchorage (UAA) has been instrumented with state-of–the-art structural monitoring system that includes accelerometers, strain gauges and wind sensors to provide a real-time display of the building health and enable rapid post-event assessment.

Moreover, the unique instrumentation layout and displays essentially turn the building itself into a living research laboratory. This effort, along with many other monitoring systems installed in the building (e.g., energy and water usage) has been coined "Engineering on Display." Datasets from seismic events and every-day operation will be integrated into student coursework, helping to bridge the gap between traditional engineering education and the use of modern technology.

Keywords: Earthquake; Sensors; Emergency Response; Technology; Education

1. Introduction

The University of Alaska in Anchorage (UAA) just completed the construction of a new 4-story, 81,000 SF, Engineering Industrial Building (EIB) on their campus in Anchorage, AK. A building information model (BIM) of the EIB, as well as the new adjoining pedestrian bridge, is depicted in Figure 1. As part of this project, UAA implemented a state-of-the-art structural and seismic building instrumentation system for the building to measure building movements and other structural and environmental data. The overall objective of the structural and seismic building instrumentation system is to demonstrate real-time structural and seismic building performance to the public, students, and staff that occupy the building as their learning environment.

Real-time data from the building monitoring systems are displayed on flat panel LCD monitors situated at key public areas of the building. These monitors are placed near areas where building system features such as structural framing, HVAC, mechanical piping, and/or electrical systems are exposed to public view. This structural and seismic monitoring system will be integrated with other real-time building monitoring systems that monitor building HVAC, plumbing, and electrical and other related building systems.

The structural and seismic monitoring instrumentation design consists of strong motion accelerometers, vibration accelerometers, strain gauges, displacement transducers, and other sensors that measure and record the building's responses to various loading conditions. However, only the strong motion accelerometers have been installed in the current phase of implementation. The instrumentation system is designed to record and display building movements and structural system stresses from seismic, wind, snow, pedestrian, and thermal loadings in the building. These measurements are recorded and displayed in real-time and data output from these systems are displayed on flat panel LCD monitors for observation by students, teachers, and the public.

Additionally, a planned future application of the real-time building monitoring system is its application to the eventual deployment of a Rapid Evaluation and Assessment Program (REAP) that will be utilized to quickly evaluate the safety of the new UAA EIB as well as other UAA campus buildings after an earthquake. REAP is an innovative first-response tool developed by Reid Middleton, Inc. structural engineers that utilizes building-specific structural analysis techniques, custom design field evaluation manuals, and a structural monitoring system with customized software designed to provide building owners and facility managers with the ability to rapidly evaluate the post-earthquake condition of their facilities to improve building occupant safety and increase business continuity

As described in Section 4.6, the three primary objectives and benefits of the UAA EIB instrumentation system are:

1. "Engineering on Display": Provide a real-world tool that can demonstrate engineering principals to students, staff, and the public. This tool will be integrated into the UAA School of Engineering's curriculum to provide a more substantive, meaningful, experience-based education.

2. Post-Earthquake Response: Monitor the behavior of the structure to inform the owners and facilities managers of the performance of the structure during a seismic event to assist with decisions regarding the safety and operability of the building.

3. Academic Research: Monitor the behavior of the structure to provide engineering researchers and seismologists with data about the site-specific ground motion and the measured dynamic response of the structure.

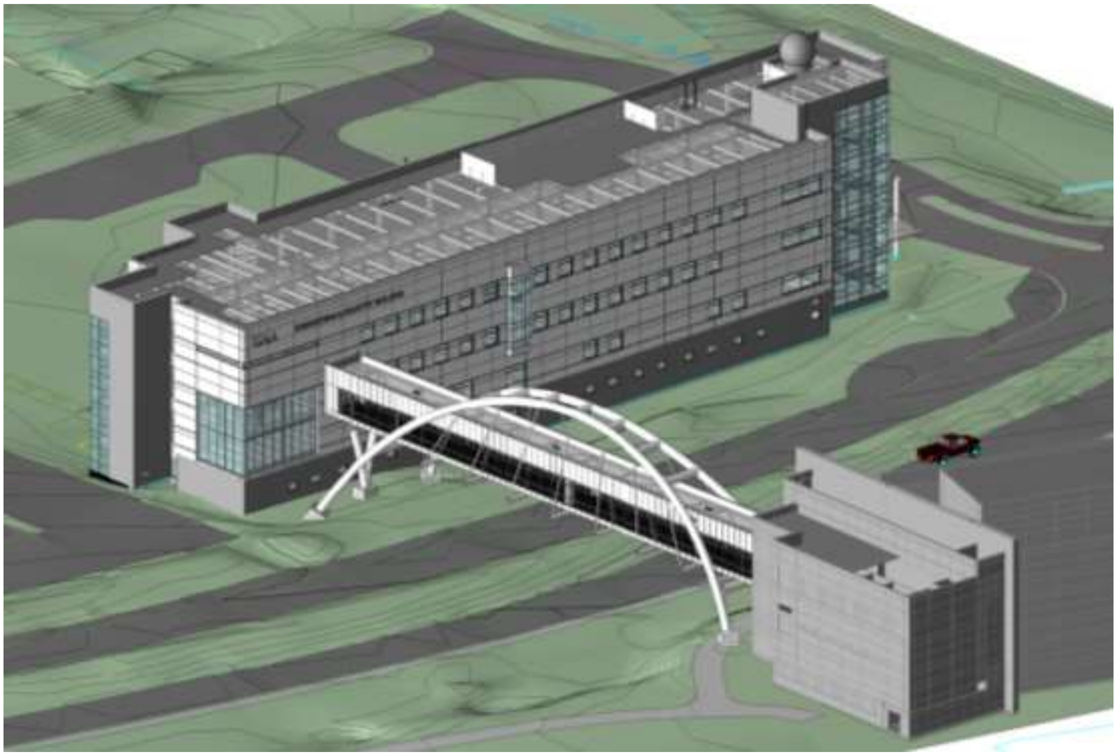

Fig. 1 - UAA EIB and Pedestrian Bridge. Building Information Model (BIM) Rendering, Reid Middleton

2. Anchorage Seismology Overview

Anchorage, the largest population center in the State of Alaska, is located in a highly active North Pacific seismic zone and overlies a deep sedimentary basin. The seismic zonation program for the metropolitan area of Anchorage revels that the area consists of site class C ($410 < \beta30 \leq 760$ m/s) (Figure 1) in the eastern and central part of the Anchorage Bowl while the western part of the basin including the downtown area belongs to site class D ($180 < \beta30 \leq 380$ m/s) (Dutta et al. 2000). Although the eastern part is located on a relatively better soil type (site class C) compared to the western part of the area, however, from the site response (SR) studies (Dutta et al., 2002), Martirosyan et al. 2003) of local earthquake data recorded by the existing state-of-the art strong motion seismic network in the Anchorage Bowl, indicate the presence of a high SR (~ 2.5) in and around the University of Alaska Anchorage (UAA) area at 5Hz (0.2 sec) central frequency (Figure 2) with respect to the rock site in the Chugach mountain on the eastern part of the area. The UAA and its surrounding area is one of the most prominent areas in the Anchorage basin, as beside two major University campuses, this area is also the location of three major hospitals of the town. Therefore, based on the observations obtained from the site response studies, the potential seismic risk of the area become significant. Moreover, the area has also been designated as one of the potential shelter areas of Anchorage Municipality during any natural disaster by the local and state emergency services. In addition, the majority of the university campus buildings are two to three storied high having fundamental frequency of their vibration around 4-5 Hz. Thus, a strong structural shaking in case of any local high magnitude earthquake is highly probable. Therefore, to study the impact of the local earthquakes on a typical building at UAA, we have decided to instrument the newly constructed Engineering Industrial Building (EIB) with strong motion accelerometers to measure the real-time characteristics of the building.

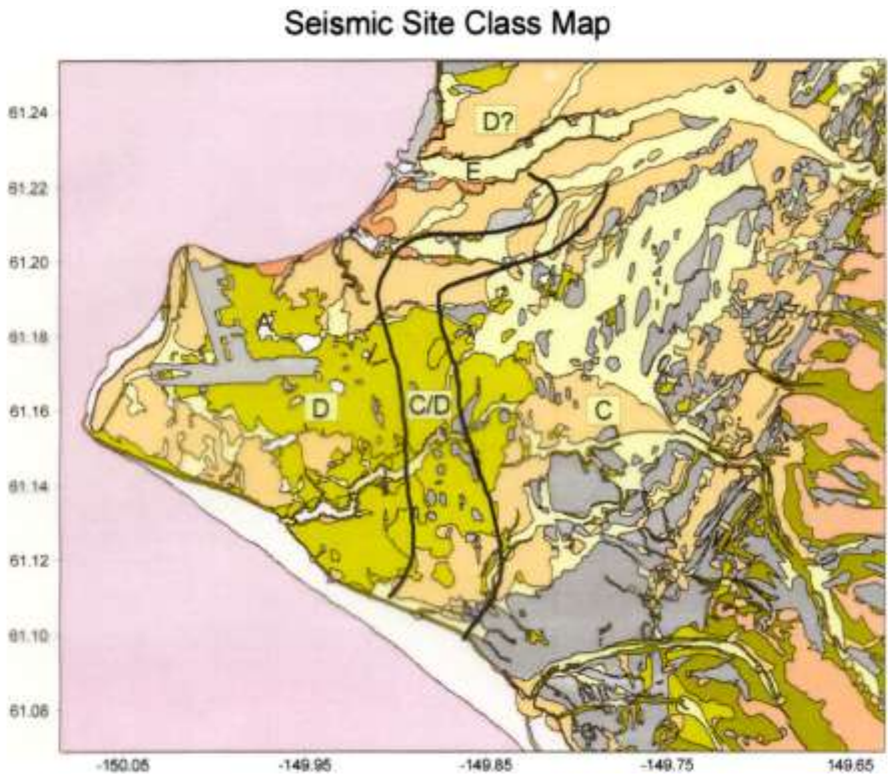

Fig. 2 - Seismic Site class map of Anchorage basin (EIB located depicted by the red circle)

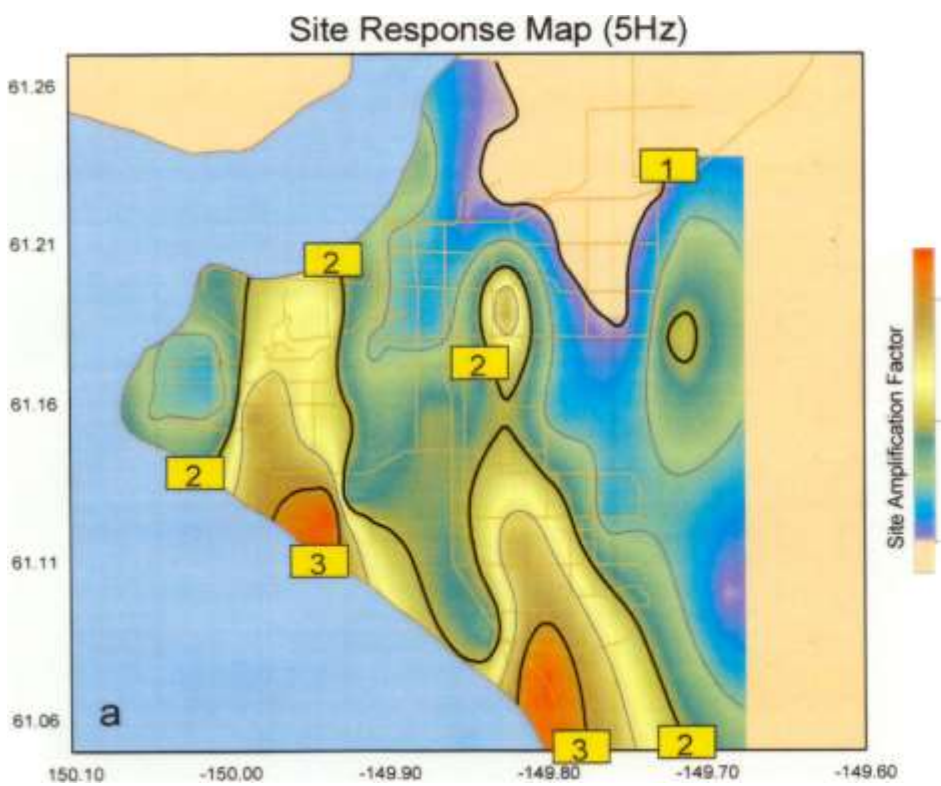

Fig. 3 - Seismic Site response map of Anchorage basin at 5 Hz (0.2 sec), relative to the location of EIB (red circle)

3. Building Instrumentation Overview

A comprehensive building instrumentation system was designed to monitor the structural response to the following loading demands and serviceability conditions. Table 1 summarizes the various conditions and what instruments are to be used to monitor the structure's response to each respective condition. Fig 4 provides a sample instrumentation layout plan of the third floor. Fig 5 provides the instrumentation schedule and sensor legend corresponding to the third floor layout plan.

Table 1: UAA Engineering Industry Building Instrumentation Summary (As Designed)

Building Loading	Instrument	Element	Location	Quantity
Seismic Event	Accelerometer	Concrete Deck	Roof, 4th, 3rd, 2nd, Base	9
	Strain Gauge	MF Connection	Roof, 4th, 3rd, 2nd	32
	Inclinometer	MF Column	Roof, 4th, 3rd, 2nd	8
Wind Loads	Strain Gauge	MF Connection	(Same as Seismic)	0
Snow Loads	Strain Gauge	Roof Beam	Mid-Span Beam, Roof	4
Floor Vibrations	Accelerometer	Concrete Deck	Mid-Span, 2nd	4
		Floor Beams	Mid-Span Beam, 2nd	4
Gravity Loading	Strain Gauge	Floor Beams	Mid-Span Beam, 2nd	4
		Columns	Base	4
Thermal Effects	Strain Gauge	Roof Deck	Above/Below	4
		Exterior Walls	Inside/Outside	4
			Strain Gauges:	***64***
			Accelerometers:	***17***
			Inclinometers:	***8***

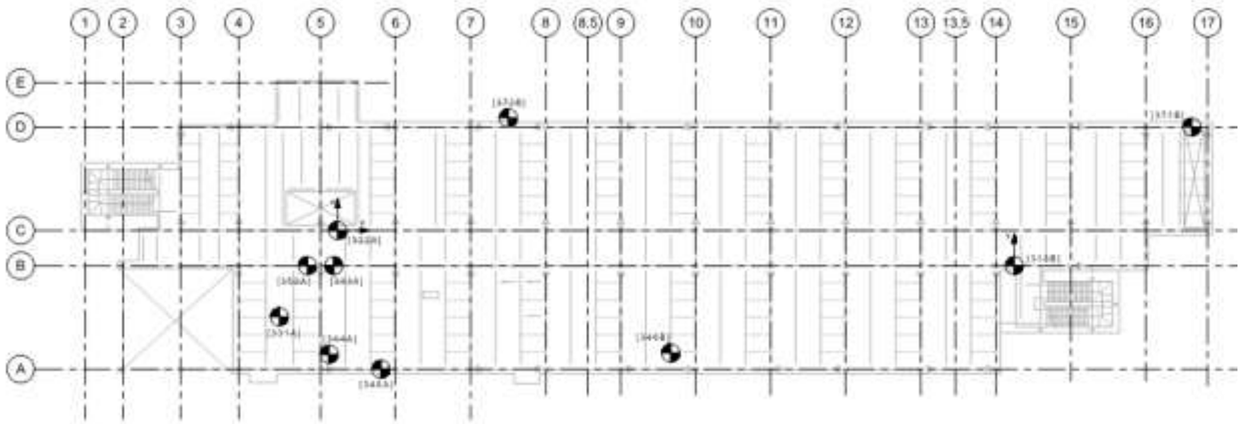

Fig. 4 - UAA EIB - Example Instrumentation Plan, Third Floor

THIRD FLOOR INSTRUMENTION SCHEDULE			
ITEM	SENSOR	QUANITY	CHANNELS
1	UNI-AXIAL STRONG-MOTION ACCELEROMETER	1	1
2	BI-AXIAL STRONG-MOTION ACCELEROMETER	1	2
3	VIBRATION ACCELEROMETER	1	1
4	STRAIN GAUGE	MF COL	1
		MF BM	3
5	INCLINOMETER	1	1
7	ANEMOMETER	2	4

SENSOR LEGEND

[1-1-1-A] : SENSOR DESIGNATION

LAST LETTER: SMS DESIGNATION ("A" OR "B")

THIRD NUMBER: ITEM COUNT TALLY

SECOND NUMBER: ITEM DESIGNATION PER INSTRUMENTATION SCHEDULES

FIRST NUMBER: FLOOR DESIGNATION

Fig. 5 - UAA EIB – Instrumentation Schedule, Third Floor (left); Sensor Legend (right))

4. Building Sensor System

The Seismic Monitoring System (SMS) is a fully-automated building monitoring system designed to evaluate the building's response to an earthquake. The SMS consists of a sensor network of accelerometers connected to a strong-motion data recorder and dedicated computer system. The SMS provides earthquake monitoring for the Main Hospital with sensors located throughout the building. The SMS uses the OASIS system manufactured by Kinemetrics, Inc., in Pasadena, California.

The basic functions of the SMS are:

1. Recording accelerations experienced by the building at sensor locations.
2. Real-time downloading of acceleration records from the strong-motion recorder during an event.
3. Immediate processing of the acceleration records on site to determine the building's earthquake responses.
4. Graphical user interface (GUI).

The results provided by the SMS should be used in conjunction with the post-earthquake inspection protocol of the REAP.

4.1. Lateral Force Resisting System Response

Strain gauges are to be mounted to select components of the UAA EIB structure's lateral force resisting system to monitor its response during an earthquake. Strain gauges are to be mounted to beam and column flanges at critical area of the moment frame connections. This will allow researchers to determine the level of elastic and inelastic demand on these structural components during the event. This information will be valuable for determining the performance of the building during the earthquake. It will also provide valuable real-world data for researchers and engineers to learn the data and advance the academic and professional design practices of structural engineering.

In addition to monitoring the moment frame connections, inclinometers are to be installed at select columns on moment frames. This will provide valuable information regarding the response of the building (i.e. how much the frame has swayed as a result of the earthquake), as well as data regarding the flexural rigidity of the connection. Researchers and engineers will use this information to validate or refute assumptions made regarding the fixity of connection (e.g. if the column-to-footing connections are a middle between fixed and pinned).

The sensor network consists of (9) biaxial horizontal accelerometers located strategically throughout the School of Engineering Building. The accelerometers are placed to maximize data on diaphragm displacements and story drifts. The SMS layout, including the sensor locations, are provided on the building instrumentation plan. Sensors are attached to the underside of the floors at each level except for the sublevel, as noted in the figures. Sensors are placed throughout the building as follows:

A system of (32) strain gauge sensors is to be installed at moment frame connections located at strategic locations throughout the School of Engineering Building. Four strain gauges are to be included at each monitored connection, two at the beam flange, and two at the column flange. See the building instrumentation plans for additional information.

A system of (16) inclinometers is to be installed at moment frame connections located at strategic locations throughout the School of Engineering Building. Two inclinometers in are to be included at each monitored connection, one at the beam web, and two at the column web. See the building instrumentation plans for additional information.

4.2 Wind Monitoring System

The building accelerations and lateral force resisting system response to wind loading are to be monitored with the same instruments used for the seismic monitoring. However, the data and observations extracted from these instruments will differ due to the nature of wind loading. For example, the moment frame connections are expected to behave elastically during a wind event, whereas they may behave inelastically for a seismic event. Therefore, because wind events are expected to occur more frequently, it is expected that the elastic data from wind monitoring may be used as part of the engineering curriculum (e.g. elastic strains may be used to determine the lateral force resisting systems' stresses, and therefore correlated to the magnitude of the wind loading).

In addition to monitoring the moment frame connections, inclinometers are to be installed at select columns on moment frames. This will provide valuable information regarding the response of the building (i.e. how much the frame has swayed as a result of the earthquake), as well as data regarding the flexural rigidity of the connection. Researchers and engineers will use this information to validate or refute assumptions made regarding the fixity of connection (e.g. if the column-to-footing connections are a middle between fixed and pinned).

4.3 Roof Snow Load Monitoring System

The roof framing system will be instrumented to monitor to roof loading due to snow loads. It is expected that this can be incorporated into the UAA School of Engineering curriculum. Strain gauges are to be installed on the tensions side (bottom) of roof beams at strategic locations throughout the roof framing. By comparing the strain for snow load and non-snow load conditions, the amount of snow loading can be estimated. Additionally, the deflection of the roof framing can be measured and correlated with the strain gauge measurements. Strain gauges are also to be installed a selected columns and used to estimate the increase in column axial stress as a result of snow loads. These structural response measurements can be compared with actual roof measurements of the snow.

A system of (8) strain gauge sensors is to be installed in the roof framing structural at strategic locations throughout the UAA EIB. Two strain gauges are to be installed to the underside roof beams at their midspan; two strain gauges are to be mounted to column webs. See the building instrumentation plans for additional information.

4.4 Gravity Load Monitoring System

The floor framing systems will be instrumented to monitor to roof loading due to gravity loads. It is expected that data obtained from this system will be incorporated into the School of Engineering curriculum. Strain gauges are to be installed on the tensions side (bottom) of floor beams at strategic locations throughout the roof framing. Additionally, the deflection of the floor framing can be measured and correlated with the strain gauge measurements. Strain gauges are also to be installed selected columns and used to estimate the column axial stresses that result of gravity loads. These structural response measurements can be compared with live loads, as groups of occupants congregate to increase the live loading of a particular area.

A system of (8) strain gauge sensors is to be installed at strategic locations throughout the School of Engineering Building. Two strain gauges are to be installed to the underside roof beams at their midspan; two strain gauges are to be mounted to column webs.

4.5 Floor Vibration Monitoring System

Floor vibrations are experienced during the life of a structure as a result of human dynamics, as well as dynamic induced by mechanical systems. However, floor vibrations are only a serviceability issue when they are perceived to be annoyances by building occupants. This is a result of vibrations that that resonate in frequencies and at amplitudes that are humanly perceptible. Additionally, some equipment (e.g. microscopes) has lower thresholds allowable vibrations. Therefore, designers typically design structures such that they are sufficiently stiff such that building meets prescribed maximum requirements for floor vibrations.

The objective of installing floor vibration monitoring instruments is to provide real measurements of the structure's dynamic response to various forms of loading. Additionally, portions of the floor structure are to be intentionally designed to differing levels of floor vibrations to illustrate fundamental concepts of the dynamic behavior of structures. Floor vibration measurements can be compared to the prescriptive vibration limitations provided by the design codes, and integrated into the School of Engineering's curriculum.

A system of (8) accelerometers is to be installed structural frame at strategic locations throughout the School of Engineering Building. Four accelerometers are to be installed at the midspan of roof beams; four accelerometers are to be installed at the midspan of floor decks. These monitors are to be installed at the second floor of the School of Engineering Building, below the commons area, as noted on the building instrumentation plans. This is expected to be an area of maximum floor vibrations due to the structural configuration and activities of the space.

4.6 Building Thermal Effects Monitoring System

Concrete and steel expand and contract when exposed to thermal heating and cooling, respectively. The amount of the thermal expansions/contraction is proportional to the magnitude of temperature change. This expansion occurs on a linear basis across the length of the thermally affected material. Therefore, thermal effects can have significant effects on large structures exposed to extreme weather conditions.

Strain gauges are to be installed at the School of Engineering Building in order to illustrate the principals of thermal expansion/contraction. This can be integrated into the engineering curriculum, and may also provide valuable data for researchers and engineers. Strain gauges are to be installed on the exterior and interior sides of the roof and exterior walls in order to measure the differential expansion and contraction.

A system of (8) strain gauge sensors is to be installed at strategic locations throughout the School of Engineering Building. Four strain gauges are to be installed at the roof, two on the exterior side, two on the interior side; four strain gauges are to be installed at the exterior walls, two on the exterior side, two on the interior side.

5. Earthquake Data Report

January 24th 2016, a M7.1 earthquake occurred near Insikin Alaska. The sensor network recorded the building responses and automatically produced a report as shown in Fig 6. The report just shows analyses with accelerometer data only.

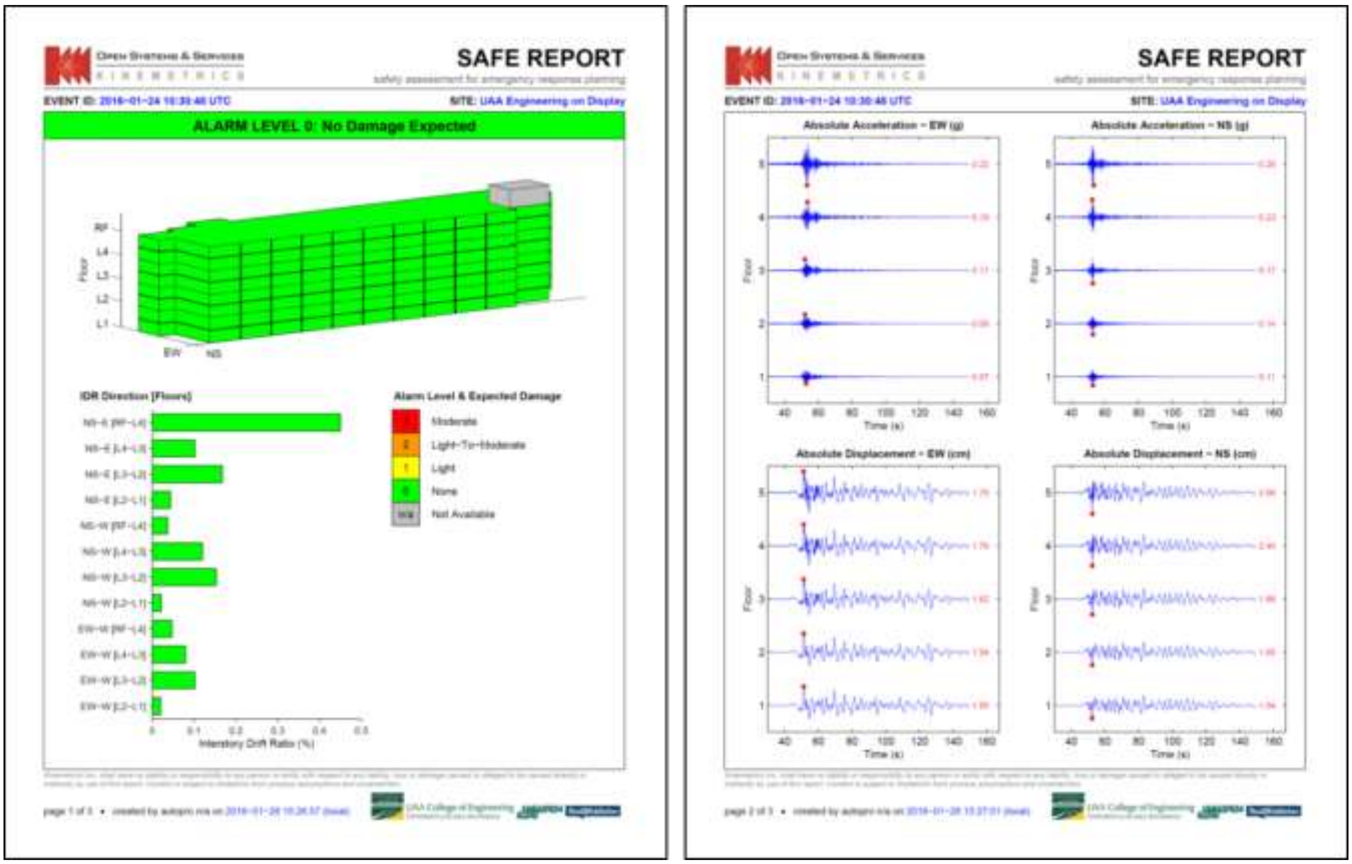

Fig. 6 – Page 1 and 2 of SAFE Report produced for 2016-01-24 M7.7 Insikin Alaska earthquake.

6. Benefits of Building Sensor System

6.1 "Engineering on Display"

The primary objective of the Engineering on Display features of the instrumentation is to turn the building itself into an educational tool for the University of Anchorage Alaska's School of Engineering. By measuring the building's response to various forms of input loading, the structure itself provides a real-world laboratory with which students can't interact, research, and tactilely experience the fundamental engineering concepts that are typically taught in textbooks and on whiteboards.

The building instrumentation was designed with a variety of sensors and types that can measure and capture various types of building behaviors. Some of the building's loading conditions and responses are irregular and unpredictable, such as earthquakes, wind and snow loading, and extreme thermal demands. Other loading conditions and responses can be planned and implemented into their academic curriculum, such as vibration characteristics, and gravity load-induced stresses/strains. Therefore, the variety and distribution of the sensors have been designed to maximum the illustration of engineering concepts and the building occupant's interaction with the instrumentation. The floor vibration sensors, for example, have been located in the main corridors and pedestrian bridge so building occupants can regularly see the dynamic response from various traffic loading conditions and be reminded of the constant engineering phenomena occurring in our day-to-day experiences.

In addition to purposeful design of the sensor types and layouts, another key feature of the Engineering of Display is the software interface and display of the data measured by the instrumentation system. Therefore, the software has been customized to allow students to visualize various forms of data and intuitively understand the engineering phenomena being measured. Features have been included to allow students and faculty to perform tests, download data, and incorporate homework interactive problems in the program curricula. The flat panel LCD monitors have been strategically located in public areas for students, faculty, and public to observe the instrumentation. Additionally, where practical, sensors have been locations to be observed by building occupants, such as strong motion sensors on the slab-on-grade, located on the ground floor corridor with a glass cover to be observed daily.

6.2 Post-Earthquake Response

In order to utilize the instrumentation system for its post-earthquake response purposes, the UAA is interested in advancing the Engineering on Display system to develop a Rapid Evaluation & Assessment Program (REAP) with a corresponding Seismic Monitoring System (SMS) for the EIB. The safety and continued operation of this building following an earthquake are essential goals to protecting UAA students and staff, and to allowing the continuity of educational services of the university. Therefore, in the event of an earthquake, UAA can utilize the measured response of the EIB to help determine if it is safe to occupy, functional, and operational.

Traditional visual-based inspections can impose high costs and inconvenience on building owners and occupants alike. For example, physical access to structural members usually requires the removal of non-structural components such as interior partitions and fireproofing. The post-earthquake detailed inspection requirements of welded steel moment frame buildings with pre-Northridge Earthquake style connections can be especially time consuming and costly to implement. Prolonging expensive downtime, limited resources such as qualified inspectors may not be immediately available after a damaging event, especially for dense urban areas. To streamline the response process and minimize conservatism, the combination of advanced structural health monitoring systems integrated with REAP tailored to the characteristics and vulnerabilities of a specific structure, empower onsite response team to more rapidly, more accurately, and more confidently make critical decisions on evacuation and re-entry. Over the past decade, this solution has been implemented in several structures throughout the world.

The Rapid Evaluation and Assessment Program (REAP) is an innovative first response tool invented by Reid Middleton structural engineers that utilizes building-specific structural analysis techniques, custom design field evaluation manuals, and a seismic monitoring system with customized software designed to provide building owners and facility managers with the ability to rapidly evaluate the post-earthquake condition of their facilities to ensure staff safety and business continuity. REAP includes inspection and structural and nonstructural evaluation information and checklist tools tailored to each building. The REAP is enhanced by the design and deployment of a real-time Seismic Monitoring System (SMS) that records and evaluates a building's forces, velocities, and displacement based on special algorithms developed through a performance-based structural analysis of each building. Corresponding performance-based earthquake engineering services are required to identify inter-story drifts corresponding to the building's seismic performance levels. It is essentially a data processing system and emergency response plan that transforms raw data into information and usable knowledge for the building owners.

6.3 Academic Research

The most common objective of instrumenting buildings with strong motion accelerometers is to provide academic researchers with data from the measured response of the building. Hundreds, if not thousands, of buildings worldwide have been instrumented with strong-motion sensors for the sole purpose of recording structural response data. Earthquake engineers and seismologists use these data to further our understanding of actual building dynamic behavior, ultimately leading to advancements in research and building code improvements. Over time, the cost-bearing public (owners and residents) indirectly benefit from this work by owning and residing in safer structures. Competition among strong-motion instrumentation manufacturers has led to advances in both performance and economy of instrumentation hardware.

After a seismic event, the data from the EIB will add to the field of instrumented building and will certainly assist in the advancement of the body of knowledge in this area of research. Because the building is to include a more expansive and diverse instrumentation system than typically installed for research purposes, there is a tremendous opportunity for researchers to use the extremely valuable the data from the building instrumentation to advance the state of structural engineering research on topics such as wind, thermal, gravity, and occupant/live loading, in addition to seismic loading. Furthermore, after a seismic event, the variety of measured data ranging from global building response (e.g. inter-story drifts and torsion) to local demands (e.g. moment frame beam and column strain measurements) will be provide researchers the opportunity to study the real-world building response in unique ways that have not been possible with traditional academic research-oriented instrumentation.

7. Conclusions

To understand the structural response of a typical building (3 to 4 stories) in the campus area, the newly constructed 81,000 square-foot four-story College of Engineering EIB at the University of Alaska - Anchorage has been instrumented with state-of–the-art structural monitoring system.

The structural and seismic monitoring instrumentation design consists of strong motion accelerometers, vibration accelerometers, strain gauges, displacement transducers, and other sensors that measure and record the building's responses to various loading conditions. The instrumentation system is designed to record and display building movements and structural system stresses from seismic, wind, snow, pedestrian, and thermal loadings in the building. These measurements are recorded and displayed in real-time and data output from these systems are displayed on flat panel LCD monitors for observation by students, teachers, and the public.

Only the strong motion accelerometers have been installed in the current phase of implementation. The remainder of the instrumentation system is expected to be implemented in a subsequent phase, pending funding availability. While the full potential value of the designed instrumentation system has yet to be harvested, this instrumentation is expected to provide value to various stakeholders in various manners. The UAA students and staff will benefit from the "Engineering on Display" aspect of the system. The UAA facility management and emergency managers will benefit from the knowledge gained from the building's measured response, post-earthquake safety guidance, and Rapid Evaluation & Assessment Program. Researchers and academic will benefit from the wealth of data measured from the building's response to wind, snow, occupant, and earthquake loads. Based on this case study of how the UAA EIB's instrumentation system is extremely valuable to a variety of stakeholders, helps advance the common good in improving the resiliency of our community infrastructure, and has economic and academic viability, it is expected that it will set a precedent that other academic intuitions and public building will follow.

8. Copyrights

9. References

References must be cited in the text in square brackets [1, 2], numbered according to the order in which they appear in the text, and listed at the end of the manuscript in a section called References, in the following format:

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