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STRUCTURAL MONITORING TECHNOLOGY FOR OPERATIONAL/BUSINESS CONTINUITY AND RESILIENCE

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Abstract

Large earthquakes are expected to cause structural damage even in modern buildings in full compliance with current design codes. While presumably safe, these and the much more frequent moderately sized earthquakes, can still negatively affect critical structures' function. For example, hospitals, by distressing staff and patients as well as supporting systems such as critical utilities, medical gases, and surrounding infrastructure (e.g. roads/bridges). Energy producing facilities, may overact shutting down plant functions or initiating evacuations which potentially costs millions of dollars in business interruption.

Today most earthquake instrumented structures focused their purpose on recording structural responses to damaging and potentially damaging earthquakes. This recorded data is then used to further understanding of actual building dynamic behavior, ultimately leading to advancements in research (e.g., damage detection) and building codes (e.g., improved empirical relations), Goel and Chopra [1]. Over time, owners, residents, and operators indirectly benefit from this work by owning, residing, operating safer structures. However, there is opportunity to benefit directly from structural monitoring technology. Advances in technology and client-based information-driven services have led to proven applications of structural monitoring in support of operational/business continuity ultimately contributing to resilience.

Although this concept of using earthquake recorded data to the benefit of building owners has been considered in the past, Celebi et.al. [2], there has only been a few implementation cases as a holistic, commercially viable solution for operational/business continuity, as a result of strategic industry partnerships (e.g., technology provider, engineering consultant, etc.), academia, and a growing knowledge and experience on the topic; mostly in the Middle East, Skolnik et.al. [3].

This paper will present commercially available technology platforms comprised of advanced sensing, performance-based engineering, centralized command console tied to mobile check-in, standard-based safety inspection tools, as well as training and certification. Implementation is illustrated with deployments at Hospitals and Energy producing facilities around the world.

Keywords: Structural Monitoring, Performance-Based Engineering, Earthquake Operational/Business Continuity, Resilience

1. Introduction

Critical and essential facilities such as hospitals, military installations, and financial institutions, cannot easily evacuate immediately after an earthquake or wait for a detailed safety assessment to reoccupy and resume operations. Post-disaster occupancy decisions are difficult, especially under such stressful conditions, and can have dire consequences if made hastily or too slowly (e.g. panic related injuries, losses due to unnecessary downtime, etc.) Examples of avoidable financial loss and injury ultimately due to uninformed decision-making are easily found across areas of low and high seismicity, Skolnik et.al. [3].

Hospitals and medical facilities, in particular, have a profound need to maintain building operational status and function in the aftermath of strong earthquakes to allow continued care for current patients and also to receive new patients injured by the disaster, Celebi et.al. [2], Wilson et.al. [4]. However, large earthquakes are expected to cause structural damage even in modern hospitals in full compliance

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with current design codes. While presumably safe, these and the much more frequent moderately sized earthquakes, can still negatively affect a hospitals' function by distressing staff and patients as well as supporting systems such as critical utilities, medical gases, and surrounding infrastructure (e.g. roads/bridges). To ensure the shelter-in-place directive during earthquakes and continue to deliver on their mission, healthcare providers must confidently make rapid decisions often with little knowledge of the actual impact on their systems and resources.

On the other hand, at energy producing facilities such as nuclear plants, when an earthquake occurs, ground motion data recorded by the seismic instrumentation is used to make a rapid assessment of the degree of severity of the seismic event (required by regulators within 4 hours). This, combined with information from a plant walkdown (within 8 hours), is used to make the initial determination of whether the plant must be shutdown, if it has not already been shut down by operational issues resulting from the seismic event itself. If on the basis of these initial evaluations it is established that the plant shutdown criteria have not been exceeded, it is presumed that the plant will not be shut down or could restart following a post-trip review, if it tripped off-line because of the earthquake.

This assumes that seismic instrumentation is operable, otherwise determination of whether the plant must shutdown is solely based on the size and proximity to the earthquake, increasing the potential for millions of dollars in losses, due to business interruption. Similar requirements are imposed to LNG facilities.

Today, most instrumented buildings and facilities with seismic and structural health monitoring systems focused the purpose of this only on the recording structural responses to damaging and potentially damaging earthquakes, like is the case in California with the State of California Strong Motion Instrumentation Program and in the United States with the USGS National Strong Motion Project. However, there is opportunity to benefit directly from structural monitoring technology and that has been demonstrated with commercially available platforms such as Kinemetrics' OasisPlus, KMIDam, KMI-LNG, and KMIBridge. These platforms take advantage of advances in technology and client-based information-driven services leading to proven implementations of structural monitoring in support of operational/business continuity, which ultimately contribute to resilience.

In this paper we present such commercially available technology platforms comprised of advanced sensing, performance-based engineering, centralized command console tied to mobile check-in, standard-based safety inspection tools, as well as training and certification. Implementation of such platforms, is illustrated with deployments at Hospitals and Energy producing facilities around the world.

2. Background

Uninformed decision-making during an earthquake increases the potential for panic, injuries, and puts hospital patients at risk.

When an earthquake hits, disaster preparedness and response professionals have to move quickly. They are expected to make dozens of real-time decisions affecting patient safety, response procedures, and the continued operation of the hospital. Where should they send their resources first? Are the patients safe? What is the status of the critical services? These decisions have to be made quickly, and often without any real information.

Is the hospital safe to occupy? How do emergency managers know? What if it didn't have to be like this? What if they had the critical information needed at their fingertips? What if they had everything needed to make informed decisions, and respond quickly?

In the case of the energy producing facilities, such as LNG plants, decisions during an emergency are too important to make without the right information. Targeting response to the correct actions can be difficult, especially when time and accuracy are critical. In these situations, real-time information on potentially damaging ground motion is crucial to initiating the proper emergency response procedures.

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At the same time, catastrophic losses could result from interrupted operations at LNG facilities during earthquakes if overreacted. Therefore, accurate assessment of structural impact, and informative alerts are critical to safe and efficient operation of these facilities during an emergency.

Decisions must be made quickly and responsibly to maintain operational continuity.

3. Solution: Oasisplus Platform

OasisPlus Earthquake Business Continuity, is a technology platform designed to provide the tools and information needed before, during, and after an earthquake to minimize impact and ensure an effective emergency response.

As a complete earthquake response platform for hospitals, OasisPlus delivers the tools and information needed to help ensure a coordinated, effective response to earthquakes to promote rapid safety assessments, help making informed decisions, and protect patient safety.

This allows for:

- Avoid Evacuations. Avoid unnecessary evacuations to protect patients and secure ongoing critical operations.
- Decision Making. Enable better-informed decision making to target emergency response to areas that need it most.
- Real-Time Monitoring. Understand the impact to the hospital building and know the condition of the patients in real time.
- Emergency Response. Leverage OasisPlus in hospital existing emergency response procedures, including Hospital Incident Command System (HICS).

OasisPlus delivers business continuity based on five key elements:

1. Advanced Sensing Technology. Implement advanced sensing technology to acquire essential data during shaking, and rapidly deliver actionable information to key decision makers, regardless of location.
2. SAFE Reports. SAFE Reports use the hospital structural monitoring instrumentation to deliver immediate information on the expected impact to everything important within the building immediately after an earthquake.
   - Structural Systems: the building itself
   - Non-structural Systems: architectural systems, mechanical, electrical, plumbing, & building contents
   - Occupants: patients, staff, and visitors
3. Command Console. Real-time information from sensors, injury & hazard reports, and occupant check-ins are presented via the console, enabling your response team to better manage the situation.
4. Mobile App. Your response team can check-in, report injuries or hazards, and receive instructions via the mobile app, simplifying communication to speed up decision-making and response.
5. Platform for Informed Decision-Making. OasisPlus delivers critical information you need to be confident in your decisions, provides situational awareness through real-time data, and promotes effective coordination of your emergency response in a manner compatible with your existing emergency response procedures.

This solution has been already implemented in various hospitals in the Western US and more recently deployed at a Children's Hospital in Seattle, Washington.

4. Case Study: Seattle Children's Hospital, Washington

In 2019, Kinemetrics, Inc. and Reid Middleton began work on the first OasisPlus implementation for a US Privately owned hospital, the Seattle Children's Hospital (SCH). The ever-expanding SCH campus,

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located in Northeast Seattle, is composed of 15 seismically independent buildings ranging in elevation and height (up to 9 stories), and totalling over 1.2M square-feet. Several major expansions followed the initial 1951 building. In terms of occupancy and use, the hospital is based on four major areas with kid-friendly names (Forest, River, Mountain, and Ocean) each divided into wings (e.g., A, B, C) with uniform floor naming across all buildings. The complexity of the campus layout, coupled with structural systems ranging in type, size and vintage, posed unique challenges for instrumentation, engineering evaluation, and information dissemination. Figure 1 below illustrates our approach and Figure 2 shows the implemented Safe Report.

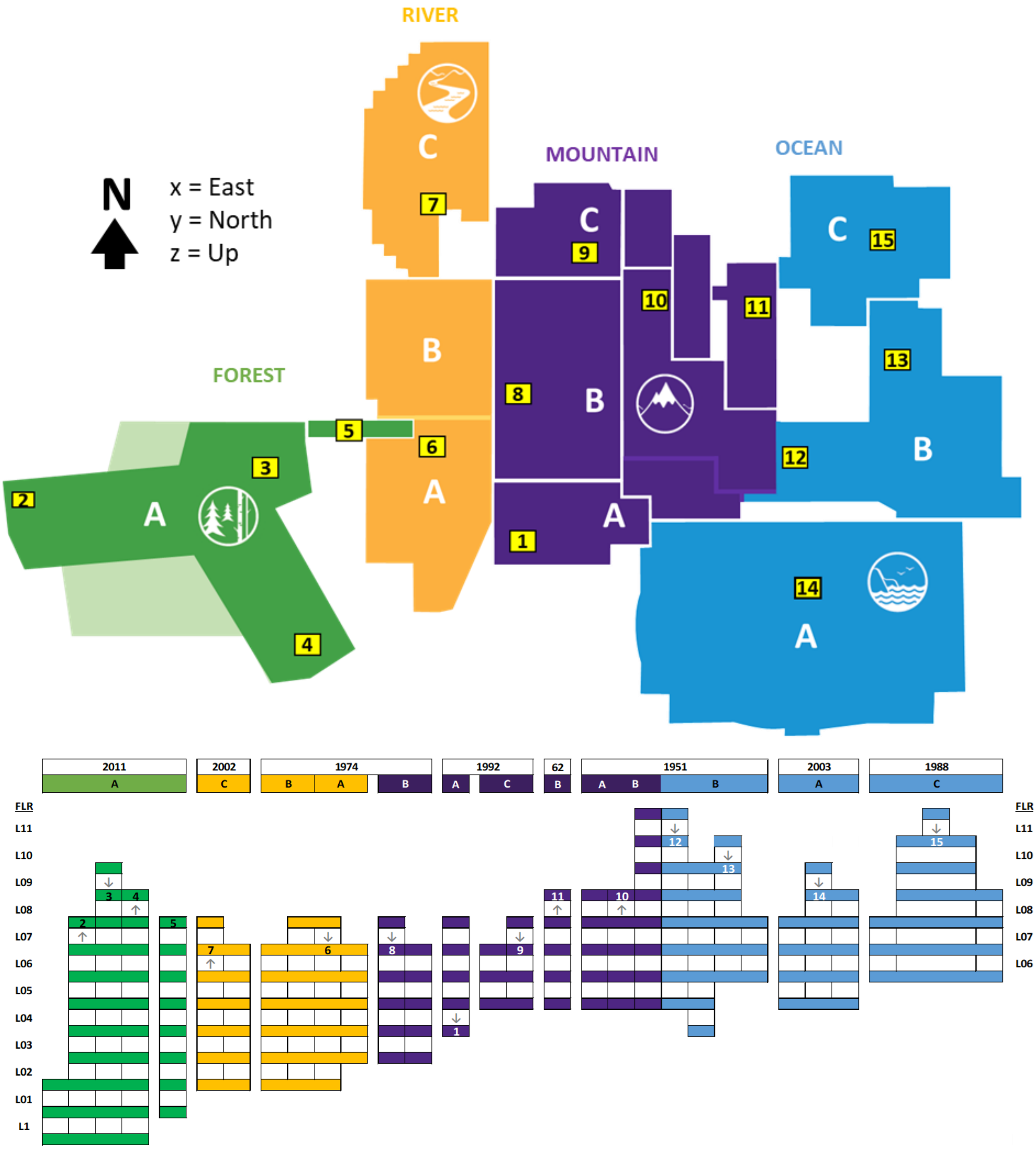

Figure 1. Seattle Children’s Hospital OasisPlus Project Approach.

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In terms of instrumentation, fifteen Etna2 Accelerographs were installed, one centrally located on the "base" and fourteen on the roof or upper levels.

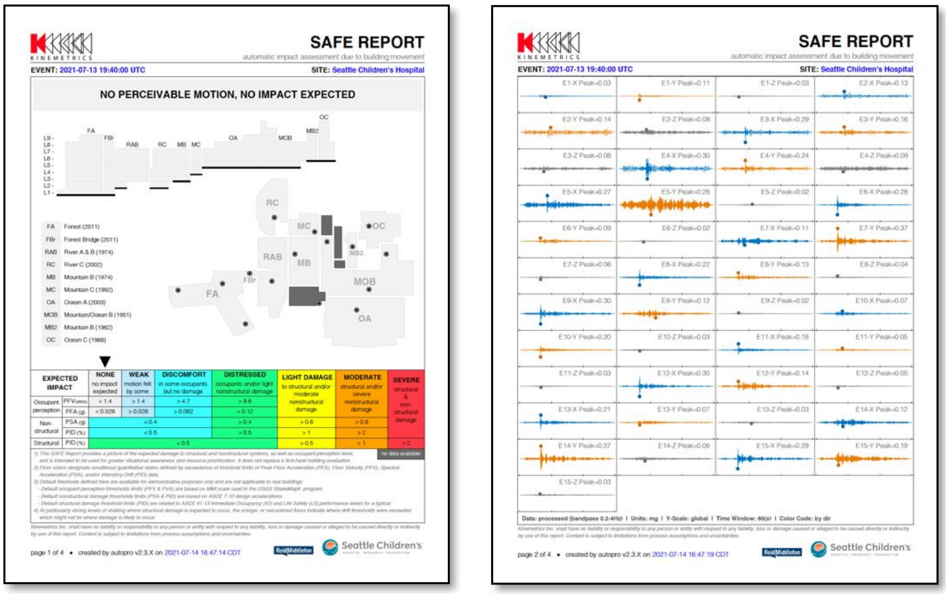

Figure 2. Seattle Children's Hospital OasisPlus' SAFE Report.

5. Solution: KMI-LNG Platform

KMI-LNG from Kinemetrics is a technology platform that enables operators to meet all their seismic-event related needs via one simple, standardized solution. Leveraging a combination of smart sensing, LNG-focused processing tools, and compliance with all industry and regulatory standards, KMI-LNG provides immediate feedback during events, to enable operators to make better decisions in driving their emergency procedures.

KMI-LNG is designed to meet the specific needs of LNG industry. It delivers seismic-event data recording, automatic retrieval, analysis and notification via hardware alarms, reports, and state-of-heath hardware monitoring with maximum effectiveness and ease of use from a single system.

Aimed at removing the guesswork from emergency response in LNG facilities, KMI-LNG quickly responds when a seismic event occurs delivering the information and tools required to enable LNG facility operators to make the most informed decisions possible.

Featuring comprehensive event-analysis and alarm-notification capabilities, this solution drastically reduces the time required for proper data analysis following a seismic event.

High reliability is ensured through redundancy of critical components, such as data storage, along with the confidence provided by the industry standard Rock+ family of recorders with phenomenal predicted MTBF values, over 1M hours.

KMI-LNG is delivered fully qualified to meet or exceed all applicable industry and regulatory standards with these key features.

- Automatic OBE/SSE & CAV analysis & alarm generation within minutes of seismic events.
- Hardware alarm notifications and easy integration with plant's DCS
- PDF file report generation.
- Easy maintenance – extensive built-in testability.

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- Complete networking supports – could use plant's local area network to remotely control and monitor the system via TCP/IP protocol.
- Designed to meet all industry standards IEEE 344, CSA ATEX and IECEx, etc.

6 Case Study: Chevron Wheatstone LNG Project, Western Australia

Owned by Chevron and designed by Bechtel, the Wheatstone LNG Project is part of Western Australia's first natural gas hub and set to become one of the largest resource projects – providing greater security of supply in the Asia-Pacific region.

To ensure safe operations the project design included provisions for earthquakes and required seismic monitoring to assess plant condition after an earthquake and to determine if Operating Basis Earthquake (OBE) limits have been exceeded to continue operations safely or initiate emergency response procedures such as inspections or plant's safe shutdown if Safe Shutdown Earthquake (SSE) limits were exceeded.

The Kinemetrics KMI-LNG's CONDOR System deployed in 2015, monitors the free-field ground motions as well as the foundation and roof responses of one of the LNG tanks due to earthquakes and determines, in real-time, whether these have or have not exceeded the plant's OBE design requirements.

The system's Alarm Panel provides visual indication of the current state of the system with LED indicators and relay contacts are interfaced with the plant's Distributed Control System (DCS) for integration with other systems and functions at the plant.

Please refer to Figure 3 for a sample of a KMI-LNG's CONDOR SAFE Report.

Figure 3. Sample KMI-LNG's CONDOR SAFE Report

7. Conclusions

Business/operational continuity comes from better-informed decision making and effective information dissemination. Commercially available technology platforms such as OasisPlus and KMI-LNG presented in this paper, are the solution to avoiding costly and potentially dangerous over-reaction by enabling better-prepared emergency response team members.

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Such technology platforms are comprised of advanced sensing, performance-based engineering, command and control capabilities, tied to a mobile app, when applicable, or to a facility Distributed Control System (DCS), in the case of the energy producing sector, as well as standard-based safety inspection tools for a comprehensive and integrated monitoring.

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