Revamping Building Structures through Design of Seismic Monitoring Network for Karachi using Tri-axial Digital Sensors

Sayed Hyder Abbas Musavi, Madad Ali Shah, Shams ul Arfeen

1PhD Scholar, Faculty of Engineering, Science and Technology, Hamdard University Karachi, Pakistan, Email: sayed.abbas@hamdard.edu.pk,
2Associate Professor, Sukkur-IBA, Email: madad@iba-suk.edu.pk,
3Assistant Professor, Faculty of Engineering, Science and Technology, Hamdard University Karachi, Pakistan, Email: shams.arfeen@hamdard.edu.pk,

Abstract: The city of Karachi is the largest city in Pakistan and the capital of the province of Sindh. Being the financial and commercial hub of Pakistan, the city of Karachi has been declared amongst the seismic hit zones of the country. The historical earthquakes detected in this region were appeared to be at locations 23.7°N 67.5° and 25.0°N 66.7°. Although the seismic activity in this city is least, nevertheless its prolong negligence is a matter of concern keeping in view the commercial importance associated to the area. In erecting the buildings of strategic importance in karachi, no care has been made so far as to comply with international building codes. Hence most of the buildings in the city are not likely to sustain seismic shaking, if it strikes. This research is regarding development of seismic resilient network for revamping existing buildings’ infrastructure of Karachi city. Through strategically installed strong motion digital sensors at various locations and floors of the buildings in the city, the real time traces are obtained. The anomalies between the traces are analyzed at various time stamps and these are correlated with the pre-defined samples of the vibrational modes of each of the sites. These differences are then used to invoke decisions in respect of strengthening the respective structures before any seismic event is occurred in future. The real time vibration information is also disseminated to data processing and recording centers and to the concerned users. The analysis of communication channels for best fit scenarios over the performance matrix of link quality, link reliability, guaranteed data transfer, error control, QoS, jitter, packet loss and throughput in relaying the data to the users and to the data processing station are performed using OPNET software and based upon the simulated results, the network is installed. The system is capable of producing results for week building structures after detecting strong motion signals through installed digital seismic sensors.

Key words: Disaster Management, Earthquake Early Warning System, WIMAX, Wi-Fi, Zigbee, Emergency Telecommunication.

INTRODUCTION

The city of Karachi, located at latitude 24° 48´ N and longitude 66° 59´ E, is the largest city in Pakistan and the capital of the province of Sindh. It is the financial and commercial hub of Pakistan. The city is located on the Arabian Sea, northwest of the mouths of the Indus River with a population of about 15 million and is one of the most populous cities in the world. In (Seismic Hazard Analysis and Zonation for Pakistan, 2007), the authors have declared the Karachi city amongst the seismic prone regions. The historical earthquakes detected in this region were appeared to be at locations 23.7°N 67.5° and 25.0°N 66.7° (Seismic Hazard Analysis and Zonation for Pakistan, 2007). Figure 1 also speaks of such fact wherein the target zone is mentioned as ‘Karachi’.

Although the seismic activity in this city is least, nevertheless it is significant keeping in view the commercial importance of the city.

For monitoring any ground shaking two types of waves, the P-Waves and the S-Waves are to be noticed; hence the attributes associated with these waves are significant to be studied. Three important attributes are
to be analysed which are responsible for strength of the shaking. These are Peak ground acceleration (PGA), peak ground velocity (PGV) and peak ground displacement (PGD). For practical scenarios, the first integral of the strong motion signal (PGA) results in PGV and the second integral results in PGD. These are then filtered with numerous iterative procedures using a High Pass Butterworth Filter with a cut-off frequency of 0.075Hz in order to remove low frequency component signals attributed to noise during the first iteration. PGA, PGV and PGD are then plotted as the peak values of the three components along the Y-axis versus X-axis which is arrival time of usually the P-Wave.

In 2005, Kanamori used a modified approach than that of Nakamura (1998) for EEW. He suggested computing a ratio ‘r’ from the following equation (Yih-Min Wu, Hiroo Kanamori, 2008):

\[
\tau = \frac{\int_0^\tau v^2(t)dt}{\int_0^\tau u^2(t)dt}
\]  \hspace{1cm} (1)

Here the numerator and the denominator are the ground motion velocity and displacement power quantities respectively and the integration is taken over the time interval \((0, \tau_0)\) after the arrival of P wave. Using Parseval’s relation, the following relation has been obtained (Yih-Min Wu, Hiroo Kanamori, 2008)

\[
\tau = \frac{1}{\sqrt{\langle f^2 \rangle}} = \frac{2\pi}{\sqrt{\rho}}
\]  \hspace{1cm} (2)
The parameter in equation 2 can be used as the indication of the average period of the initial portion of the P wave which corresponds to the P wave pulse width getting increased with the shaking magnitude and is used to calculate the event magnitude.

2. Karachi Seismic Monitoring Network:

The Karachi Seismic Monitoring Network (KSMON) infrastructure is consisted of 35 onsite stations and one data processing station which are electronically connected with country’s other alerting systems to provide beforehand warning information to the population and first responders in case of any severe impending natural disaster. The network is being deployed along the potential sites of seismic threats which detect the individual events, calculates location and size and traces of shaking are transmitted to the remote monitoring station using communication channels both wired and wireless. These sites of seismic threats are high rise buildings, critical installations and places of densely populated regions. The KSMON is composed of MEMS accelerometers, velocity and displacement sensors connected through DSL, Wireless and point to point radio wave communication systems with following two main sections:

1. KSMON Onsite Stations (KOS)
2. KSMON Data Processing Stations (KDPS)

The KSMON onsite stations (KOS) are equipped with Guralp Systems’ instrumentation. Managed with solar panels possessing 7 days fully operational autonomy, each of the KOS fixed on the earth or wall is calibrated with GSM/GPRS alarm systems connected with remote data processing and monitoring stations and also to the environmental and industrial sensors for emergency shut off through intelligent data loggers.

Each instrument (Strong Motion / Low Motion / Medium Motion) is linked to Guralp Systems’ serial server /UPS module responsible for providing uninterrupted power and TCP/IP connectivity for data streams. Through many Ethernet switches, all these are connected to a common local network. In each building, data from the Guralp Systems’ devices is communicated to a server computer over which Scream software is running. This server and software is responsible for data collection and distribution to the other installations. Furthermore, an ADSL modem is used for internet access for the equipments and forwards requests for GCF data to the Scream server. Scream can also convert incoming streams to various commonly-used formats including UFF (both ASCII and binary variants). A GPS system is connected to the digitizer whereas the data is also relayed through VSAT module.

The CMG DM-24 as shown in Figure 2 has the advanced features such as 3 or 6 low noise 24-bit ADCs, additional full-rate data channel for user signals and calibration, Low power 32-bit DSP and ARM processor (<1 W recording 4 channels at 100 samples/s), multiple concurrent data rates up to 1000 samples/s, STA/LTA ratio, level, external and software triggering, UTC time stamped data from attached GPS receiver, 8 environmental channels with 20-bit resolution (3 × mass position, temperature, 4 × user), Calibration using step, sinusoid or pseudo-random broadband noise signals, 64 Mb Flash memory with fast FireWire data transfer, fully configurable using Guralp data modules and software. The DSP software on the DM24 supports up to 7 cascaded filter/decimation stages. At each stage, the sample rate can be divided by a factor of 2, 4 or 5. The internal ADC outputs data at 2000 samples per second, so decimated data streams are available from 1,000, 500 and 400 samples/sec down to 1 sample/sec (Website Guralp Systems, 2010). On the CDPS side, Earthworm which is the real time seismic dispensation system is in place to track the waveforms of 1 second packets emerging from KOS.

DSS (Data Subscription Service) is a packet format, widely used in strong-motion projects, which enables data and statistics to be requested from a seismic installation. A DSS server is designed to handle many concurrent requests from clients with varying levels of privilege, and may prioritize requests according to their origin and urgency (Website Guralp Systems, 2010).

Guralp Systems (2010) DCM data modules include a module which can communicate with installations using DSS as either a server or a client. A simple DSS server is also available which receives requests on a network port and replies to them. Each DCM in this network runs a DSS server providing data on:
- peak acceleration levels
- RMS (root mean square) average acceleration levels
- spectral intensity
- magnitude of horizontal acceleration (combined N/S and E/W components)
These statistics are relayed to a central data centre once every second, where they can be used to trigger automatic warning systems. When the statistics indicate that an event has occurred, or there is a problem with the structure, DSS allows station operators to request the raw seismic data and determine the best course of action (Website Guralp Systems, 2010).

It is necessary that information about the health of the components of the whole system is guaranteed. Guralp digitizers provide a range of slow-rate auxiliary channels for reporting the system's state of health and other diagnostic information, known as multiplexed ("MUX") channels (Website Guralp Systems, 2010; Website Guralp Systems, 2010). The number of MUX channels depends on the model and configuration of digitizer. Generally, three channels are used to report the sensor mass position, and another measures the internal temperature of the digitizer. In addition to these, up to 12 MUX channels are given (Website Guralp Systems, 2010). Some digitizers have a separate AUXILIARY port which can be used to access these channels (Website Guralp Systems, 2010).

3. Communication Set-up:

The communications infrastructure for the KSMON is being designed as to characterize the system to meet both the wired and wireless characteristics. Different options are being demonstrated for the KOS connected with KDPS.

We have analyzed the communication options for wireless-cum-wired solution wherein KOS is connected with KDPS either through WiMAX (Wireless Interoperability for Microwave Access) IEEE 802.16e/m Protocol, or Wi-Fi, or Zigbee or XBee or through point to point radio wave communication technologies or via satellite communication channels or all for ensuring link redundancy so as to establish reliable, fast, robust and secure communication.

Dissemination of Seismic Activity Messages:

The seismic activity messages after the occurrence of the event are being transmitted from data processing station to the people at risk, first responders, hospitals, installations at risk, media and so on automatically. For KOSMON System, we have developed Splendid SMS Delivery software over Microsoft®.NET Framework Version 2.0 or above running in Windows 98/2000/XP/2003/Vista environment. The screen shots of the
The alert messages are delivered within shortest possible time so as to save the lives and property of the people and to give rescue call to the first responders.

4. Analysis of KSMON Using OPNET:

The KSMON network’s simulated environment is shown in Figure 4. Each of the indicated subnets represent the KOS which is connected to the KDPS though WIMAX communication technology. Figure 5 is the status of progress of simulation phase of simulated WIMAX model of the KSMON designed in OPNET R&D Modeler Version 14.5, whereas some of the simulated results are given in Figure 6. The communication channels are analyzed over the performance matrix of link quality, link reliability, guaranteed data transfer, error control, QoS, jitter, packet loss and throughput in relaying the data. The best fit results are obtained before fixing up the KOS at the respective sites. The system components and devices were also calibrated using MATLAB and LABVIEW tools before its installation at the sites.

5. Discussion of Results and Conclusion:

The city of Karachi being commercially important for the Pakistan’s economic survival is constantly under threat of probable seismic attack. No care has been made in respect of building codes in erecting the strategically important buildings in this city which is a cause of concern to the public and property at risk from the seismic threats. This research is for initially detecting those buildings which are at risk from such threats. For achieving the desired objectives, 35 sites were selected to detect potential of the seismic threat. The number of sites can be increased for future experiments. The Guralp Systems’ instruments have been deployed at the sites designated as KOS and KDPS. Through strategically installed strong motion digital sensors at various locations and floors of the buildings in the city, the real time traces are obtained. The anomalies between the traces are analyzed at various time stamps and these are correlated with the pre-defined samples.
of the vibrational modes of each of the sites. These differences are then used to invoke decisions in respect of strengthening the respective structures before any seismic event is occurred in future. The real time vibration information is also disseminated to data processing and recording centers and to the concerned users. The analysis of communication channels for best fit scenarios over the performance matrix of link quality, link reliability, guaranteed data transfer, error control, QoS, jitter, packet loss and throughput in relaying the data to the users and to the data processing station are performed using OPNET software and based upon the simulated results, the network is installed. The system is capable of producing results for weak building structures after detecting strong motion signals through installed digital seismic sensors.

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