Civil Engineering Society
Department of Civil Engineering
University of Peradeniya

CES Annual Seminar 2017
Civil Engineering for Urban Resilience

Proceedings
CES Annual Seminar 2017

Civil Engineering for Urban Resilience

26th August 2017
E.O.E. Pereira Theatre
Faculty of Enigngeering
University of Peradeniya.

Agenda

8.00 a.m.	Registration
8.30 a.m.	Lighting of oil lamp
8.35 a.m.	Welcome speech by Secretary of Civil Engineering Society
8.40 a.m.	Address by Head, Department of Civil Engineering
8.50 a.m.	Address by Dean, Faculty of Engineering
9.00 a.m.	Sponsor's message and Address by Executive Director LANWA (Ceylon Steel Corporation Limited)
9.20 a.m.- 10.00 a.m.	Talk on Urban Water Management in Metro Colombo by Dr. Srikantha Herath, Team Leader, Centre for Flood Control and Water Management, Metro Colombo Urban Development Project.
10.00 a.m.-10.30 a.m.	Refreshments
10.30 a.m.-11.15 a.m.	Talk on Sustainable Transport Plan for Kandy by Prof. Amal Kumarage, Department of Transport and Logistics Management, University of Moratuwa.
11.15 a.m.-12.00 a.m.	Talk on Seismic Hazards How safe is Colombo and its Suburbs? by Prof. Nimal Senevirathne, Senior Professor, Department of Civil Engineering, University of Peradeniya.
12.00 a.m.-12.30 p.m.	Panel Discussion
12.30 p.m.- 2.00 p.m.	Lunch Break
2.00 p.m.- 2.45 p.m.	Talk on Impacts from climate change on water safety and scarcity for water centered sustainable cities by Dr. S.K. Weragoda, Chief Engineer, National Water Supply and Drainage Board.
2.45 p.m.- 3.30 p.m.	Talk on Landslide Disaster and Resilient Construction in Kegalle District, Sri Lanka by Eng. H.M.L. Indrathilake, District Officer, National Building Research Organization, Kegalle.
3.30 p.m.- 3.50 p.m.	Panel Discussion
3.50 p.m.	Vote of thanks by CES Vice-president
4.00 p.m.	Refreshments

Table of Contents

About Civil Engineering Society

Among the many societies which are acting lively throughout the Peradeniya University, the Civil Engineering Society (CES) holds a major position. The CES is a prominent society in the Engineering Faculty of the University of Peradeniya which provides a common platform through various activities for the Civil Engineering students, staff, and the industry to interact, and thereby, enrich their academic and professional skills. Being one of the longest-service organizations within the university system in Sri Lanka, the CES has survived and thrived through over 40 years of its history.

The history of the CES goes all the way back to the year 1973. At that time the university was named as The University of Ceylon. The CES was under the auspices of Prof H.B De Silva, and the Dean of the faculty at that time Prof A.Thurairajah.

The inaugural President of the society was Dr. K. Shanmuganthan. The first event organized was a talk by Mr D.G.L Ranathunge of irrigation department, which was held on February 15, 1973 and the talk was on hydrology. The annual seminar of the CES was also initiated in the year 1973.

In the year 1974, Prof A. Thurairajah was appointed as the president of the CES. He held the position for two years. During that time he did a great service towards the development of the society. Over the years there were not many changes in the structure of the society, apart from the addition of one editor in 1979 and several standing sub-committees.

Much emphasis was given to the Mahawali project during the latter part of the 70s and early 80s in most of the activities of the CES including the Annual Seminar. But due to the political turmoil in the country during the late 80s, the activities and the progress of the Civil Engineering Society were retarded. And in early 90s, with the better change in the field of civil engineering industry, the CES emerged with a renewed spirit. The CES adopted new strategies giving much concern to new frontiers, such as Environmental engineering and Transportation engineering.

Vision

The Civil Engineering society will be a significant contributor to Faculty of Engineering in achieving its vision of becoming the centre of excellence in engineering education and research in South Asia.

Mission

The mission of the Civil Engineering Society is to provide a common platform, through various activities, for the civil engineering students, the staff and the industry to interact and thereby,enrich their academic and professional lives.

Some CES Activities

- CES talk series is organized twice a month under the patronage of resource per son from industry, higher education institutes and abroad to share their experi ences.
- CES newsletter disseminated the details organized by the CES and novel engi neering knowledge among the engineering undergraduates.
- CES annual seminar links, indus try and the faculty.
- CES workshops provide an exposure to students to mix with the industry.
- Civil Engineering field trips provide budding engineers the way theory is in practice.
- Civil Engineering project symposium is a stage for final year engineering stuents to exhibit their research potentials.
- Spaghetti bridge competition paves a path for students to apply the theoretical knowledge in to practical application.
- CES quiz competition assesses practical knowledge in Civil Engineering applica tions.
- CES visual production competition helps to understand the linkage of theoreti cal and practical applications within the industry.
- CES concrete mix design competition exposures the undergraduate to the prac tical applications on concrete mix designs.
- CES lab cleaning day makes the faculty clean.
- Job fair brings the job opportunities to the doorstep of the faculty, for fresh engineers yet to graduate.
- Vortex is the annual get together of the CES and it is the concluding event of an official year.

Themes of CES Annual Seminars in recent years

2016 Applications of Computational Methods in Civil Enginnering
2015 High-rise Buildings
2014 Highway planning and Design, Construction and Maintenance
2013 The Challenges of Urban Development, Sri. Lankan Perspectives
2012 Transport Sector Challenges and Role of Expressways
2011 Urban Environmental Challenges
2009 Design, Construction and Maintenance of Bridges
2006 Small-scale Hydropower Development in Sri Lanka
2005 Alternative Materials for Constructions

CES Executive Committee Members
Academic year 2017

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CES Annual Seminar 2017
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Urban Water Management in Metro Colombo

Center for Urban Water - CUrW

By

Dr. Srikantha Herath
Team Leader,
Centre for Flood Control and Water Management,
Metro Colombo Urban Development Project.

Urban Water Management in Metro Colombo Center for Urban Water - CUrW

Dr. Srikantha Herath
Team Leader,
Centre for Flood Control and Water Management,
Metro Colombo Urban Development Project.

1. Background

Flooding in Colombo metropolitan area has for many years been hampering public life and obstructing traffic and commercial activities on a regular basis. The flooding is due three major causes: (a) lack of outfall capacity (b) lack of storage capacity, and (c) bottlenecks in the river and canal system (bridges, culverts, narrow river bends, blocking bridge piers/abutments, pipeline crossings, etc.).

In 2012 the World Bank and the Government of Sri Lanka (GoSL) agreed upon a loan for a Metro Colombo Urban Development Project (MCUDP). The overall Project Development Objective of the Loan is to support the GoSL in:

1. reducing flooding in the catchment of the Colombo Water Basin
2. strengthening the capacity of local authorities in the Colombo Metro politan area to rehabilitate, improve and maintain local infrastructure and services through selected demonstration investments.

The flood control projects are divided in to two groups; one primarily aiming at the macrodrainage system, including the greater Colombo catchment/basin, and one aiming at the microdrainage system, which primarily covers the metropolitan area. Measures include new diversions (canals or tunnels), widening of river/canal stretches, river-bend widening, smoothening or bend cut-offs, enlarging existing outfalls, construction of new gate structures, upgrading street drains, enlarging culverts, etc.

In addition, apart from structural measures a number of non-structural measures are being considered to strengthen the flood management capacity, of which the most important component is a Real-Time Control (RTC) System, and/or a Flood Early Warning System (FEWS). In a related development, in 2015, the Government of Sri Lanka announced an ambitious plan to develop the Western Province to a large Megalopolis, and a new ministry, the Ministry of Megapolis and Western

Development (MMWD), was established to implement the programme. Sri Lanka Land Reclamation and Development corporation that implement the Metro Colombo Development Project also comes under MMWD. For the Ministry of Megapolis and Western Development assessing short term and long-term flood risks is important to safeguard its investment and ensure sustainable urban development. Thus it was decided to enhance the scope of the proposed RTC to incorporate also current and future risk assessment. A new facility to handle Flood Control and Water Management is currently being setup that will

1. Develop an integrated flood control and water management informa tion system

2. Provide early warning support for the Metro colombo area

3. Develop optimal operational rules for the flood control facilities such as pumps and storage facilities considering also the potential storage and use water to make a pleasant urban environment.

4. Assess current and evolving future risk to Megapolis from urban devel opment as well as climate change.

2. Colombo Drainage System

Although Colombo City basin is part of the Kelani River Basin, it is protected from river overflow from a series of bunds and gates. Thus the catchment for consideration in the RTC design is limited to the Metro Colombo Drainage Basin shown in Figure(1). City flooding occur due to high intensity rainfall within the catchment that cannot be drained adequately. There are two major challenges in reducing risk in Colombo.

1. The City drainage depends on outfalls to Kelani River as well to the sea as shown in Figure (2). The Kelani river outfalls cannot function when the Kelani river flows are high. Of the 8 major extreme rainfall events during the past 32 years, 4 have coincided with high Kelani River water levels.

2. The terrain is extremely flat and flooding occurs locally before drainage even after pumps become effective. Thus, high density rainfall measure ments as well as rainfall forecasting is extremely important to prepare for extreme events. Radar raingauges would be ideal for such applica tions but are not available at present.

Considering the above following strategy is adopted for the RTC.

- Assess areal distribution of rainfall using a dense raingauge network in the basin. Use numerical weather forecast to anticipate rainfall in the Ke lani basin 1-2 days in advance. Verify models and forecasts using satellite based rainfall estimates.

- Forecast Kelani River water levels using a hydrological model for the mountainous region and a hydrodynamic model for the region down stream of Hanwella • Carry out extensive risk assessment case studies to improve preparedness for anticipated rain events.

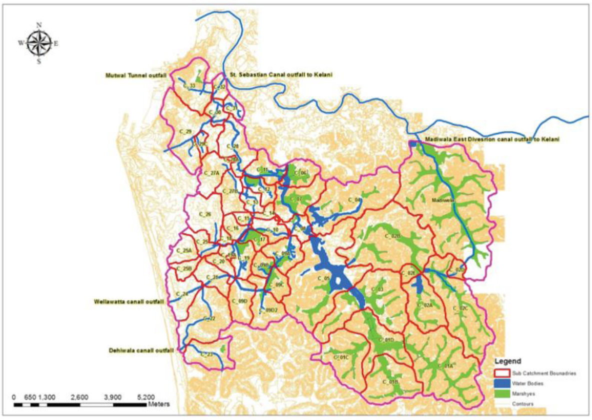

Fig. 1. Metro Colombo Drainage Basin

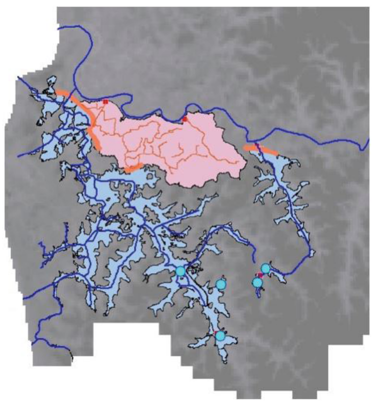

Fig. 2. Colombo drainage system

3. Sustainability

Sustainability of the System is a major consideration that is being addressed in the development stage. A sustained capacity development programme with the collaboration of educational and research institutions in the country, support for continuous R & D, fostering collaboration among of academia and the line agency professionals are some of the key concerns addressed together with the development of the RTC. Maintenance of the System in the future require diversification of its activities beyond disaster management. Integrating urban water management with flood control, Catering to Megapolis development needs; Risk Assessment, Cost benefit analysis are some of the areas the centre the center is currently engaged with.

4 System Implementation

The major components of the center is shown in Figure (4). Component A is the physical infrastructure shown in Figure (3). Component D is the real time rainfall and water level monitoring that are collected at the center (component A) through fibre-optics as well as GSM/GPRS transmissions. These data are assimilated in to computational systems engaged with (a) Rainfall Forecasting, (b) Hydrologic and Hydro-dynamic models and (c) Risk assessment and Operational procedures development unit. The servers for the computations are all cloud based and monitoring devices are IoT enabled that makes it possible to seamlessly carryout data integration, forecasting and dissemination tasks using internet protocols. Figure (5) shows the procedure adopted in rainfall forecasting using wrf model. At first incoming weather type is forecasted and a cluster of wrf models optimised for incoming weather type are run. The most appropriate model is selected based on closeness to satellite radar rainfall map produced by Japan aerospace agency (GSMAP) which is available at real time at 10 km resolution. The workflow of rainfall forecasting and data integration, feeding to hydrological and hydrodynamic models is shown in Figure (6). Currently the operational workflow can be completed in one hour and is automated. The hydrodynamic model used for this operational forecasting system has a spatial resolution of 250 m . A nested hydrodynamic model of 30 m resolution is currently being set up to run once the operational model trigger an extreme event.

Fig. 3. New Center Building under construction

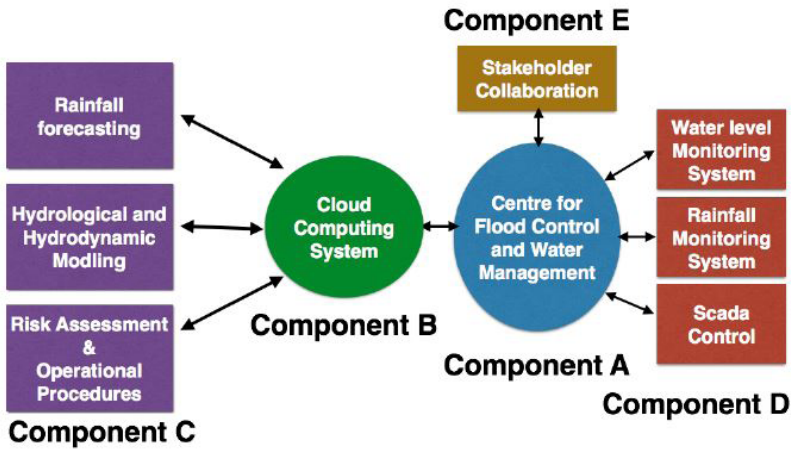

Fig. 4. Main Components of the system

Fig. 5. Weather forecast scheme

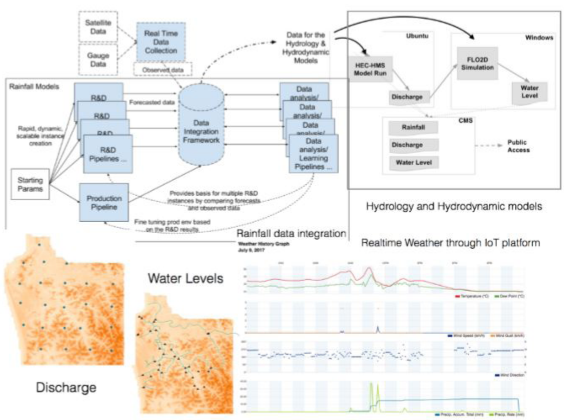

Fig. 6. Data integration and simulation workflow

5 .Services

The center currently provide computational and design support for urban stormwater management facility implementation including onsite retention and infiltration systems. It will also provide environmental services for wetland management and landuse planning activities under the Ministry of Megapolis and Western Development. A detailed exposure database has been compiled to rapidly evaluate potential flood damage to promote appropriate flood risk reduction investment. This database is currently being expanded to include commercial exposure to facilitate loss estimations as well. The most important development currently being undertaken is the integration of real-time dynamic data such as transportation to weather forecasts to improve qualify of urban life.

CES Annual Seminar 2017

Civil Engineering for Urban Resilience

Sustainable Transport Plan for Kandy

By

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Sustainable Transport Plan for Kandy

Amal S. Kumarage[a] and Gunatileke Bandara[b]

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1. Introduction

Kandy is located in a mountainous terrain 116 km away from Colombo in the Central Province of Sri Lanka. It is recognized as the second-busiest city of the country with a population density of around 2,500 persons per sq.km. A sacred site for the global Buddhist community due to the situation of the Temple of Tooth, Kandy was declared a world heritage site by UNESCO in 1988. The Kandy Municipal Area (KMA) is about 12 sq. km and bounded by the Mahaweli River on three sides and by mountains to the South. The core area of KMA, its Central Business District (CBD), is around 3 sq.km, and serves as a regional centre for culture, commerce, tourism, administration and transport. This area attracts a large number of vehicles and passengers daily, resulting in average speeds of between 4 kmph to 15 kmph on busier roads. Such low speeds in the transportation network leads to lower economic productivity in the city, and to negative social and environmental externalities.

2. Background

There are a number of on-going transport sector developments in and around Kandy. In Sri Lanka the general tendency is that such projects when implemented by different agencies with financing from different sources and even for the same city, end up being totally uncoordinated and often fail to deliver the expected benefits to society. This paper traces the development of a Sustainable Transport Plan for Kandy and its current status of implementation under different project proponents.

The origins of the current plan date to the Kandy City Transport Study [University of Moratuwa/ University of Peradeniya, 2011] a study carried out for the Road Development Authority based on solving the increasing traffic problem in Kandy.

This study was presented to the World Bank by the Road Development Authority at the outset of the Strategic Cities Development Project (SCDP) in 2013 which led to the Kandy Transport Improvement Study (Kumarage, 2013) for the then Ministry of Defense and Urban Development. Based on this and other studies for urban upgrading, the World Bank agreed to provide funding of around USD 100 million for Kandy City with the bulk of this intended for transport improvement. The SCDP project which is currently in its 3rd year of implementation has initiated a number of actions in pursuit of these recommendations. The largest of which is the proposed Kandy Multimodal Transport Terminal (KMTT) which is estimated to cost around USD 40 million. The total transport sector investment which will be around USD 100 million includes road rehabilitation programs, junction improvement and traffic management programs, planning and design of parking facilities, public transport modernization as well. In 2015, the Road Development Authority also started investigating a tunnel trace as an eastern by-pass to the city another components of the study, while the Central Province Passenger Transport Service Authority (CPPTSA) initiated the Sahasara bus reforms project in August 2016. The Sri Lanka Railways has also initiated the double tracking of the railway line around Kandy and is studying the potential for electrification and modernization.

3. Kandy City Transport Study (2011)

Data

Field surveys were conducted to identify transport-related issues, their severities and limitations in proposing recommendations. These field surveys enabled to establish travel demand and its characteristics for all types of transport including private vehicles, public buses, para-transits, goods transport, railway and pedestrians. In addition, several surveys were conducted to assess the physical capacity of transport infrastructure. The findings of these surveys were further strengthened and updated with the result of another set of surveys conducted in 2013 for Kandy Transport Improvement Program. Further studies were done under the SCDP in 2015.

Data Analysis

Traffic counts conducted at each of the entry points to the KMA and CBD areas indicate that there are a total of 318,000 passengers entering the KMA in 56,000 vehicles on a daily basis. Private vehicles made up 79% of the vehicle flow but carried only 32% of the passengers. On the other hand, route buses made up 9% of Average Daily Traffic (ADT), but carried 64% of passengers across the KMA cordon. This was equivalent to 5,100 buses and 214,000 passenger trips arriving at the 3 bus terminals located within the CBD. In addition to roadway traffic, rail also carried about 3,000 passengers to the city every day: just 1% of the total number arriving. Apart from the passengers coming from the outside, residents within the city made around 200,000 intra city trips. While overall traffic speeds within the KMA were observed at 17 to 26 kmph, the speeds on busier roads with heavy bus flows were below this average, recording between 4 and 15 kmph. Origin –Destination surveys conducted for private vehicles and freight vehicles revealed that about 16.3% of private vehicles, (i.e. about 28,000 vehicles) and 37.6% of goods vehicles, (i.e. about 5,000) engage in thoroughfare and have no business inside the KMA. Similarly interviews conducted with bus passengers at these terminals indicate that 95% of their trips are home-based. Around 32% of them arrive to the CBD for work, 21% for schooling and the balance for shopping, business and recreational purposes. Further nearly 40% of bus passengers arrive for bus to bus transfers at Kandy terminals. The surveys also identified that 97% of 5,000 buses that arrive daily also terminate within the CBD. The three bus terminals located within the CBD handle around 300,000 passengers daily turning the entire city in to a bus terminal with buses and pedestrians causing severe impacts on traffic flow.

Identified Issues: The findings of data analysis and stakeholder consultations concluded that the main root causes for inefficient transport system in Kandy consist of limited road infrastructure, conflicting land use, poor orientation of bus routing, terminal and stops, inadequate by-pass roads for KMA and CBD, inappropriate traffic circulation and parking demand management measures, underutilization of the railway network, and lack of management of para-transit modes such as school vans and three wheelers. Inefficiency of transport system has also led to increase in social and environmental issues such as quality of air, water and noise pollution.

Conclusions and Recommendations

It study concluded that Kandy City should be a traffic restrained area given its cultural context as a Heritage City, its population density, as well as its geographical and environmental setting. In seeking a sustainable traffic management solution, these two studies have identified several strategic interventions. Among those interventions, reallocating land-use inside the city and setting up three satellite cities at Peradeniya/Gatambe, Katugastota and Tennekumbura were key long-term recommendations to eliminate unnecessary vehicle movements inside the city. Furthermore, improving the capacity of by-pass roads, especially providing East-West by-pass tunnel, is proposed as a long term solution to take away significant portion of current through traffic. Re-routing bus services, integration of bus terminals and railway station, introduction of new railway commuter services are recommended as medium-term interventions to facilitate through-trips while reducing pedestrian movements in the city core. Capacity improvement of main city entry corridors and intersections, regulation of school transport services, promoting off-street parking while regulating on-street parking through a pricing policy and improving pedestrian facilities are identified as short-term solutions to increase network speed .

4. Strategic Cities Development Project (2014-todate)

The Strategic Cities Development Project was initiated in 2014. This project implemented by the Ministry of Megapolis & Western Development further developed transport strategies for the Kandy under two specific headings namely, for traffic management and for public transport improvement. An international consultant, DIMTS together with UNI Consultants was engaged for this purpose. This strategic plan was based on the objectives of (a) retaining public transport share at 60% and (b) ensuring congestion free traffic management as well as to (c) improve walkability within the city and (d) improve the quality of the urban environment. The project has now completed the conceptual designs for (a) Kandy Multi Modal Transport Terminal, (b) on-street satellite terminals for Katugastota and Getambe, (c) bus route –re-planning, (d) Junction improvement for 21 intersections, (e) Grid City Road re-design with improved pedestrian facilities and bus priority lane, (f) walking paths especially for visitors to enjoy the city, (g) Parking facility at Nuwerawela, (h) Parking facility at Bogambara, (i) improvement of by- pass roads, (j) a terminal operating system for the KMTT and (k) new by-pass road for Katugastota which will open access for development as a Satellite city and location of new bus terminal.

5. Sahasara Bus Reforms

The Sahasara Bus Reforms was conducted on the Digana and Kadugannawa corridors starting August 2016 including 48 routes and 350 private buses by the CPPT-SA. This project was aimed at improving the operations of buses through (a) pooling of revenues, (b) use of technology for real time bus operations, (c) use of smart card technology for ticket payment, (d) improving quality of bus operations and (e) improving regulatory processes. The Sahasara method is awaiting approval of the Cabinet of Minister as a national program and in the interim will be implemented under the SCDP project for the changes required for the route re-planning and management required for the relocation of bus terminals from the Good Shed bus terminal for construction due to start in mid-2018.

6.Conclusion

The transport plan for Kandy which is currently being implemented by different agencies is aimed at achieving a sustainable solution for mobility in Kandy which will include, a higher access of quality public transport, reduced on-street parking and improved quality of urban infrastructure including walking facilities and improved traffic circulation, improving on-street parking and modernization of bus transport. This coupled with the initiatives to widen the main road arteries together with double tracking and electrification of the railways, rehabilitation of the by-pass roads, eastern by pass tunnel will ensure the long-term sustainability of mobility in Kandy.

More importantly from a professional perspective, the Table 1 shows the initial 20 proposals made by the Kandy Transport Study (University of Moratuwa, 2010) and their current status. This shows that a well formulated plan carefully nurtured up to implementation can be implemented even by different agencies through a well-coordinated program.

Table 1: Initial 20 proposals made by the Kandy Transport Study and present state

Proposal	Status
1. Creation of Basic Infrastructure for Satellite City at Peradeniya	Planning being done by UDA
2. Creation of Basic Infrastructure for Satellite City at Katugastota	New by-pass to open new land being designed by RDA
3. Creation of Basic Infrastructure for Satellite City at Digana	Not initiated yet
4. Double Tracked Suburban Rail between Peradeniya and Katugastota	Peradeniya to Kandy in progress
5. Railway Extension to Digana	Not initiated yet
6. Park and Ride Service	Not initiated yet
7. Tunnel from Thennekumbura to William Gopallawa Mw	RDA has initiated
8. Extension of Tunnel to Hedeniya to meet the Expressway	Expressway approach changed
9. Improvement of Guhagoda Road by-pass	To be implemented by RDA
10. Improvement of Dharmasoka Mawatha by-pass	Implemented under SCDP
11. Improvement of Dutugemunu Mawatha By-pass	Improved
12. Improvement of Kuda Ratwatte By-pass	Improved
13. Improvement of Pichchamal Mawatha by-pass	Being Designed by RDA
14. New by-pass from Thennekumbura to Katugastota	Digana to Katugastota rehabilitated
15. Integrated Transport Terminal at Good shed	Initiated under SCDP
16. Re-routing local bus routes through the city	Initiated under SCDP/Sahasara
17. Improvements to Junctions and Traffic Circulation System	Initiated under SCDP
18. Development Pedestrian Path network	Initiated under SCDP
19. School Van Clustering Scheme	Not initiated
20. Electronic Road Pricing System	Not initiated

7. Acknowledgements

The authors acknowledge the continuing support of Ms. Namalie Siyambalapitiya, Director Planning of the RDA, who initiated the Kandy Transport Study and the support from Dr. I. M. S. Sathyaprasad and Mr. Janaka Weerawardena to complete it. The inputs from the SCDP Project Director. Mr. Anura Dissanayake and the PMU, the World Bank, Mr. Brendan Finn, Consultant and the international consultant DIMTS in association with UNI

Consultants and especially the inputs of Dr. T. Sivakumar, Deputy Team Leader is acknowledged.

CES Annual Seminar 2017

Civil Engineering for Urban Resilience

Seismic Hazards
How safe is Colombo and its Suburbs?

By

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Seismic Hazards: How safe is Colombo and its Suburbs?

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University of Peradeniya

Abstract

This paper describes the outcome of a comprehensive study carried out to analyse the seismic hazard affecting Sri Lanka. The main seismic threat is from oceanic earthquakes originating at failed Mannar rift zone and Comorin ridge off the west coast with some secondary influence from south Indian crustal earthquakes. The analyses were performed using DSHA, PSHA and seismic wave propagation using FLAC software. The effect of wave attenuation through the soil overburden was not considered in the analyses. The seismic scenario included 100 year earthquake catalogue with an characteristic earthquake of magnitude 6.9 at a distance 90 km from the west coast. Historical records of earthquakes in the vicinity of Sri Lanka indicated that 1615 earthquake was the most significant earthquake to affect Sri Lanka. The analysis showed that NW to SW coastal areas are the most vulnerable to seismic hazard. There is also reflection of seismic waves within the central highland leading to higher peak ground acceleration than the levelled ground.
Based on the analyses described above, a seismic hazard map for Sri Lanka dividing the country into two zones of seismic intensity and response spectrum were proposed. The study was constrained by the lack of recorded data of past earthquake response within the country. Torectify this need a network of seismic stations was proposed in the paper.

Keywords: Mannar rift zone, Gutenberg - Richter relationship, earthquake

1. Earthquakes and Their Impact

Earthquakes are originated at plate boundaries (inter plate) or at fault zones inside a plate (intra plate). Major inter plate activities which may affect Sri Lanka occur at Sunda Trench Indonesia to the east or at Himalayas to the north. There are no records of significant intra plate activities within Sri Lanka though minor tremors are recorded from time to time. However, intra plate earthquakes have occurred in the sea beyond the western coastal line of Sri Lanka.

In seismology the region inside the earth where seismic activity originates is called the hypocenter. In our context, this may be about 10 – 15 km below the

ocean floor. The point directly above the hypocenter is called the epicenter. The energy generated by an earthquake will cause stress waves which travel through the ground causing damages to structures in its path.
The dominant seismic waves at close distances are compression and shear waves which dissipate with the distances spherically. When these wave fronts reach the ground surface, they are transformed to Rayleigh and Love waves (surface waves) which dissipate with square of the distance. These surface waves retain their energy over a long distance and cause more destructions than body waves.

2. Richter and Mercelli Scales

The energy expressed in logarithmic scale released by an earthquake is measured by Richter scale which uses the seismographic measurements at 100 miles horizontally from the epicenter. The damage caused by an earthquake is measured by Mercalli scale. What is important an engineering sense is the potential damage caused by an earthquake not its Richter magnitude.

3. Past Seismic Activities close to Sri Lanka

The earliest documentary record of an earthquake affecting Sri Lanka is based on a pamphlet published in Lisbon in 1616 describing an event which took place on 14th April 1615 near Colombo (Gunasekara (2000)). This record is described in detail in Seneviratne et al (2016). Eventhough the original article is not very scientific and contains many religious overtones still there are many interesting and important scientific facts which can be gathered as highlighted below;
In the period preceding the main event, there are accounts of: "Dead fish thrown up from the sea so poisonous that people who ate them died. The atmosphere most infected with putrefaction and bad odour, which killed people and birds. People were scared to go to the seaside let alone bathing as those who did were fallen sick"
.
The above facts are consistent with gas releases prior to the main event through seabed which is a possible activity in the active Mannar rift zone. "On the day of earthquake, the sun set half an hour earlier than on other days". The logical explanation for this may be a gas emission at the source of tectonic activity rising up in the atmosphere blocking the sun. If this is correct, the tectonic activity occurred approximately in the direction of west of Colombo. The distance to the epicentre is proportional to the height of clouds at the time of sunset, which can be calculated using basic geodetic principles. A distance of 90 km would require a cloud height of 12.5 km to advance the "sunset" by 30 minutes.

"It was seven in the evening when thunder shook the air with such force and the earth quaked so violently that, unable to remain in the houses people rushed out to the streets fearing to be buried under the falling ruins of the buildings. Then bolts of thunder fell from the heavens. The thunderbolts had their effect, destroying and laying low not only the most sumptuous edifices but also the meanest cottages leveling all, and the few that the fire had not consumed were destroyed by the earthquakes".

Thunder, lightening and fire have been commonly observed in such earthquakes in the past according to the literature. The number of casualties of this earthquake has been stated as 2000 with many houses destroyed and wide deep cracks were visible on the ground. Based on the damage, Vitanage (1995) estimates the magnitude of the earthquake as 6.5 with epicenter very close to Colombo. No other earthquakes of similar magnitude have been reported in the literature since the above earthquake. However, there were a number of seismic events particularly the events in 1938, 1956 and 1993, which were felt in many parts of the island though no casualties or significant damage to property. 1938 earthquake which had an epicentral distance of 90 kilometers to the west of Colombo was strongly felt in the western province and the central highlands but less noticeably in Kandy and Matale districts and in the eastern province. Within Sri Lanka very little seismic activity (3 - 3.5 Richter scale) have been recorded in the past (Fernando and Kulasignhe 1986). No major seismic activity has been recorded coming from south east and north of Sri Lanka in the recent past except the Tsunami causing 2004 earthquake originating at Sunda trench.

4. Geological Setting of Sri Lanka

Sri Lanka is located in the North Western region of the Indo-Australian plate. The interplate seismic activity around this plate is governed by Himalayas to the north on which it pushes against the Euroasian plate and by Sunda trench to the east on which it undergoes subduction, cause of earthquakes and tsunamis. The seismic activity to the far west at the mid-Indian ocean ridge and to the south is less significant to the above, as they are zones of crustal extension. However, some seismologists discuss the possibility of emergence of a new plate boundary to the south of Sri Lanka (Dissanayake (2000)). The above interplate events are not considered significant as far as Sri Lanka is concerned, (Thaldena et al 2013) but the tsunami hazard due to seismic activity at the Sunda trench is considerable.

In the present study, the intraplate activities spanning NW to SW coast of Sri Lanka in the vicinity of failed Mannar rift zone and the Comorin ridge which were not hitherto considered important are analysed in detail. This is particularly important considering the heavily populated and economically important areas near the west coast and/or within western province in the vicinity. The intraplate activities originating in the other regions around Sri Lanka are not considered important except to the north of island where intraplate seismic activity in South India may have some influence. The intraplate seismic activity within Sri Lanka also appears to be insignificant.

5. Geological Significance of Failed Mannar Rift Zone and Comorin Ridge

Sri Lanka is believed to be geologically the southern continuation of peninsular Southern India although the island today is separated from the mainland India by a narrow stretch of shallow sea. This stretch of sea is now a part of the Indian Ocean but it opened-up at the time the super continent Gondwana broke-up during the Jurassic period (Curray, 1984, Baillie et al., 2002, Kularatne et al 2015). Continued rifting of continents always leads to formation of large ocean basins but it produces narrow seas or inland lakes at initial stages. Rifting produces faulted blocks of rocks with the faulting extending laterally for tens to hundreds of kilometers, and vertically downward to the mantle providing pathways for rising magma. Zones of initial rifting therefore, are always geologically very active as they are sites of active volcanism and seismicity.

The narrow sea between Sri Lanka and South India is a failed rift zone; this is the underlying reason for the absence of active volcanism and seismicity today. However, the Cauvery and Mannar basins produced by the rifting process is floored by faulted blocks of continent and sedimentary successions which are about 10 kilometers thick laid down on the faulted sea floor since the Cretaceous period. During exploratory drilling for oil in the Cauvery and Mannar basins, frozen basaltic lava flows have been encountered (Rana et al., 2008). These are inter-layered with sediments indicating that the rift zone had been volcanically and seismically active in the past.

Seismic exploration of the sedimentary succession in the Cauvery and Mannar basins has indicated relative disposition of faulted blocks of rocks on the basin floor. As the sediment load increases one cannot rule-out reactivation of the fault zones and relative motion between the already faulted blocks of rocks generating some seismicity. In the Bay of Bengal to the east and northeast of Sri Lanka, there is also evidence of sea floor spreading. The settling of sedimentary successions has given rise to earthquakes with magnitude around 5 in the recent past, the latest being in April 2009. Although highly active seismic zones are quite far away from Sri Lanka, the potential of the above sedimentary basins to the NW and SW of Sri Lanka becoming foci of future low magnitude earthquakes (up to M6) has to be borne in mind. However, the seismic status of Sri Lanka is dominated by failed Mannar rift zone and Comorin ridge (NW basin) as very few significant seismic activities have been recorded in the NE basin.

6. Seismic Monitoring in and around Sri Lanka

A Milne seismograph was installed in Colombo Observatory in 1909. This was replaced by a Milne-Shaw seismograph in 1927. This seismograph had been connected to a global network comprising 350 seismographic stations. The original seismograph records were kept at the Department of Meteorology which succeeded the Colombo observatory in 1972. Therefore, measured earthquake data at Colombo are available from 1909 to 1992 though they need to be processed to obtain digitized time history records.

Three seismometers were installed by Geological Survey and Mines Bureau (GSMB), one in 2000 at Pallekele (PALK) connected to Global Seismographic Network (GSN) and the others in 2010 at Mahakandarawa (MALK) and Hakmana (HALK), connected to GEOFON Network. The waveform data and earthquake parameters from these seismometers are available through internet from GSN and GEOFON networks through GSMB.

The major problem of seismic monitoring of Sri Lanka performed in the past by government agencies is the lack of monitoring data available throughout the island. This is normally facilitated by having a series of seismometers at strategic locations. Up to date no such network has been established.

7. Earthquake catalogue for Intraplate seismicity in and around Sri Lanka

Early earthquake catalogues on the seismicity around Sri Lanka were prepared by Vitanage (1995) and Abayakoon (1995). In addition, a number of Indian catalogues cover many earthquakes in the south Indian region (Menon et.al. 2005). In the present study to investigate the seismicity around Sri Lanka, an area bounded by Latitude 0˚N - 20˚N and Longitude 70˚E - 90˚E was selected as shown in Figure 1. The records from Abayakoon (1995) and Uduweriya (2014) are based on the data reported by many global data bases such as IRIS data base. The data which goes back to 1063 A.D. consisting of past seismographic observations and estimations based on damage intensity or from paleoseismological studies was used in preparation of the catalogue. The epicenters of the earthquakes taken from the catalogue are illustrated in Figure 1.

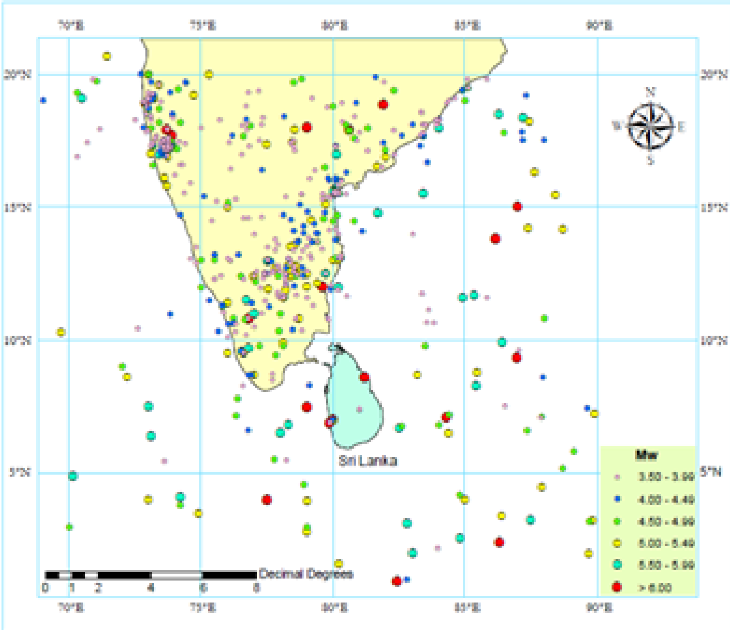

Figure 1 : Epicentres of past earthquakes

It is clear from Figure 1 that a high intensity earthquake zone exists along the NE, SW axis spanning from Ongole to Kerala. However, this fault region is far away from Sri Lanka to have any significant impact on the seismic status of Sri Lanka except in the northern region.

The seismic status close to Sri Lanka appears to be governed by the activities in the western coastal region in which failed Mannar rift zone and Comorin ridge can be easily identified as the main tectonic features. This is very clearly visible in Figure 2, which shows the filtered version of the catalogue created by narrowing down the original area to 3.5˚N-8.5˚N and 75˚E-80˚E window. The seismic activities in the other coastal regions of the catalogue appear to be insignificant in comparison according to the available data at present. The completeness of this catalogue has been tested according to the procedure described by Stepp (1973). It shows that 100 year data is sufficient for the completeness of the catalog (Seneviratne et al (2016)).

8. Analysis of Seismicity of Sri Lanka

Three types of analyses namely, DSHA(deterministic seismic hazard analysis), PSHA probabilistic seismic hazard analysis) and numerical analysis using finite difference FLAC software were performed. Considering the geology of Comorin Ridge and Failed Mannar rift zone, a characteristic earthquake of 6.9

Richter magnitude occurring at a distance of 90 km from NW - SW coastal line (along Mannar rift zone) has been chosen for the DSHA and the finite difference analysis. This magnitude is for 475-year return period given by Gutenberg-Richter relationship. PSHA was performed using the complete earthquake catalogue.

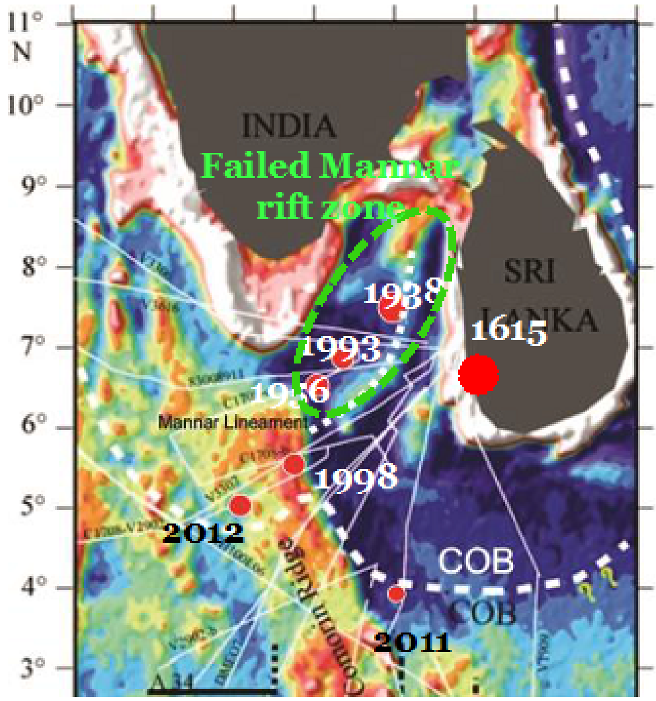

Figure 2 : Epicentres of earthquakes occurred in failed Mannar rift zone and Comorin ridge

i. Deterministic Seismic Hazard Analysis

DSHA predicts the seismic response (defined by peak ground acceleration (PGA)) seismic response at a point, distance D away from the seismic source based on an attenuation relationship available in the literature derived using observed data from seismic sources within the zone. For the seismic scenario given above, two attenuation relationships available in the literature namely, Gitterman et al (1993) and Kun-Sung and Yi-Ben, 2005 are calibrated against the monitoring data from GMSB for earthquake of magnitude of 4.7 at a distance of 270 km from the western coastal line. The comparison showed that Gitterman et al (1993) gives the most suitable relationship for the used calibration data. The prediction for the given seismic scenario (6.9 magnitude at 90 km) given by Gitterman et al 1993 for selected locations within Sri Lanka.

ii. Probabilistic Seismic Hazard Analysis

PSHA was performed by considering eleven seismic zones in and around Sri Lanka. The complete earthquake catalogue since 1900 was used in the analysis. Three attenuation relationships suitable for the whole region under consideration were selected. The prediction of PGA and Spectral Acceleration (SA) at important locations within Sri Lanka was carried out. In each zone, the magnitude, M of 475-year return period earthquake was calculated considering all past earthquakes within that zone. This earthquake was placed on the boundary of the zone closest to the point of interest at which the PGA and SA was calculated for magnitudes of M and M+0.3 using three attenuation relationships; Abrahamson and Silva (1997), Campbell and Bozorgnia (2008) and Raghu Kanth and Iyengar (2007). The epistemic uncertainties were dealt with by logic tree approach. The final PGA and SA at the point of interest were determined using the envelop of response spectra from all the eleven zones.

9. Seismic Hazard of Colombo and Suburbs.

DSHA and PSHA analyses performed gave reasonably consistent results. For the design purposes two structural classes were identified as Class I (command centres, schools, hospitals, dams, public gathering places, ancient/cultural structures, highrise buildings etc.) and Class II (all the other engineered structures). In Colombo and suburbs both Class I and Class II structures should be designed against the PGA 0.1g.

The proposed response spectrum is illustrated in Figure 3 and the relationship given below.

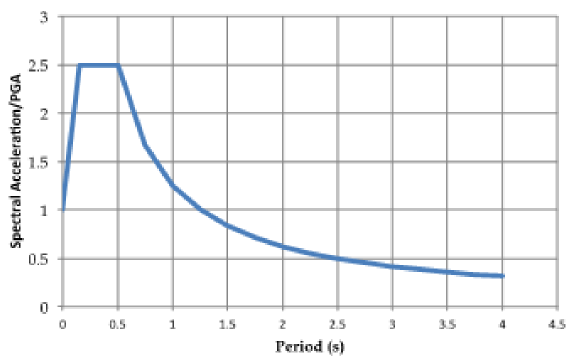

Figure 3 : Proposed normalized response spectrum

$$SA = \begin{cases} (1+10T)*PGA & 0 \le T \le 0.15 \\ 2.5PGA & 0.15 \le T \le 0.5 \\ 1.25/T*PGA & 0.5 \le T \le 4.0 \end{cases}$$

where T is the period of a structure.

10. Seismic Monitoring Programme

In carrying out a comprehensive study on seismic status on Sri Lanka, recorded ground response at key points distributed throughout the island is required. The actual monitoring data at present are available only from three stations (Hakmana, Pallekele and Mahakanadarawa) of GSMB which are approximately aligned North-South through the centre of the island. The most vital region of Western province does not have a single monitoring station. In the study described in this paper, lack of seismic monitoring data was a serious set back in trying to select appropriate attenuation relationships.

Therefore, there is an urgent need to establish a network of seismometers throughout the island so that the actual seismic response of any part of the island may be estimated to a sufficient accuracy. The authors propose the seismometer configuration shown in Figure 5 for this purpose. The technical specification of seismometers should ensure that the frequency range of 0.1 Hz to 25 Hz is adequately represented.

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Acknowledgements

University of Peradeniya and Faculty of Engineering, Peradeniya for financial and other assistance.

UNDP and DMC for partially financing this work.

GSMB and Department of Metrology for giving past earthquake records.

All academic staff, post graduate and undergraduate students of earthquake research group, faculty of engineering, Peradeniya for their contribution.

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Civil Engineering for Urban Resilience

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Impacts from climate change on water safety and scarcity for water centered sustainable cities

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Impacts from climate change on water safety and scarcity for water centered sustainable cities

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Climate change has been in the forefront of discussion in the global arena since mid 1970s when the simple models developed by scientists established the existence of a greenhouse effect caused by the concentration of carbon dioxide in the atmosphere, mainly due to human action. Since then, the acceleration of the warming process since 1980s had first worried scientists who had been engaged in research in this area and then civil society leaders and finally policy makers. In particularly, the consequences of such an accelerated global warming have been identified as catastrophic. On the other hand, the rising and increasingly dense urban population, combined with decades of unsustainable practices, has had an immense impact on the world's infrastructure. Urbanization is one of the great driving forces of the twenty-first century. Bringing together large numbers of people within a complex system can lead to vulnerability from a wide range of hazards, threats and trends.

Consequently, the urban planners have become more vigilant on urban resilience. The advent of the concept of resilience was derived from an increasing need to handle new and more intense threats to modern societies. Particularly, increasing exposure and vulnerability of contemporary cities are pushing the civil engineering community to focus on natural hazard risks on an urban scale. The definition of resilience is highly variable depending on the subject area, which it is applied to. Essentially, the general requisites that bring together the different literature definitions of resilience pertain to the capacity of a system to absorb, adapt and recover from an external stress, while limiting disruptions to its normal functioning.

As an approach to make urban cities as resilient, the concept of sustainable cities was derived and it has been further defined as livable cities. The most of the focuses given so far under the smart cities are based on energy and urban water management. Moreover, water will be the crucial factor deciding sustainability as scientists have already shown many possible approaches on ensuring renewable energy sources. Accordingly, the idea of the water smart city approach has been proposed to exploit these opportunities in a smart way.

The water smart city approach integrates urban planning and the urban water cycle, and makes a good business out of it for society as a whole. This concept includes integration of stormwater, groundwater, wastewater management and water supply to cope with societal challenges related to climate change, resource efficiency and energy transition, to minimize environmental degradation and to improve aesthetic and recreational appeal. This approach develops integrative strategies for ecological, economic, social, and cultural sustainability. Water smart city approach needs a safe and sure water management including the emerging threats of climate change and variability, rapid urbanization and population growth, energy constraint and tightening environmental regulation through to their consequences on social, economic and environmental recipients.

However, water supplies in all over the world find an increasing trend of wide range of risks caused by microbial pollution with pathogens typically of major relevance. Furthermore, pollution of raw water sources with agricultural chemicals and siltation of the reservoirs by runoff during rainy season. In the mean time, enhancement of algal blooming due to increased temperature and eutrophication as well as capacity gaps with the utility to consistently supply safe water in adequate quantity to the population is identified to be the current and future climate change-related challenges to the utilities managed urban water supplies.

Therefore, increasing the resilience of the utility managed urban water supplies is important to proactively identify and manage risks posed by climate change through implementation of climate resilient water safety plans (WSPs). Implementation of the climate resilient WSPs requires integration and coordination between government, partner organization and the community to effectively manage various risks to water supply system from catchment to point of consumption. The scope of WSP implementation guidelines for urban utilities builds on the following two major elements; adapt the generic water safety plans for urban utilities and incorporate the risks posed by climate change on the water supply systems from catchment to point of consumption during development and implementation of the WSPs.

Urban services must guarantee proper management of water treatment, supply and distribution, wastewater collection, treatment and disposal, and other related services. The term 'smart water management' points to water and wastewater infrastructure that ensures water, as the most precious resource, and the energy, which is used to convey it, is managed effectively. Such water and wastewater management systems must be technically sound and economically viable in the long term to ensure sustainable development. These systems should be supported with monitoring and networking capabilities so that they can be connected with other service systems so as to obtain more reliable information to assess their functionality, efficiency and to facilitate the interaction of each other. Water loss management is also important as water supplies are stressed by rapid population growth usually accompanied with water scarcity. Many regions are experiencing severe droughts, and others experience that the aquifers are depleting faster than they are being replenished.

In addition, being resilient against flooding is a key challenge for urban communities and one for which civil engineers can play a vital role. Flooding and its effects on infrastructure has recently become a key concern in the world, with incidences of climate change and sea level rises expected to become more frequent. Sea level rise poses even a larger threat to coastal cities, which accounts for three-quarters of all large cities and half the world's population. Salt water intrusion is expected to contaminate coastal surface water sources, and groundwater sources, decreasing thus their quality. An increase in sea level is also expected to lead to an increased probability of flooding of sewerage systems and wastewater pollution control plants, and to a reduced ability to discharge combined sewer overflows by gravity.

It is imperative that urban water managers adopt appropriate water intelligence within their various management systems, and develop the capacity needed to realize the full potential of integrated communication tools in this field. Numerous experiences suggest that smart water management tools can be easily integrated. However, the current approach and lack of standardization within this sector may foster future problems of interoperability and reliability of smart water management tools, possibly preventing future integration of system solutions. Furthermore, the role of civil engineers is becoming more and more significant and advances as they have to play a foremost role in utilizing the existing infrastructure and develop new facilities to address the global demand in developing water smart cities.

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Civil Engineering for Urban Resilience

Landslide Disaster and Resilient Construction in Kegalle District Sri Lanka

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Landslide Disaster and Resilient Construction in Kegalle District, Sri Lanka

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ABSTRACT

Landslide is one of the most frequent and major natural disasters in mountainous terrains especially during mon-soonal rainy periods among floods, cyclones, droughts earthquakes in Sri Lanka. Although the area of influence is small, extent of damage caused to lives, properties and environment by a landslide is immense. The term, landslide is used to denote a wide variety of mass movements which cause downslope transport of soil and rock material un-der the influence of gravitational force. National Building Research Organization (NBRO) is the mandated pioneer organization to handle the Landslide related activities in Sri Lanka. According to the observation gathered during the past period and historical records NBRO has identified ten administrative districts are prone to landslides, namely Badulla, Nuwara Eliya, Rathnapura, Kegalle, Kandy, Matale, Kaluthara, and part of Galle, Matara, and Hambanthota. In perusing records, Kandy (Sinhapitiya in 1977; Bahirawakanda in 1993), Matale (Pitakanda in 1982, 2012; Watagoda in 2012), NuwaraEliya (Katayapatana in 1986; Watawala in 1993), Ratnapura (Patulpana in 1983 ; Helauda in 1993) , Kegalle (Bulathkohupitiya-Bambarakanda,Getiyamulla in 1989), Kalutara (Agalawatta, Bulathsinhala in 2014) and Badulla (Meeriyabadda in 2014) districts of Sri Lanka had a large number of land-slides. According to the experience gained on 1989 and 2016, Kegalle district is also one of the major landslide prone district declared by NBRO out of above ten administrative districts of the country and a catastrophic land-slide event has experienced due to torrential and prolongs rainfall during 14th to 17th of May 2016 in the district. It caused to loss of lives, properties, infrastructures and the environment. As per requested made by district secre-tariat and divisional secretariats of Kegalle district, NBRO was conducted geological investigations on the reported landslide incidences. Since 16th of May 2016 to 31st of March 2017, 541sites have been investigated. According to the risk level, the buildings and infrastructures of investigated sites have been categorized as high, medium and low risk. The event has recorded 51 number of death and 99 number of missing in Kegalle district and Aranayake is the mostly affected Divisional Secretariat Division (DSD). According to the field

data, 1965 number of buildings units including houses, commercial places and other public places such as schools, temples as well as the infrastructures (roads, electricity, water and communication line etc.) are under high risk. Statistical data reveal that, 109 (6.8%) number of large to medium scale landslides has recorded while 1255 (79.4%) of small scale cutting failure and po-tential landslide 100 (6.3%) have reported. Four larger scale killer landslides are occurred, namely Samasara Kan-da, Elangpitiya in Aranayake DSD, Kalupahana Estate in Bulathkohupitiya DSD, Panawala and Densworth Estate in Dehiowita DSD.

Fig 01: Elagapitiya landslide in Aranayaka DSD

Table 01: Summarized data for investigated sites

Divisional Secretariat area (DSD)	Risk Level			Total (High+Medium)	Type of Land Failure					
	High	Medium	low		LS	PLS	SF	CF	RF	Others
Aranayaka	571	1527	195	2098	5	12	12	257	4	4
Bulathkokohopitiya	447	841	145	1288	2	26	15	179	7	7
Dehiowita	166	321	135	487	6	7	14	97	8	18
Deraniyagala	43	303	82	346	0	3	2	143	7	8
Galigamuwa	94	251	13	345	0	4	4	169	1	6
Kegalle	226	816	152	1042	4	21	17	213	5	3
Mawanella	108	249	19	357	0	5	5	58	3	2
Yatiyantota	145	268	86	413	3	8	11	36	3	9
Ruwanwella	78	89	19	167	0	7	4	21	4	5
Warakapola	58	147	42	205	0	4	4	31	2	4
Rambukkana	29	79	01	108	0	3	1	51	4	2
Total	**1965**	**4891**	**889**	**6856**	**20**	**100**	**89**	**1255**	**48**	**68**

Although main causes for above mentioned failures to occur are natural and effects created due to manmade activi-ties, the decisive triggering factor is the high intensity rain fall. Therefore to identify influence of rainfall on initia-tion of land failures during this catastrophic event, the rainfall intensity data at daily interval from 1st January 2016 to 31st October 2016 have been downloaded from www.rainfall.nbro.gov.lk. For this purpose, rain fall data has been collected from rain gauges installed in Aranayake, Dedigama, Dehiovita, Daraniyagala, Gatiyamulla, Kithulgala and Kegalle MV.

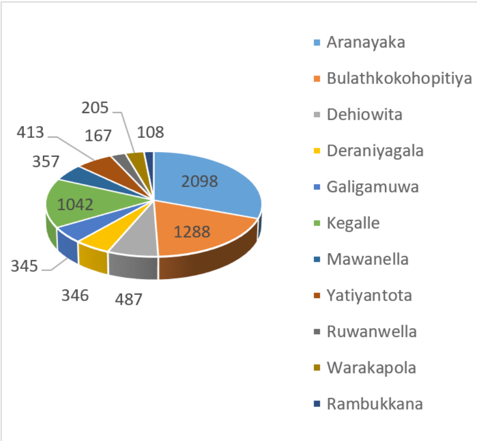

Fig 02: Percentage of risk of each DSD in Kegalle district

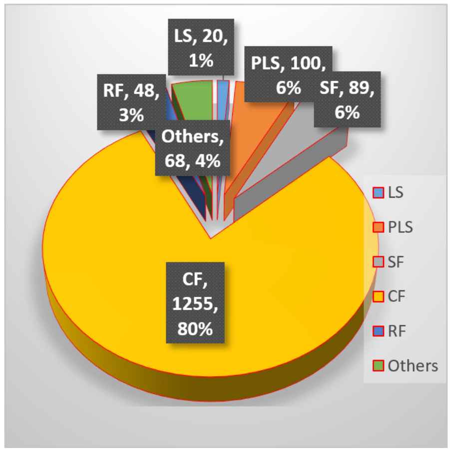

Fig 03: Percentage of different types of ground failure

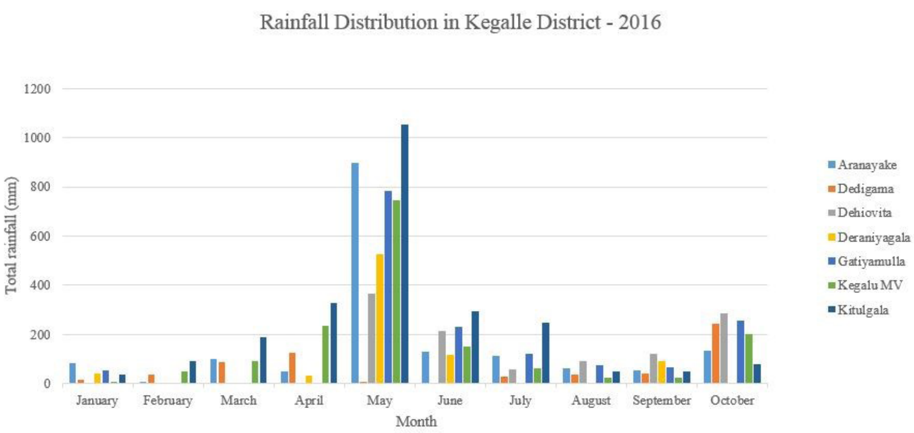

Fig 04: Distribution of rainfall in 2016 at Kegalle district

Basically natural causative factors for Landslide cannot be controlled but man made activities such as poor surface drainage management, improper land use practices and development activities as well as the various type of unau-thorized constructions have caused to induce ground failures during the continuous heavy rainfall.

Most of the natural hazard such as deep seated landslide or slope failure can't be controlled and proof housing is not practicable for a such locations, but design of houses those can resilient to manmade disaster which are raise during the extreme weather condition is possible. A hazard resilient house is not a "post disaster" structure. Post disaster structures are mostly important public building or critical infrastructure facilities, which are required to remain in operational condition following a disastrous event.

- Major type of disasters experienced in Sri Lanka in the past and likely to occur in the future.
- Problematic geo-environmental conditions that can have a damaging im pact on housing.
- How, when and where the disasters or hazardous conditions are likely to occur or prevail.
- How the disasters and hazardous conditions affect the structural stability and functionality of a house.

Key Words: Landslide, cutting failure, rainfall

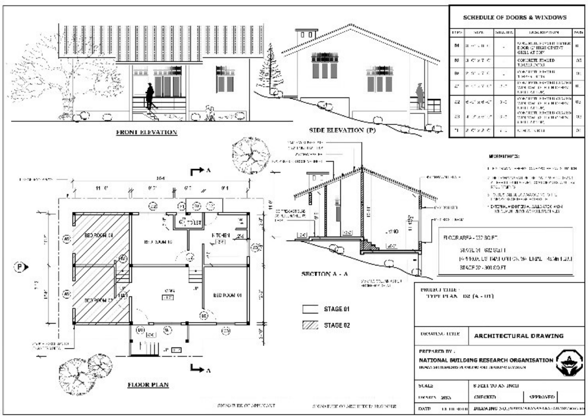

Fig 5(a): Proposed disaster resilient and mitigation building plan

Fig 5(b): Proposed disaster resilient and mitigation building foundation

Fig 5(c): Proposed disaster resilient and mitigation

Notes