INVESTIGATION OF STRUCTURAL DEFECTS IN GOVERNMENT HOSPITAL BUILDINGS IN SRI LANKA

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138732L

Degree of Master of Engineering in Structural Engineering Designs

Department of Civil Engineering

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DECLARATION

I declare that this is my own work and this dissertation does not incorporate without acknowledgement any material previously submitted for a Degree or Diploma in any other university or institute of higher learning and to the best of my knowledge it does not contain any material previously published or written by another person except where the acknowledgment is made in the text.

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The above candidate has carried out research for the Masters Dissertation under my supervision.

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Dr. K. Baskaran

Date: 05/03/2018

Abstract

Sri Lanka has a free of charge health care system heavily subsidized by the government. The national health system of Sri Lanka is guided by the concept of the welfare state. The major armed conflict, which started in 1983 came to an end in May 2009 affecting almost all the sectors in the whole country.

At present, Sri Lanka aspires to become a higher middle income country. It faces the challenge of becoming a high performer in all sectors affected. Social health protection is hailed to be placed high on the national agenda. Within this context safety of built environment of the government hospital sector too is one of the most important matter and the upgrading of aesthetic aspect of the built environment is also a long await need.

A government hospital complex is a main component of major cities all over the country. But the common perception of government hospitals is attributed to the unpleasant experience due to the poor condition of built environment rather than the valuable and highly committed service being provided free of charge to the society.

This particular study was conducted to investigate structural defects in Government Hospital Buildings (GHBs).

Government Hospitals in Western province were selected for visual observation and photographic survey based on convenience and by judgement of the fact that over utilization of hospitals in Western province.

Also, it was highly important being aware of the local and international picture referring to past studies regarding the same area of study. As the chief structural material of most of the GHBs is Reinforced Concrete (RC), attention was drawn to refer to cracking inherent to RC as well. Observations and information gathered were carefully reviewed. Direct and indirect causes of defects could be identified based on the historical data and the observations made.

Further the attention was drawn on the current practice of Designing of Hospital Buildings in Sri Lanka and an attempt was made to find whether structural and performance issues identified and the maintainability aspect are addressed at the initial design stage.

It was revealed that there is neither detailed registry of GHBs nor detailed building audit of defects being carried out.

The main reason for immerging poor quality building either by new construction or renovation work is the lack of supervision of the work by competent personnel. The Attention on setting up a well-structured Building Management Division which is entrusted clearly with the entire responsibility regarding the GHBs is identified as a necessity in upgrading the condition of GHBs.

A special attention on performance and maintainability aspect of GHBs at the initial design stage has hardly been paid rather than adopting the common practice of designing of all types of buildings.

Despite the constraints in vertically expanding, the government hospital buildings observed are at an acceptable structural condition thus not requiring complete demolition.

Key words: Government Hospital Buildings, Detailed Building Audit, Structural Defects

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LIST OF ABREVIATIONS

AHB	Annual Health Bulletin
BSR	Building Schedule of Rates
CEB	Ceylon Electricity Board
CECB	Central Engineering Consultancy Bureau
CM	Corrective Maintenance
DVD	Digital Versatile Disc
GHB	Government Hospital Buildings
HDU	High Dependency Unit
JCI	Joint Commission International
LCB	Limited Competitive Bidding
LRH	Lady Ridgeway Hospital
MICU	Medical Intensive Care Units
MR	Maintenance Requests
NCB	National Competitive Bidding
NINDT	National Institute of Nephrology, Dialysis and Transplantation
OPD	Out Patient Department
RC	Reinforced Concrete

1. INTRODUCTION

1.1. Background

Sri Lanka has a universal health care system that extends free healthcare to all citizens, which has been a national priority. As per 2014 statistics, there are 622 government hospitals in the country with total bed capacity of 80,105. [1], [2]

Also, a large number of private hospitals have appeared in Sri Lanka, due to the rising income of people and the demand for private healthcare services. But they are mostly limited to Colombo and its suburbs and also have high prices.

Colombo district is the most populous district of the country with a population 2.35 million followed by Gampaha district which records a population of 2.34 million. Also Colombo district shows the highest density of 3,487 persons per square kilometre in 2014. The next highest density of 1,744 was recorded from the adjoining district Gampaha. [3]

However, as of 2014, the public sector accounted for 73% of the hospitals and 93% of the available bed capacity in Sri Lanka, while handling over 90% of the total patient admissions and outpatient visits to hospitals. The public sector provides for bulk of inpatients care, approximately 95 percent, providing a safety net to citizens. More than six million hospitalizations occurred in 2014. Figure 1.1 shows some heavily crowded situations at outpatient departments of government hospital buildings. A total of fifty five million outpatient visits occurred in 2014 in public sector. Hence an assurance of safe condition and performance of government hospital buildings is emerged to be of priority concern.

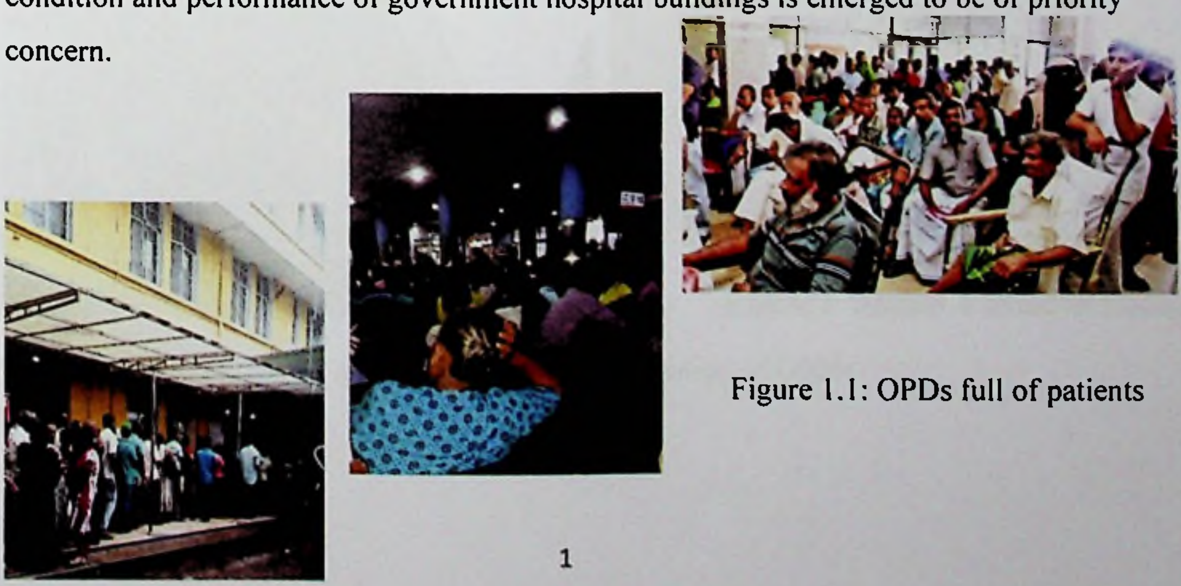

Figure 1.1: OPDs full of patients

Considerable deterioration of both structural and non-structural elements can be observed related to most of the GHBs as illustrated in Figure 1.2.

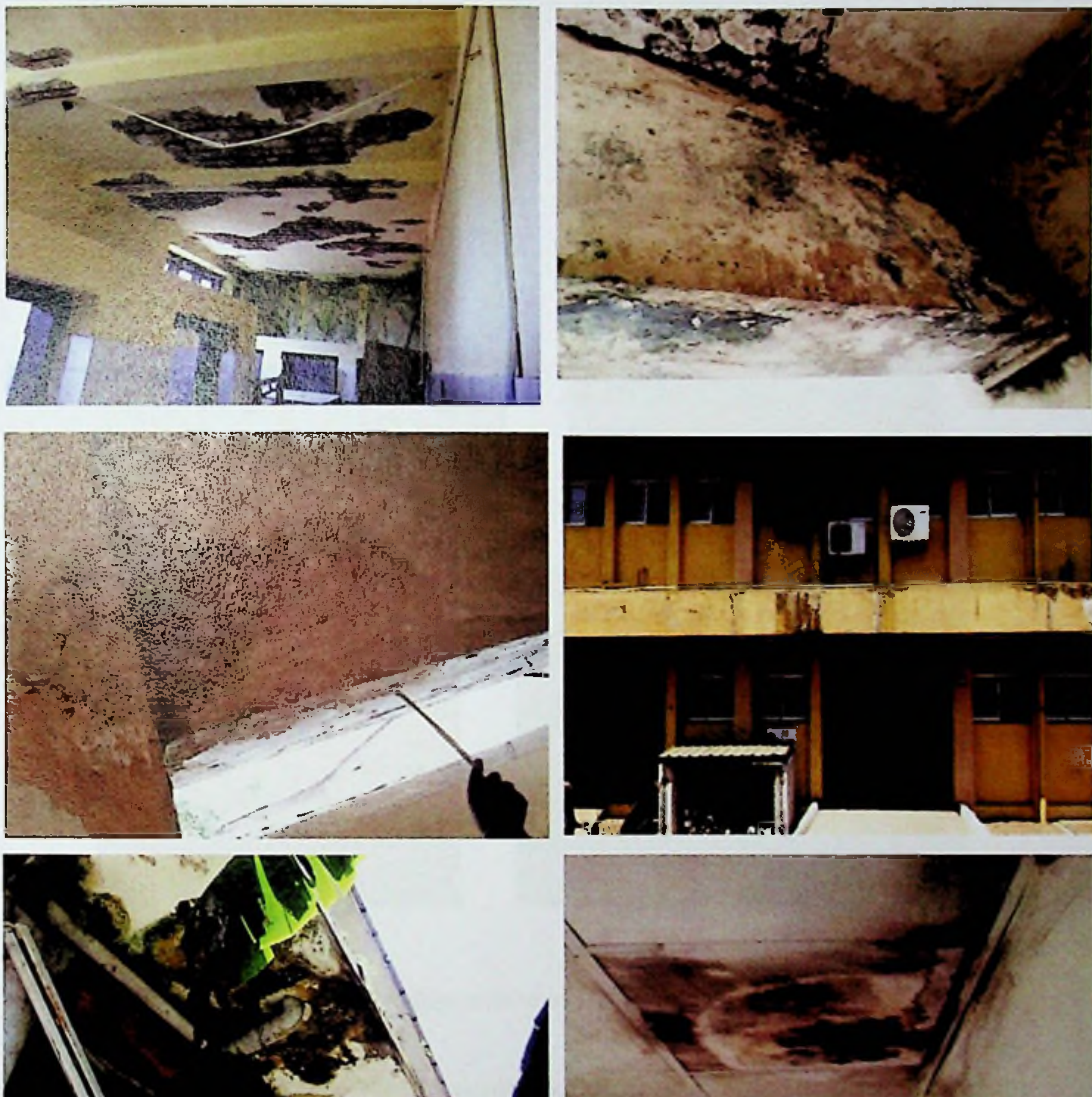

Figure 1.2: Deteriorated situation of GHBs

Also, Srilankan health sector infrastructures were affected due to the long term war situation existed. Figure 1.3 below shows the poor appearance of OPD building of Lady Ridgeway Hospital witnessing that upgrading of aesthetic aspect of GHBs is a long await need.

Figure 1.3: Appearance of OPD building of LRH

This particular study on government hospital buildings was supposed to be at an utmost importance under the circumstance of having lack of attention on well planned technical approach for upgrading built environment of Government Hospitals.

1.2. Objective

The Main objective of this particular study was to investigate structural defects in GHBs and to understand direct and indirect causes so that to develop remedial measures. In achieving the main objective, this study was sub divided into several sub objectives as illustrated below.

- Conducting a literature review

It was aimed to be aware of general perception and practices regarding the public hospitals both locally and internationally. Defects inherent to two chief construction materials, reinforced concrete and the brick masonry were aimed to be given special attention when gathering information on common defects of GHBs. Global approaches of repairing procedures and assessment of buildings etc. were aimed to be given attention. Also, the attention on Sri Lankan health system and the legislative background was considered to be important.

- Visual observation and photographic survey of selected GHBs

Closed observation and photographic survey on certain GHBs were planned in achieving main objective.

- Categorization and reviewing of data

Critical and most frequent defects and direct causes of defects of reinforced concrete structural members, brick/block works and finishes were supposed to be realized and confirmed based on historical data together with field survey data. Indirect causes of defects were supposed to be realized based on general observations and background information gathered during the study.

- Comparison of the status of GHBs with certain other buildings.
- Study the current practice of Structural Designing and Construction of GHBs
- Remedial measures

Immediate solutions to remedy the existing condition of reinforced concrete structural members, brick/block work and finishes etc. were focussed to be illustrated within the report regardless of the cost factor.

- Arriving at Conclusions and recommendations

1.3. Methodology

Literature review was carried out regarding the area of concern related to hospital buildings locally and internationally, mainly through internet. Also, certain references related to building defects and assessment of buildings etc. were studied

Inspection of local GHBs and a photographic survey was carried out to identify defects. The photographic survey was carried out in 18 numbers of hospitals including mainly the Lady Ridgway Hospital (LRH) in Colombo 08 which is the largest public, free of charge Paediatric Hospital in the World. It serves as the national referral centre for paediatric care for Sri Lanka [1]. Observations were made in a nine-story building and four-story (02nos) buildings recently constructed and 02 numbers of two-story oldest buildings within the Lady ridgeway Hospital premises.

During the same period of study it could be attended with the condition assessment of Head Quarters Building of Ceylon Electricity Board (CEB), an eight storied building constructed in 1960s and located very close to sea. Based on this, an attempt was made to get a comparative assessment regarding structural condition of observed Government Hospital Buildings. The opportunity that could get involved with the CEB Head office renovation project in parallel with this particular study period could also be effectively incorporated in understanding, predicting, comparing advantageous/disadvantageous of a complete renovation work of a building over a new construction work and arriving at conclusions etc.

Also, observations were made on the conditions of private hospital buildings and compared with the state of GHBs. Further the attention was paid on current practice of structural design, construction and maintenance of GHBs.

Direct and indirect causes of defects were evaluated based on observations and reviewing the information gathered. Accordingly this dissertation was concluded presenting recommendations on remedial measures.

1.4. Outline of the Thesis

Background and the importance of this particular study are discussed under Chapter 1 illustrating some statistical facts and the present state of GHBs. Information through literature review regarding the local and international studies related to the same area of study is illustrated under several sub headings in Chapter 2.

Chapter 3 reviews the field survey data illustrating the defects identified in the structural members, masonry walls and finishes subsequently presenting the causes of defects. This chapter further discusses about the current practice of structural design and construction of GHBs and the current practice of maintenance of GHBs.

Based on the standard practices and procedures studied under Chapter 2, remedial measures for identified defects are presented in Chapter 4. Entire study is concluded in Chapter 5 presenting the recommendations on GHBs at the end.

2. LITERATURE REVIEW

2.1. International Picture

2.1.1. General issues

International journal of sustainable construction engineering and technology *on* Assessment of Operational Maintenance in Public Hospital Buildings in the Gaza strip, a country experienced the challenges and negative effects on the health sector due to repeated and continuous war situation from 2008 to 2014, illustrates that the lack of attention to maintenance Management in hospitals has led to deterioration of buildings and reduced the health care services [4]. It further states that though it is impossible to produce buildings, which are maintenance free, however, maintenance work can be minimized by good design and proper workmanship, In addition to proper management of the process that involves assessing performance, and maintenance management of buildings. Study has shown that neglecting maintenance may fall into several defects which may lead to structural failures. Humidity is a major source of problems in buildings worldwide as moisture can damage the building structure, the finishing and furnishing materials, besides being a direct cause of human discomfort. This study concludes that all public hospitals implement Corrective Maintenance (CM) and only three hospitals employed Preventive Maintenance (PM) along with CM. No routine inspection on plumbing and water systems etc. is done and react only when there is a problem and neither maintenance plan nor quality control system is practiced for repair and PM. They further revealed that maintenance staff does not have access to formal training programs on maintenance techniques and, planning and policy.

2.1.2. Common defects

A case study on public Hospital Buildings in Malaysia shows that the building maintainability aspect has always been neglected at the design stage at which some of the defects could be eliminated with proper attention and consideration initially at that stage [5]. This report further brings concise details of several studies done on hospital buildings in Malaysia and Singapore and mentioned that defects commonly identified are hair line cracks , fungi, peeling and blistering of paint, discoloured paint, staining, water marks on ceiling, sweating of wall, leakages, corrosion, popping tiles, bad plumbing etc. Amongst the causes of defects presented in the report condensation has been mentioned to be as one of the causes due to different temperature between two sides such as above and below floor level or inside and outside building wall etc. The issue of condensation affects internal ceiling creating fungi and water mark etc. and this situation has been identified in four hospitals during the study. The study finally suggested that it is important for all stakeholders to pay attention on building aspect when designing and construction to reduce the cost due to unnecessary building defects.

2.1.3. Cracks in RC structural members

Cast in situ concrete structures are hardly ever built under ideal conditions so, for a variety of reasons, defects may occur as the concrete is being cast or very soon afterwards. The cause may be unsuitable or defective materials, unsuitable construction methods, poor workmanship, and failure to appreciate the hazards associated with a particular structural form or with prevailing weather conditions. Some structural details, such as congested reinforcement or very narrow sections, can greatly increase the risk of occurrence of defects. Unsuitable concrete mix design can cause a variety of defects ranging from variation in colour to severe honeycombing, and it must be remembered that a mix that achieves satisfactory strength may not be satisfactory in other respect.

Cracks that occur soon after concrete has been placed are often described vaguely to "shrinkage", but true drying shrinkage throughout the section of a concrete member may take months to become significant.

If cracks appear in an exposed concrete surface very soon after it has been finished or even, in some cases, before finishing is complete, they are termed plastic shrinkage cracks. They are caused by rapid drying of the concrete surface while the body of the concrete is still plastic.

Concrete may continue to settle, especially in deep sections, after it has started to stiffen and anything that obstruct this movement, such as reinforcement or formwork tie-bolts may act as wedge so that a crack forms immediately over the obstruction. Cracks of this type are known as plastic settlement cracks [6].

The most common cause of cracks in concrete is the shrinkage that occurs as the material dries. As concrete cures, the water that has been mixed with the cement and sand begins to evaporate. This causes the concrete to shrink slightly. Because the concrete surface is restrained by form work or surrounding objects, it tries to resist the effects of shrinkage. The additional tension on the material that occurs when the concrete shrinks leads to cracks [7].

Corrosion of embedded metals in concrete can be greatly reduced by placing crack-free concrete with low permeability and sufficient concrete cover [8].

The chemical reaction or hydration continues to occur for days and weeks after pouring the concrete. Necessary water can be made available for this reaction by adequately curing [9].

Control joints are planned cracks. Control joints give room for shrinkage and thus control joints help in avoiding random cracks. Typically a 4" thick concrete slab should have the concrete joints around 8-12 feet apart [10].

Figure 2.1 below illustrates the frequently possible locations of various types of cracks.

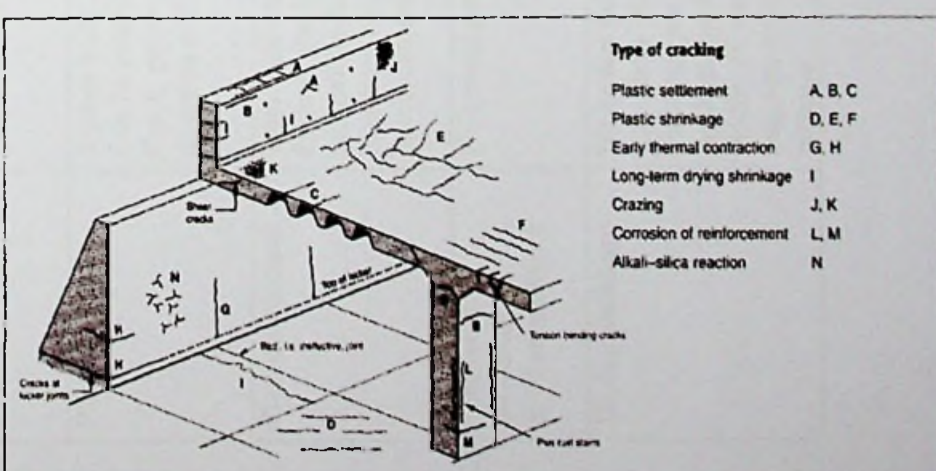

Figure 2.1: Examples of intrinsic crack in a hypothetical structure [11].

Comprehensive details on Types of cracks inherent to reinforced concrete could be referred in many of the references out of which extracted details are illustrated in Table 2.1.

Table 2.1: Details of cracks in Reinforced Concrete Members [12]

Type of Cracking	**Form of Crack**	**Primary Cause**	**Time of Appearance**
Plastic shrinkage	1-2mm wide , 300-600mm long , 20-50mm deep Can be extended through the full depth of a member. Crack pattern is random or diagonal but forms in the direction of finishing operation carried out.	Excessive early evaporation	30 min to 6 hrs.
Plastic settlement	1mm wide cracks occur on the top surface. Follows the lines of the upper most bars forming series of parallel cracks. Run from surface to the bars. Forms between the lines of the reinforcement	Poor mix design leading to excessive bleeding & high slump Excessive vibrations, Inadequate cover over embedded items	10 min to 3 hrs.
Formwork Movement & Thermal Shock	No typical pattern	Bend or bulge during the placement	On removal of formwork
Drying shrinkage	No typical pattern (Transverse, pattern or map cracking) Can form at any location where there is a restraint to shrinkage movement. Approximately right angles to the direction of restraint. Width of the crack depends on length of the member, concrete drying condition and distance between positions of restraint.	Excessive mixture of water, inefficient joints, Large joint spacing	Several weeks to months. Form after concrete gains its full strength and crack can pass through weak aggregates.

Table 2.1: Details of cracks in Reinforced Concrete Members- Cont.… [12]

Type of Cracking	**Form of Crack**	**Primary Cause**	**Time of Appearance**
Thermal expansion & contraction	Transverse	Excessive heat generation, excessive temperature	1 day to 2–3 weeks
Crazing	Close pattern of narrow and shallow i.e., say 0.1mm wide Few millimetres deep Occurs both on exposed surfaces or on surfaces in contact with formwork Interconnected cracks forming closed polygonal loops Polygonal areas are typically 10-75mm across	Changes in properties close to the surface or occurrence of a steep moisture content gradient	1 to 7 days, sometimes much later
Load Induced Cracks	Depends upon the location. (Cracks due to bending or bulging is very common)	Inadequate Design Loading in excess of the design load etc.	Probably several months, possibly much later
Freezing and Thawing	Parallel to the surface of concrete	Lack of proper air void system, non durable coarse aggregate	After one or more winters
Corrosion of reinforcement	Over reinforcement	Inadequate cover, ingress of sufficient chloride etc.	More than 2 years
Alkali–aggregate Reaction	Cracks parallel to the least restrained side	Reactive aggregate plus alkali hydroxides plus moisture	Typically more than 5years, but weeks with a highly reactive material
Sulphate attack	Pattern	Internal or external sulphates promoting the formation of ettringite	1 to 5 years depending on material

2.1.4. **Defects in brick wall structures**

Major defects result from [13];

(a) The application of forces, either externally or internally, greater than those which the building materials can withstand:-For example, excessive settlement of foundation or poor strength resulting from bad workmanship.

(b) The changes of materials that take place with time:- As an example, the size of the most porous building materials increases with an increase in their water content and vice versa. Often these changes will not be noticeable, but sometimes may result in defects of appreciable magnitude. The decrease in size when wet materials dry out leads to shrinkage cracks particularly noticeable in the early life of the building. On the other hand absorption of water or moisture may lead to expansion in ceramic products like bricks and tiles.

(c) Changes in temperature of various parts of the building:-This is a common feature due to diurnal and seasonal changes of temperature. For a country like Sri Lanka, located close to the equator, the brick walls facing either north or south can be exposed to about10-12 hrs. of direct sun light per day during certain parts of the year.

These defects which occur due to any of the above reasons or a combination of reasons will often be visible as cracks.

2.1.5. Repair procedures

Engineering Manual for "Structures Repair" by RailCorp is to describe and detail standard repair procedures for defects commonly found in structures owned and maintained by RailCorp [14]. Those can be easily carried out by maintenance personal and general contractors.

The manual further describes the advantages of adopting standard repair procedures as follows:

– The standard repair procedures included in this Manual are both structurally sound and practically achievable. Adherence to these procedures will reduce the incidence of inappropriate and ineffective repairs or repairs that have adverse effects on the structure;

– Repairs will be undertaken in a consistent fashion throughout RailCorp, whether carried out by day labour or by contract;

– Engineering input into detailing sound repairs for individual works will be minimised, and duplication of effort in developing repair procedures avoided;

– The cumulative knowledge and experience gained in carrying out repairs can be incorporated in the standard repair procedures. This is an effective means of passing on knowledge.

Aim of the repair procedures are illustrated as below

– To restore the strength and serviceability of the structure, either to the "as new" condition, or to the condition that is required for current or envisaged use ("fit for purpose").

– In developing repair details the normal design practices, as specified in the relevant Australian Standards, are applied. There should be the same level of confidence in the repaired structure as in a new structure.

– Some of the repair procedures aim to restore the original integrity of the member. A few procedures that are included are not repairs as such, but rather actions that can be taken to reduce or arrest further deterioration of the structure, or make the structure easier to maintain

Before execution of any repair work, the manual recommends to plan the repair work by concerning followings.

- Carry out detailed damage survey. Indicate location, extent, severity and particulars of the damage.
- Investigate the cause of damage or deterioration by conducting field and laboratory tests as necessary. If corrosion is present establish the cause. Alternatively, determine if it is necessary to engage the services of a specialist consultant to carry out the investigation.
- Assess the strength and stability of the damaged structure.
- Establish the urgency of repairs.
- Examine alternative repair options, materials and methods.
- Estimate the cost of repairs. Obtain competitive quotations/ tenders if necessary.
- Prepare a project repair report on the basis of the above.
- Recommend if the repair work be done by day labour, contract or through specialist agencies.
- Organise the repairs

2.1.6. Assessment of buildings

A Denmark study on "Assessment of building" describes that a database interface called TOBUS has been established which allows diagnosis of physical degradation regarding construction as well as building services [15]. A check list of objects has been defined as a common object list for the general building assessment. An object includes a specific part of the building or its installation. The assessment of the need for retrofitting of an office building due to its physical degradation is undertaken by means of a systematic registration of the entire building, dividing it into objects. The registration of the physical degradation is undertaken object by object whereas for each object type, the physical degradation of the building is described by four degradation codes defined.

To work together with the diagnosis, a database interface on works for retrofitting building constructions and services has also been prepared. For each object type, four work codes have been defined corresponding to the degradation codes.

The study further revealed that this tool for applying diagnosis and work codes, respectively appears to function satisfactorily.

The works proposed in the works-database has been connected to a price data base estimating the costs for each individual retrofitting action allowing the elaboration of refurbishment scenarios.

A Switzerland study on "Building refurbishment; habitat upgrading" by J.L Genre, F.Flourentzos, T.Stockli describes about EPIQR, a decision tool combining financial, technical, energy and comfort analysis [16].

The report states that physical state of the building elements and the functional state of the building services as well as the type of housing and its occupation have to be determined first. Starting with the acquisition of a complete set of data regarding the building to be studied, EPIQR allows users to:

- Establish a complete description of the general state of the building;
- Perform a diagnosis of the physical and functional state of the building;
- Determine in detail the nature of work to be carried out, its global and detail costs;
- Optimise the energy consumption of the building after refurbishment;
- Take the measures required to correct problems of air and indoor environment quality;
- Compare refurbishment scenarios taking into account the gradual degradation of building elements.
- Study different retrofit possibilities

2.2. Local Picture

2.2.1. Health system in Sri Lanka

Annual Health Bulletin (AHB) states that comprehensive information of government health sector in Sri Lanka provided in the bulletin are vital information of government health sector [3]. National Health Strategic Master Plan 2016- 2025 is currently being implemented.

A study on "An assessment of health emergency preparedness and response capacity of Sri Lanka" by Sampath Tennakoon, Health Emergency and Disaster Management Training Centre (HEDMaTC) of Faculty of Medicine, University of Peradeniya reveals that Knowledge about the "safe hospital concept" is not widespread in Sri Lanka and the budgetary allocations are inadequate to implement the modifications proposed by that study [17].

Report on National Safe Hospital Training Assessment facilitated by Reynaldo joson and Aurturo Pesgin brings information presented below [18].

A training program has been conducted as part of a WHO initiative to strengthen Sri Lanka's activities for safe hospitals in 2014. Persons from Ministry of Health, Medical officials from government hospitals and representatives from Central Engineering Consultancy Bureau have participated for the program. At the program participants have been asked to assess the structural, non-structural and functional indicators of safe hospitals using the WHO Western Pacific Regional Office (WPRO) Safe Hospital Vulnerability Assessment Tool.

Medical officials representing the various hospitals utilized the WPRO Vulnerability Assessment tool to determine the status of their hospitals at the training. In order to be recognized as a safe hospital, the institution needs to remain structurally sound, well organized and fully operational at times of emergency and disaster. The report states that for doing this there must be proper monitoring of its structural, non-structural and functional indicators.

Structural indicators include: (A) the building location, (B) design specifications, (C) materials used for the hospital or health facility, and (D) permit and clearance. These important elements are said to be crucial for the building to withstand adverse natural events.

As per the report Non-structural indicators include: (A) Building documents/drawings/plans, (B) Architectural elements, (C) lifeline facilities, (D) medical and laboratory equipment, (E) safety and security of people, equipment and supplies. These elements are essential to the daily operations of hospitals and health facilities. If these are damaged, they would not be able to function, and may even cause physical injury to patients and personnel.

Functional indicators include: (A) site and accessibility, (B) internal circulation and interoperability, (C) equipment and supplies, (D) emergency standard operations procedures and guidelines, (E) logistic system and utilities, (F) security and alarm, (G) transportation and communication systems, (H) plans for emergency and disaster, (I) human resources, and (J) monitoring and evaluation. These are also important in the continuous operations of hospitals and health facilities.

Report further states that early identification or prevention of structural problems such as major and minor hairline cracks are prudent to improve stability of the building.

Specifically, 63% of individuals claimed that their hospital had cracks that needed to be examined by a qualified civil or structural engineer. Collectively, 88% believed their institutions were not built with fire resistant non-toxic materials.

Roughly half (56%) of individuals believe that their hospitals have obtained all the necessary building and occupancy permits. 56% also claim that building alterations have been conducted with proper consultation of engineers and review of the plan building . Collectively, 63% believe the complete set of as-built construction drawings is not readily available for reference purposes.

As per the building documents/drawing/plans indicator data gathered from the WPRO vulnerability assessment tool, report mention that to ensure safety of hospitals, building documents including plans and permits must be approved. The procedures entailing this should encompass construction plans, technical specifications, structural computations signed and sealed by appropriate professionals which is then submitted to and approved by the building official of the local government. 31% of the participants claim to have fully adhered to these procedures while a collective 46% indicated that they did not. 46% also claimed to have adhered to the occupancy permit. Furthermore, 46% admitted that they did not have updated as-built plans.

Under the discussion and conclusion, report states that an obvious hurdle in the analysis performed on the data gathered from the WPRO tool of the Safe Hospitals' Training program conducted in September, 2014, is that information gathered was limited to best knowledge available from the participants. As these participants were in the process of being trained, they may have not been fully prepared to complete the WPRO assessment tool. Thus the response options included "unsure of status". To collect stronger evidence, it may be more effective to involve a team consisting of an engineer, architect and a medical officer from each hospital. With these measures in place, it may be feasible to consider implementing the WPRO assessment tool as part of quality control method in the hospitals in the future.

The report further states that implementing safe hospitals in Sri Lanka remains a priority. The data gathered from WPRO vulnerability assessment tool proves that hospitals in Sri Lanka may need to undergo changes to improve the structural, non-structural and functional integrity of institutions.

2.2.2. Seven storied main building at Negambo Hospital

Sunday times paper on June 07, 2015 had reported about the critical deterioration of the seven storied main building constructed in year 2000 [19]. It stated that a walk around the recently-evacuated building is an eye-opener. The roof of each and every floor is fungus-ridden with major water-leaks through the concrete slabs. On some floors, makeshift aluminium chutes from the centre of the ceiling have been directed out through the windows to channel the water out. One needs only to look under a floor-tile to see water collected, while from the ceiling like icicles hang calcium carbonate.

An assessment has been carried out by Atomic Energy Authority and the University of Moratuwa. Requirement of immediate evacuation from the building has been identified. Strengthening of the building for lateral stability and a complete renovation work due to the presence of almost all the types of defects, were known to be required to overcome the situation of the building. Main cause of the above situation was known to be inappropriate design and construction of the building.

2.2.3. Factors influencing the service life of buildings

The paper on Factors Influencing the Service Life of Buildings by W.P.S. Dias, [20] has presented details of several case studies on buildings of ages from 7 to 125 years and many of those evaluations have been largely based on visual inspection of buildings. Two of those are Hospital buildings of which extracted details are illustrated bellow.

Table 2.2:- extracted details of GHBs from the study on factors influencing the service life of buildings by W.P.S. Dias [20]

Building	Year & Age of building at Inspection in years	Building type	Deterioration	Comments
Bandaranayke Wing, Colombo General Hospital	1958 (30)	RC frame and Slab	Severe corrosion in Toilet areas	High chloride levels through operation
Angoda Mental Hospital	1925 (72)	Steel frame, RC slabs	Toilet area slab badly corroded	Poorly maintained

The paper further states that "the service life of structures depends on a variety of factors, such as (i) their purpose; (ii) Socio economic considerations; (iii) Materials of construction; (iv) Surrounding environment; (v) Degree of maintenance.

The study further suggested that serious repair work may become necessary after around 30 years if reinforced concrete elements of a building are exposed to a chloride source. Combination of load bearing brick wall and timber floors has been mentioned as the best combination for ensuring long service life whereas in almost all cases the reinforced concrete elements were said to be undergone significant corrosion, specially roofs and toilet areas.

The paper describes about the depth of carbonation and mentioned that reinforced concrete in all environments will experience carbonation and when the carbonation front reaches the reinforcement, the chemical protection given to it by the concrete will be lost and corrosion will take place especially in a moisture environment. It further states that depth of carbonation is considered to be a function of the square root of time.

The report on "useful life of buildings" by W.P.S Dias illustrates the table, taken from BS 7543:1992, as represented below and it defines "normal life" as a minimum of 60 years. The report states that it must be emphasized that "design life" is a very imprecise entity. This is because it depends on a variety of factors, such as (i) The quality of the original construction, (ii) The environment in which the building is located, and (iii) The quality and degree of maintenance carried out.

Table 2.3: Categories of design life for buildings (from BS 7543:1992)

Category	Description	Building Life	Examples
1	Temporary	Up to 10 yrs.	Site huts; temporary exhibition buildings
2	Short life	Min. 10 yrs.	Temporary classrooms; warehouses
3	Medium Life	Min. 30 yrs.	Industrial buildings; housing refurbishment
4	**Normal life**	**Min. 60 yrs.**	**Health, housing and educational buildings**
5	Long life	Min. 120 yrs.	Civic and high quality buildings

Further the report presents a table for useful life estimator based in part on historical data and re-illustrated below.

Table 2.4: Useful life estimator[20]

Case	Main Material	Environment	Useful Life (years)
Base Case	Reinforced concrete	dry[3], non-aggressive	60
Variations in Material	Structural steel[1]	dry[3], non-aggressive	80
	Masonry and/or Timber[2]	dry[3], non-aggressive	100
Variations in Environment	Reinforced concrete	wet[4], non-aggressive	40
	Reinforced concrete	wet[4], aggressive[5]	30

[1] The steel should be readily inspectable and accessible for routine maintenance

[2] This indicates that there is sparing use of steel that is subjected to corrosion

[3] This indicates that the main materials are protected against moisture, either by coverings (e.g. roofing sheets) or coatings (e.g. plasters)

[4] A wet environment indicates poor maintenance (e.g. leaking roofs or cracked plaster)

[5] The most pertinent aggressive environment for any steel in buildings is a chloride environment; sulphates can also attack the concrete itself.

While providing the above table the report states that poor quality construction could reduce useful life by up to 20 years; this would depend on the combination of material and environment. Further the above values for useful life imply a reasonable level of maintenance. Major refurbishments in each of the above categories could increase useful life by half the corresponding period of useful life per refurbishment. However, it is unlikely that useful life would be extended beyond twice the values quoted above.

2.2.4. Cracks on masonry walls

As per the lecture notes of M.T.R. Jayasinghe under the M.Eng. Degree course on Structural Engineering Design; the cracks that occur in walls are classified according to the direction as follows.

i. Vertical
ii. Horizontal
iii. Diagonal

The direction of crack can be coupled with the following for further information.

i. Straight ii. Toothed

2.2.4.1. Vertical cracks [21].

i. Due to Temperature variations

Since Sri Lanka is a tropical country with long hours of sun shine, temperature induced cracks are common feature on walls that are exposed to the direct sun light. The most common location for the occurrence of a thermal crack is the wall portion below a window. These cracks will generally appear at the end of the first five months spell of direct sunlight after the construction of the Building.

Initially they appear as hairline through cracks. Through cracks are those penetrate the full width of the wall thus appear on both inside and outside face. Those cracks will generally widen up to about 0.3-0.5mm. The crack is almost vertical and extends from the window sill level towards the foundation level.

The cracks that occur in masonry walls can also be explained with reasoning similar to those given for early thermal cracking in water retaining structures. When masonry walls receive a considerable amount of sunlight over long hours, the temperature of the masonry walls would rise by a few degrees. However, this expansion is generally restrained by cross walls, foundations, lintels or concrete floor slabs. Thus compressive stresses would be high at sections where the masonry wall area is minimum; generally below the windows. When subjected to compressive stresses, masonry shortens due to creep. During the night, the temperature drops where the shortened masonry wall has to occupy its original length. Thus tensile stresses will develop in the masonry wall which would be higher below the windows. This process will happen every day in a season of direct sunlight falling on the wall. If these tensile stresses exceed the tensile strength of masonry wall can crack.

ii. Due to Moisture movement

Bricks are produced by burning. These bricks are used to construct walls using cement and sand mortar. Bricks, which are dry after the production can undergo certain amount of expansion if they are used for the construction of walls without allowing sufficient time for the moisture expansion to take place. On the other hand, the use of nonstandard size bricks in Sri Lanka increase the number of joints in the brick work thus causing the masonry wall to shrink.

iii. Due to Foundation expansion

This occurs when the foundations are laid on shrinkable clayey sub soils that is drier than normal either due to abnormal climatic dry conditions or due to the ground having cleared off large trees immediately prior to the start of the construction of the building. The trees could have made the ground exceptionally dry and sufficient time has not been allowed for between the felling of trees and the start of construction.

2.2.4.2. Horizontal cracks [21]

Horizontal cracks in masonry walls can occur at following locations:

i. In pitched roofs at eaves level
ii. Underneath flat concrete roofs
iii. When there is water seeping through brick work
iv. When the slab below internal partition walls deflects

2.2.4.3. Diagonal cracks [21]

Diagonal cracks on external walls due to following facts are illustrated in Figure 2.2 below:

i. In pitched roofs at eaves level Foundation movement caused by shrinkable clayey soils
ii. Foundation movement caused by heaving of clayey soil,
iii. Cracks at the edges of an opening due to uneven stress distribution
iv. Thermal expansion of exposed roof slabs

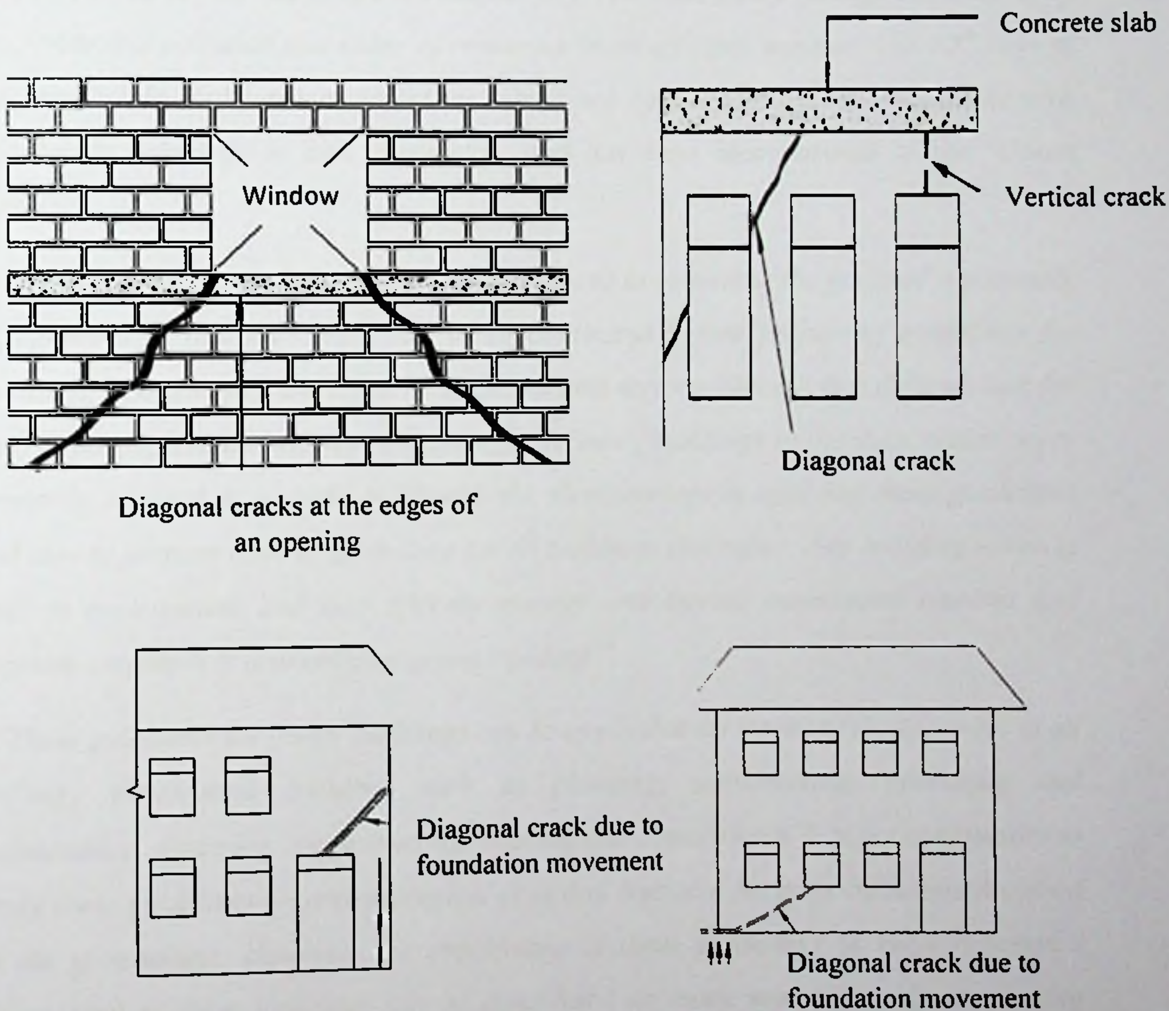

Figure 2.2: Diagonal cracks at Masonry walls

2.2.5. Guidelines on Sri Lankan government buildings

Ministry of Mahaweli Development and Environment has published a Guideline for Green and Environment friendly buildings for the state institutions in April, 2016. 06th, 07th and 8th paragraphs under the "Introduction" are reproduced below [22].

"The concept of sustainable development which was introduced to the world in 1992 propagated the use of limited resources in a sustainable manner in order to conserve them for future generations without putting them into jeopardy. As an extension to this concept, the green concept was introduced in 2010 and the objective of that was to keep the global temperature at bay by reducing the emission of greenhouse gases through minimizing of environmental pollution and using of resources in an efficient manner. The 12th item of the sustainable Development objectives which has been endorsed in 2015 deals with sustainable consumption and production, and has been incorporated to the 'Green Concept''.

"Guidelines on green buildings are key components in achieving the goals of sustainable development. A thorough study has to be conducted before preparing guidelines for buildings, because they are constructed by various sectors. Since it is a difficult task for such a thorough study in preparing these guidelines, 'buildings in the state sector' were primarily selected as a model to identify the shortcomings in applying these guidelines and also to prepare a set of guidelines for all buildings thereafter. Any building which is built in environment and user friendly manner and having maintained comfort and hygienic condition is also called a green building."

" These guidelines for green buildings can be applied at all stages of the life cycle of an ordinary government building such as planning, constructing, operating and maintenance, repairing, reconstructing, altering and demolishing. It is not compulsory to apply these guidelines on archaeological sites and National heritage buildings declared by the government. However, the application of these guidelines in reconstruction / redesigning of these buildings can be considered or made mandatory upon granting permission by the relevant institutions"

Under the section "present situation" the guideline present following important information regarding the government buildings.

"There is no detailed registry of state buildings and details of buildings belongs to each institution also have not been documented comprehensively. The survey which was conducted by the Department of Census and Statistics in 2012, had covered only population and houses. The survey had not covered the government buildings".

Further the guideline has set certain policy principles out of which few are represented below supposing that as related and important with the area of concern under this study.

"Priority should be given to the projects of reconstructing or rebuilding of existing buildings or providing the opportunity to expand such buildings in order to minimize the need of constructing new buildings"

"Conduct of Energy Audit and Carbon Foot Print audit for every building once in 3 years in order to enhance energy efficiency"

"Conduct a water usage audit of every building once in 3 years to enhance the efficiency of water use"

Under the section 24 –technical guideline, following important facts too are presented.

"Encouraging the use of a concrete slab for the roof of the building in order to minimize the use of Asbestos and to use a space similar in size of the building as an open area. Introduce suitable green cover on top of the slab in order to reduce the penetration of heat into the building along with maintaining proper ventilation within the building"

"Appointing a manager for dealing with green sustainability, energy index and carbon footprint calculation for every institution for a building or a set of buildings (on requirement)".

2.3. Summary of Literature Review

State of knowledge and awareness obtained through literature review constitute of various important areas.

General issues and common type of defects of GHBs of certain countries are also common to the local picture. Those studies on hospital buildings reveal about the necessity of adequate attention at the design and construction stages in reducing the cost due to unnecessary building defects. Further the local studies reveal that poor quality construction could reduce useful life of buildings by up to 20 years and major refurbishments could increase useful life by half the corresponding period of useful life per refurbishment.

Comprehensive details about defects such as cracks, corrosion and spalling of concrete, leakages and forming fungi, condensation etc. related to chief construction materials such as reinforced concrete and brick masonry are readily available through various studies and references. Humidity and the changes in temperature of various parts of the buildings are the major sources of problems in buildings. Service life of structures depends on a variety of factors such as quality of the original construction work including the material and the workmanship, surrounding environment and the degree of maintenance etc.

As per the global point of view rehabilitation activities in buildings often constitute an excellent opportunity for improving the human living environment, energy balance and the indoor climate. Building refurbishment is often considered as a technical matter that concerns technical experts and engineers, and it is hailed that narrow technical or financial vision can deteriorate people's living environment.

Certain countries have developed their own standard procedures and methodologies in upgrading the condition of built structures. Also building owners considering carrying out major refurbishment or retrofit works are faced with the problem of deciding which works they should undertake within budget constraints. At this stage detailed costing is generally too expensive, but without information on cost, no strategic decision can be made and therefore some European countries have developed data base software interfaces such as EPIQR as decision making tools to assess the state of deterioration, extent of rectification required and cost estimates etc.

Vital information on Sri Lankan health system is presented in the Annual Health Bulletin, a yearly publication of Ministry of Health. A new guideline on green and environment friendly building for the state institutions has been published in April 2016 by Ministry of Mahaweli Development and Environment. Also, the guideline is applicable for the major renovation works of government buildings.

3. REVIEW OF FIELD SURVEY DATA

Observations were made in 18 hospitals. Composition of buildings in a hospital premises can be categorized under different context such as below. LRH being one of the oldest hospital established in 1895 [1], was considered in gathering more information for the understanding of composition under certain categories of hospital buildings.

- Different age categories
    - o recently constructed and old buildings
    - o Specified age groups etc.
        - Composition in LRH
            - More than 50 years - 35%
            - 25 – 50 Years - 13%
            - 10 – 25 Years - 17%
            - 0 -10 years - 35%
- Different uses such as
    - o Wards
    - o OPD/Clinics
    - o Accident service
    - o HDU/Theatres/MICU

- Dispensary/Investigation
- Quarters
- Ancillary services (canteen, Laundry, Kitchen, garages) etc.

Observations under this particular study were limited to the accessible areas in wards, OPD/Clinics and accident service.

- Different structural forms

At present there are no GHBs more than ten- story in the country. Therefore different structural forms related to 'tall buildings' or 'high-rise buildings' whose height creates different conditions in the design, construction and use than those that exist in common buildings were not immerged important with respect to this study.

- Composition in LRH
  - More than four story buildings - 4%
    (A nine-story building)
  - Four story buildings - 8%
  - Single and two story buildings - 88%

Details of certain GHBs such as ages of buildings could be clearly identified. Table 3.1 illustrates the observations made on such GHBs out of eighteen hospital buildings observed.

Graphical representation of defects presented in figure 3.1 was developed using the observations made in all 18 hospital premises and indicated the occurrence of defects as a percentage of total no. of hospitals observed irrespective of any of above categorization. Photographic survey data of defects in GHBs is presented in Appendix 01.

Defects most common to each hospital premises mentioned above are due to ingress of moisture into masonry walls and RC structural members and because of that severe structural problems such as corrosion of embedded reinforcement etc. are initiated.

Table 3.1 Observations made on inspection of buildings

Building	Year & Age of building at Inspection in years	Building type & No. of stories	Defects observed
Nephrology and Neurology wards of LRH	2015 (02)	RC frame and Slab– (four- story)	- Corrosion of steel hand rails - Cracks on walls
Eye unit of LRH	2010 (07)	RC frame and Slab- (four- story)	- Flexural cracks in beams - Horizontal and vertical cracks on walls - water damping patches on walls - peeling off paints - water logging & random cracks at roof top slab
New nine-story building-LRH	2000 (16)	RC frame and Slab- (nine- story)	- Peeling off paint of soffits under toilet areas - Wall cracks (tiled and plastered walls) - Condensation and damages to ceiling finishes - Fungi - Corrosion of steel doors - random cracks on roof top slab
OPD and Administrative block of LRH	1957 (60)	RC frame and Slab- (two-story)	- Severe corrosion in toilet areas and balcony areas and exposed reinforcement on slab soffit and spalling of concrete - Fungi, Discoloration, Peeling off and blistering of paint water leakages,

Table 3.1 Observations on inspection of buildings Cont....

Building	**Year & Age of building at Inspection in yrs.**	**Building type & No. of stories**	**Defects observed**
National Institute for **Nephrology, Dialysis** and Transplantation – **Colombo 10**	2009 (06)	RC frame and Slab-(four- story)	- Accumulation of large amount of water on slab soffits affecting ceiling and wall finishes. (condensation)
Kandana (Divisional Hospital)	Old buildings	Structures of RC frame and Load bearing wall	- Deterioration of slabs, water leakages etc. - Fungi, peeling off & blistering of paints - Leakages associated with plumbing lines
Base Hospital Homagama	Recently constructed and Old Buildings	Structures of RC frame and Load bearing wall	- Wall cracks, - Slab deterioration - Peeling off paint of soffits - Blistering appears in the wall plasters
North Colombo Teaching Hospital - Ragama	Recently constructed and Old Buildings	Structures of RC frame and Load bearing wall	- Excessive cracking in walls, - Slab deterioration is visible in old buildings, walls are cracked in old buildings, - Peeling of and blistering of paints are visible almost all the walls and some slab soffits in old buildings. - Separation cracks between RC members and walls etc. - Sever corrosion of main reinforcement of columns above 4th story level of an ongoing construction work and spalling of concrete
Negambo Hospital	Recently constructed Building		- Directly Observed design faults - Almost all the types of defects were observed in the seven- story building.

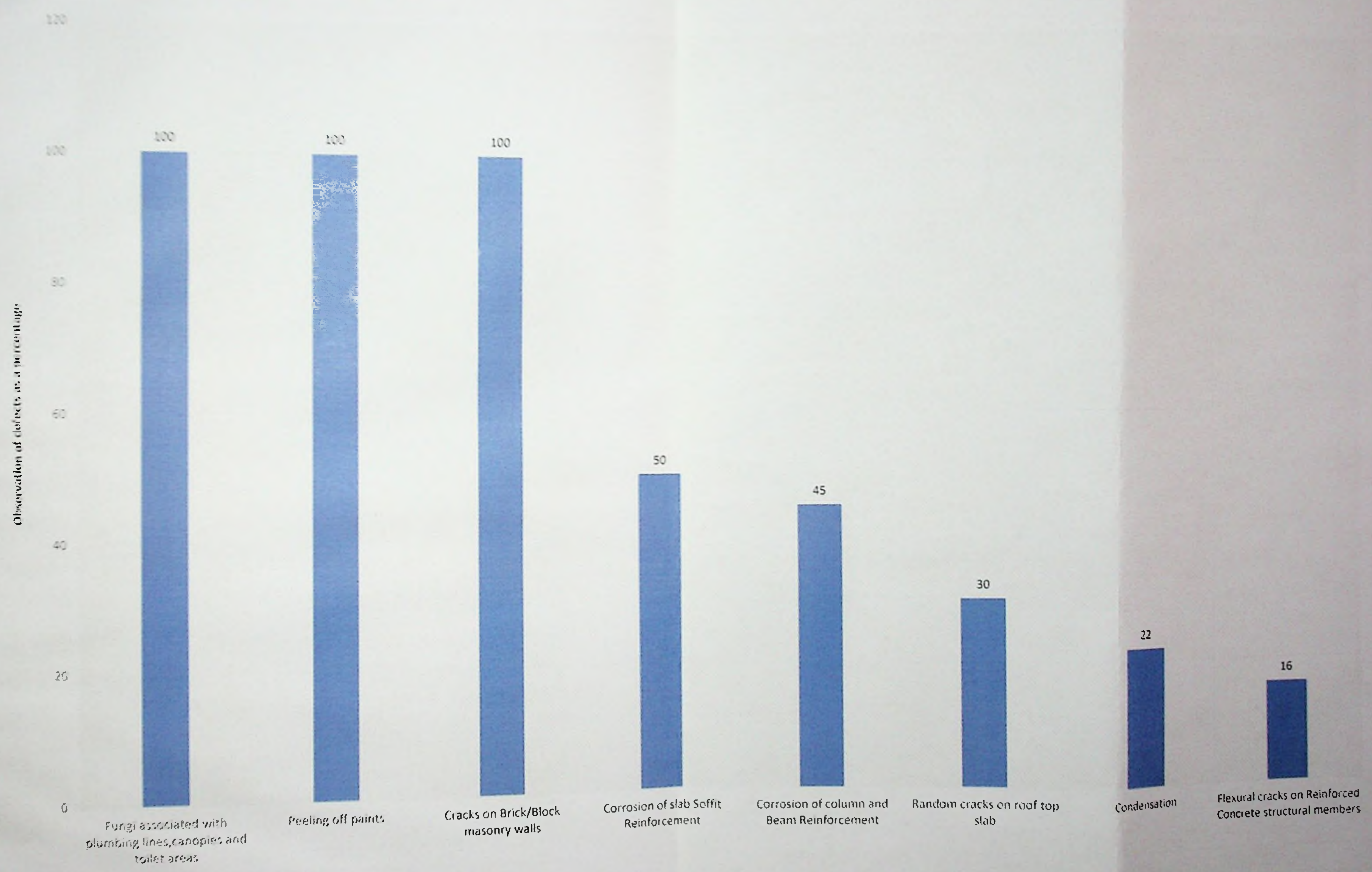

Figure 3.1: Quantitative analysis of Common Defects as per the observations

3.1. Fungi, discoloration, peeling off and blistering of paints

This situation was observed in both old and newly constructed buildings. Figure 3.2 shows the formation of fungi at canopy areas of OPD building and peeling off and blistering of paints in slab soffits of OPD building and the areas affected in newly constructed nine- story building.

Figure:3.2: formation of fungii,peeling off and blistering of paint at LRH

3.2. Severe corrosion of reinforcement of slab soffits and spalling of concrete

Slab soffits of old buildings were subjected to severe corrosion of reinforcement and spalling of concrete. The situation observed in the OPD building of LRH is shown in Figure 3.3 below. Improper rectification work to such defect in the same building is shown in Figure 3.4. Soffits under toilet areas, canopy slabs etc. had been undergone this situation.

Figure 3.3: Corrosion of reinforcement of slab soffits of OPD building of LRH

Figure 3.4: Improper rectification work to corroded slab reinforcement

3.3. Condensation of water on slab soffits and walls

Accumulation of large amount of water under slab soffits and adjacent walls by condensation was observed at the non-air conditioned areas adjacent to operation theatres which operates at low temperatures below about 18^0C . Figure 3.5 shows this situation clearly observed at the NINDT at Colombo 10. Ceilings and wall finishes were considerably affected by this situation, and Figure 3.6 shows such affected areas observed at the nine- story building in LRH.

Figure 3. 5: Condensation and accumulation of water under slab soffits at NINDT

Mineral fibre Ceiling sheets had been used for the affected ceiling shown in figure 3.6 below.

Figure 3.6: Ceiling affected due to condensation

Nine-story building - LRH

3.4. Severe corrosion of main reinforcement of columns under construction

Figure 3.7 shows a very critical and unacceptable situation such that sea sand had been used for structural concrete work at NCTH, Ragama and observed severe corrosion of main reinforcement.

Fig 3.7: Severe corrosion of reinforcement of column concreted using sea sand at NCTH - Ragama

3.5. Direct and Indirect Causes of Defects

3.5.1. Defects in structural members (Concrete)

3.5.1.1. Flexural, Shear and Torsional cracks

One important aspect associates with cracking is public perception. I.e., if a crack develops in a concrete element, public feel that their total product has failed without considering the cause or its effect. Cracks influence the satisfactory behaviour and durability of a concrete element, it reduces shear capacity of the section and results in loss of aesthetics.

These cracks are known to be occurred mainly because of the reaction of the structural elements to the change of loading pattern, reaction of the structural elements to settlement and natural aging of the structure.

In the Eye unit of LRH it was observed flexural cracks less than 0.3mm due to which no adverse effect when reinforcement cover is adequate.

Figure 3.8: Flexural cracks on beams

Eye Unit LRH

In addition to that, in the seven- story building in the Negambo hospital the main cause of the above cracks were observed to be load induced cracks due to the inadequacy of the designed sections.

3.5.1.2. Random cracks

Direct causes of random cracks observed mainly on roof slabs are supposed to be due to breakages occur through thermal, chemical or mechanical processes causing shrinkage, expansion etc.

Observed roof top slab surfaces can be the concrete overlays done on the water proofing and heat insulations done over the original concrete surface (specially the nine-story building at LRH) but expansion/controlled joints could not be observed.

Concrete is a quasi-brittle material with low capacity for deformation under tensile stresses. Mechanical loading, harmful reactions and environmental loading cause concrete to develop tensile stresses. When these tensile stresses exceed the tensile strength of concrete cracks start to initiate.

Concrete is strong in compression, but weak in tension, therefore with crack initiation steel will carry the tensile forces and control the crack widening. However, the cracks will act as channels through which moisture, oxygen and other harmful elements like Cl, CO_2 etc. reaching reinforcement and initiate corrosion. With time, there will be more corrosion and finally the cover concrete can spall off due to the pressure exerted by rust. Indirect causes of such situations can be minimized by taking appropriate precautions in design, material selection, construction practice and maintenance that will ensure the satisfactory use for extended period of time without any significant loss of aesthetics, service life and serviceability.

It is described below above types of concrete cracks, and some of their possible causes as per some references.

3.5.1.3. Direct Causes for Cracking [23]

- Dry conditions during curing period

Water is an essential factor for hydration process of curing to harden the concrete. Heat released during this reaction when dry humidity atmospheric condition exist, the surface water evaporates rapidly; hence the curing occurs slowly than the interior. This uneven curing causes cracks.

- Loss of volume due to moisture loss (I.e., shrinkage)
- Excess water quantity in fresh concrete

Most often used cement is Portland cement, which is a hydraulic type of cement and needs water to develop strength. With sufficient water, concrete is easy to work with. When concrete dries and hardens, the excess water evaporates and concrete starts to shrink. As a result cracks develop in concrete.

- Misuse of correct proportions of ingredients and workmanship.
- Loss of support

  Cracks can occur due to inadequate support or premature removal of forms.
- Severe deterioration resulting in serious corrosion of reinforcement
- Sudden climatic changes i.e., freezing & thawing

  (Not common to Sri Lanka)
- Chemical reactions such as Alkali–aggregate reaction and Sulphate attack
- Some errors or shortcomings in construction (workmanship, materials)
- Physical damage, explosion, impact, fire

3.5.1.4. Mechanism of Cracking and deterioration [24],[25]

Cracks can be mainly categorized as pre hardening cracks (pre-setting cracks) and cracks in hardened concrete.

- Pre-setting cracks

Cracks form during placing, compaction and finishing caused by movement of concrete before it dries.

Types of pre-setting cracks

- o Plastic shrinkage cracks

In the first few hours of concreting, concrete is plastic and has a little strength. In the mix of concrete, air and water have the least density and they move to the surface of concrete mix while other materials are going down. This upward movement of water is known as bleeding. In times of high temperature and low humidity or under windy conditions, the bleeding water evaporates rapidly than the bleeding rate. Due to the reduction of concrete volume, it tries to shrink but unable to do so, due to the restraint condition of underlying layer. As a result, tensile stresses develop, causing irregular cracks to develop in the low strength concrete.

- Plastic settlement cracks

While water moves upward, heavier particles move downward or obstructed by top layer of reinforcement or shuttering. The plastic concrete may arch over the top of individual reinforcing bars causing tension in the surface. Cracks develop in regular spacing over the embedded items such as reinforcement steel, adjacent to forms and mostly in conjunction with voids under bars.

- Cracks caused by movement of formwork

If the formwork is not strong enough to bear the stresses, it may bend or bulge during the placement and compaction.

- Cracks in Hardened concrete

These cracks occur due to drying shrinkage, movement or settlement of the ground or placing high loads on concrete structures than for what they have been designed to carry. Careful and correct placement helps to prevent serious cracking after hardening.

Types of hardening cracks;

- Drying Shrinkage Cracks

When Water/Cement ratio is higher than it needs to react with cement, considering the workability and compaction excess water remains in capillary pores in cement paste and in times of low humidity, it losses from surface. This evaporation causes concrete to reduce its volume called as drying shrinkage. If this shrinkage movement is restrained by externally or internally, a stress develops in concrete. If this stress exceeds the tensile strength of concrete, concrete tends to crack. Maximum rate of developing a crack is several months to three or four years after casting, which depends on the rate of drying caused by environment. First this affects the surface layer, while corners have the most probability to crack as they loss moisture in adjacent two layers. Members with large cross sectional dimensions crack due to the restraint by inner surface of undried concrete.

These cracks are commonly occurring in following locations.

- In ground slabs where horizontal dimension is much greater than the other. Cracks form across the middle of the slab, parallel to the shorter side and can be diagonal at corners.
- In suspended slabs supported on stiff edge beams. The location of cracking can be influenced by voids in the slab such as those left for service or stair wells.
- At significant changes in cross sections.

- Early Thermal Contraction Cracks

Concrete hardens as a result of hydration process between cement and water, which generates heat. The peak temperature depends upon the cement type and content, initial temperature, geometry of the member, type of formwork and surrounding conditions. Temperature in members having large cross sectional areas is higher than the smaller ones. Due to this heat, concrete get expanded, but it is restrained by previous pours, resulting in compressive strength to grow. This stress is very low and relieved by creep. After concrete reaches its maximum strength it starts to cool and reduce the volume causing tensile stress to develop which is much higher and cannot be relieved by creep. Due to the concrete's poor tensile strength, and stress caused by restraint to temperature related contraction, concrete cracks. In thick members there are different temperatures in place to place. When surface layer cools and contracts it is restrained by a layer before, which is having higher temperature and cause cracks.

- Crazing

Crazing occurs either in an exposed surface or a surface in contact with formwork. This can happen due to the change of properties close to the surface or at places where there is steep moisture content. A formwork face of smooth and of low permeability increases crazing. Crazing appears within few days of casting but can occur at any time under appropriate climatic condition such as low humidity. These cannot be seen until there is dirt as they are narrow and shallow as well as not affecting the durability.

- Load Induced Cracks

These cracks occur mainly due to overloading of the members. Types of load induced cracks are

  - Flexural (bending) cracks
  - Shear cracks
  - Tension cracks
  - Punching shear cracks
  - Cracks due to anchorage or lap failure

- Other

  - Corrosion of reinforcement and deterioration of concrete

Corrosion of reinforcing steel and other embedded materials is one of the leading causes of deterioration of concrete. When steel corrodes, the resulting rust occupies a greater volume than steel. The expansion creates tensile stresses in the concrete, which can cause cracking and spalling of the surrounding concrete.

Atmospheric carbon dioxide reduces the alkalinity of concrete and will lead to promoting corrosion. Chlorides (the main source of which is from sea spray near the coastline) will also lead to such reduction in alkalinity, and also promote electrolytic corrosion processes in both reinforced concrete and steel.

  - Alkali–aggregate reaction

This type of failure occurs when the active mineral constituents of some aggregates react with the alkali hydroxides in the concrete. This occurs in two forms as alkali-silica reaction and alkali-carbonate reaction. Indication of alkali-aggregate reactivity is a network of cracks, closed or spalling joints or displacement of different portions of a structure.

- Sulphate Attack

Sulphates react with Tricalcium Aluminate (C3A) in cement to form a compound ettringite will cause the damage to concrete while it depends on principal factors such as the percentage of C3A in the cement, permeability of concrete, solubility of sulphate.

Sulphates are found in water and sometimes in aggregates while Portland cement contains sulphates as gypsum ($CaSO_4$). Maximum acceptable sulphate in concrete is about 4% by weight of cement.

3.5.2. Defects in masonry walls (Brick /Block)

Both the brick and cement blocks had been used for the walls of the GHBs whereas engineering bricks had been used in old buildings and cement blocks had been used in recently constructed buildings.

Figure 3.9:
Walls of brick masonry in 60 years old OPD building of LRH

Figure 3.10:
Walls of Block masonry in 02 years old Nephrology and Neurology wards of LRH

Most commonly occurring defects such as cracking, fretting and fungi formations etc. were observed regarding masonry walls. As far as concerning Lady Ridgeway Hospital most of the horizontal, vertical and random cracks were observed in block masonry walls in recently constructed buildings as shown in figures 3.11 and 3.12 rather than in old Buildings. Vertical crack shown in figure 3.12 penetrate the full width of the wall and these type of cracks occur due to temperature variations

Figure 3.11: cracks in Eye Unit LRH

Figure 3.12: Cracks in nine-story building - LRH

Almost all the walls adjacent to toilet areas showed water dampness and severe formation of fungi were observed in the areas of waste sewer and water supply lines, near the A/C out door units as shown in Figures 3.13 and 3.14.

Figure 3.13: Water damp patches at LRH

Figure 3.14: Deterioration associated with plumbing lines and A/C outdoor units at LRH

3.5.2.1. Causes of defects in masonry walls

The leaking pipe inside the walls and un plastered duct walls and leaking toilet walls were the causes for damp patches of the walls. The stagnated water flows through the paths along conduits in slab is finally appears at walls.

Cracks are very common in buildings and the technical discussion about the causes are well described in Chapter 2: Literature review.

3.5.3. Defects in Finishes

Basically the Ceiling, Wall and floor finishes are considered under this section. Figure 3:15 illustrates the deterioration of wall and soffit plasters at OPD building of LRH. Seepage of water from outside, adjacent washing and toilet areas, A/C out door units, plumbing lines etc. have been the major reasons for such deteriorations.

When observing the other affected wall and ceiling surfaces, it was noticed that different layers of paints were present and underneath layers also had been peeled off with the top most paint layer.

Further the figure 3.16 illustrates the cracks on wall and floor tiles in nine- story building at LRH.

Figure 3. 15: - Fungi and deterioration of wall plasters of OPD Building -LRH

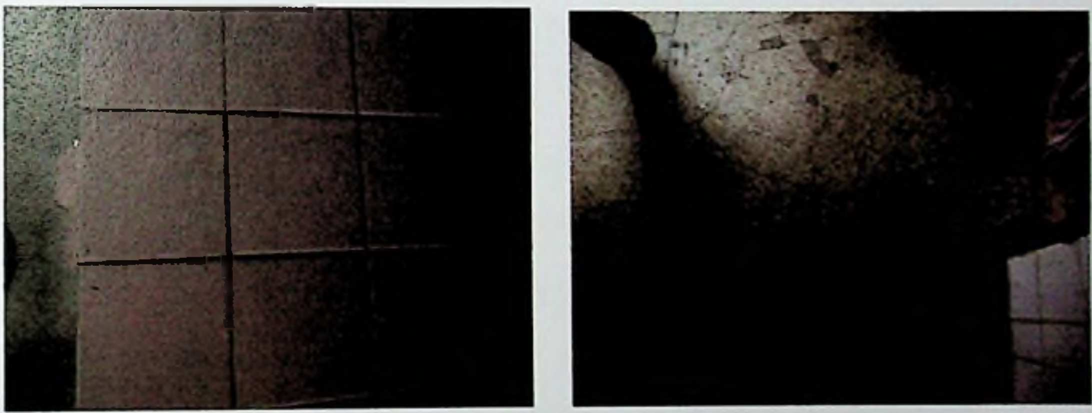

Figure 3.16: Cracks in wall and floor tiles of nine-story building at LRH

3.5.3.1. Causes of defects in finishes

Defects in structural RC members and the masonry walls have been the cause for the most of the defects in finishes.

Other than the direct causes such as condensation, sweating, water seepages etc. the poor workmanship, poor maintenance, improper arrangements of services such as A/C out door units as shown in Figure 3.18 and use of poor quality material etc. were observed to be as the causes affecting the finishes. Other than that, matters such as inadequate surface preparation and application of water base paints instead of solvent base paints on old plaster works etc. would have been the major reasons for the problems associated with painted surfaces. Attention has not been given for a concept of uniform theme of paint colours regarding all the GHBs.

In GHBs the floor finishes are more often observed as locally manufactured homogeneous floor tiles and locally manufactured ceramic wall tiles. But in some foreign funded buildings some other types of tiles were observed with lots of defects.

Figure 3.17 illustrates the difference in floor and wall finishes with different quality material in two buildings of LRH.

Figure 3.17: Improper arrangement of A/C Outdoor units

Figure 3.18: A Lobby area finished with locally manufactured tiles in OPD building at LRH renovated with local funds

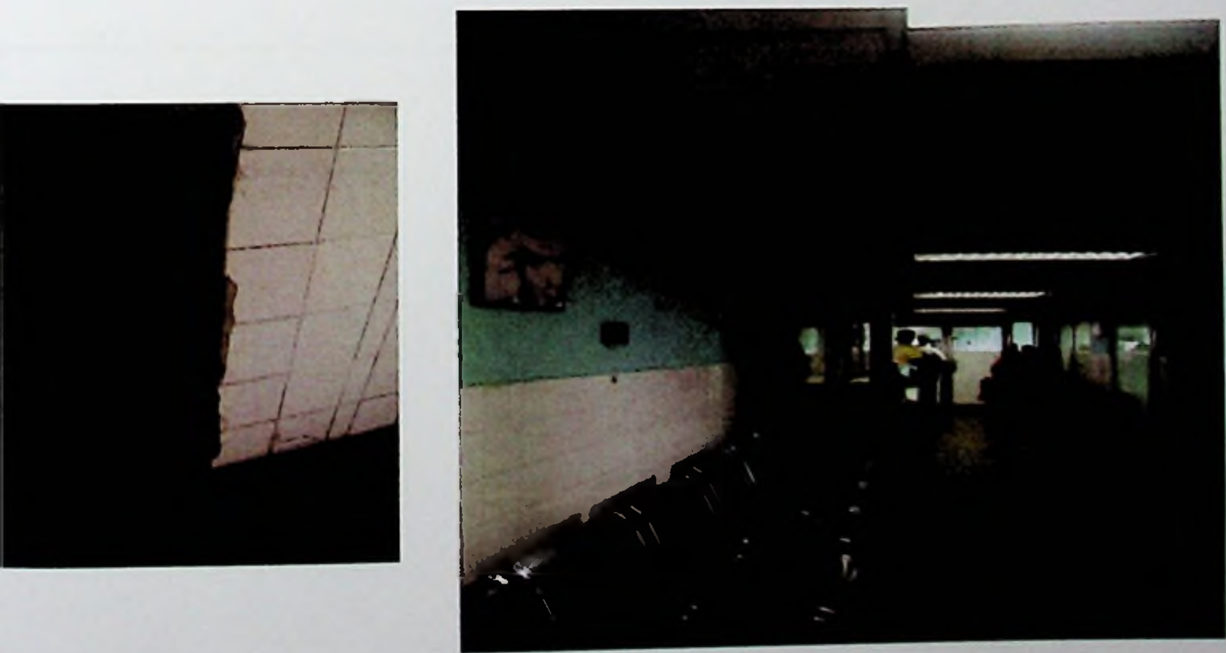

Figure 3. 19: A Lobby area finished with imported tiles in recently constructed nine-story building in LRH renovated with foreign funds

3.6. Comparison of the Condition of GHBs With Private Hospitals

Table 3.2 illustrates a comparison of situation of GHBs with Private Hospital Buildings.

Table 3.2: Comparison of GHBs with Private Hospital Buildings (PHB)

Government Hospital Buildings	Private Hospital Buildings
Cater for larger no. of patient visits and admissions	Cater for smaller no. of patient visits and admissions
Users are from the low and middle income levels of the general public.	Users are from the middle and higher income levels of the society.
Range from single story to multi story buildings scattered within a larger plot of land area.	Consists of one single multi storied building in a limited land area.
Air condition facility is provided only for certain areas.	Entire area is provided with Air Condition facility.
Not adopting maintenance plans. Only corrective maintenance is practiced.	Adopting maintenance plans and quality management systems to comply with international certifications such as Joint Commission International Accreditation Standards for Hospitals etc.

3.7. Predicting the Structural Condition of Observed GHBs

A thorough observation of the condition of head office building of Ceylon Electricity Board which has been constructed in 1960s and located very close to sea happened to be carried out during the same period of study about the GHBs.

It was clearly obvious that the degree of deterioration of CEB head office building is critical than the condition of GHBs observed. Figure 3.20 shows the existing condition of CEB head office building which is located at Sir. Chittampalm A. Gardiner Mawatha, Colombo 02.

Figure 3.20: Condition of CEB Head Office Building

CECB had been assigned to carry out a structural assessment of CEB head office building and accordingly concrete core samples extracted from various floors were checked for load testing to determine concrete compressive strength. Further in order to assess the durability, core samples were tested for extent of carbonation and specially the roof top for water absorption.

Based on the information gathered from field tests, laboratory tests and visual inspections existing condition of structural material of CEB head office building was assessed.

Accordingly the maximum and minimum concrete cube strength were 44.26 N/mm^2 and 27.2N/mm^2 respectively. Also no significant carbonation depth was observed. As per the test results concrete strength and quality is in satisfactory level and in general thermal, moisture and possibly air born chlorides from sea spray have affected external structural elements.

Therefore when no design related problems are inherent and hence design member capacities and structural robustness are satisfactory regarding government hospital buildings, concrete strength and quality can be assumed satisfactory.

Further, the cost for a complete renovation of CEB head office building has been estimated as around Rs. 500 million whereas the cost of a new building to accommodate occupants of existing CEB head office building incorporating more space and additional facilities to match with contemporary building solutions is around Rs. 2.5 billion.

3.8. Local Practice of Designing and Construction of GHBs

3.8.1. Consultancy services for government hospital buildings

Hospital Works section of Central Engineering Consultancy Bureau (CECB) is the main consultancy service provider for major construction projects undertaken by Ministry of Health. Since 1990, CECB provides consultancy services for renovation and upgrading of existing buildings, and construction of multi-story buildings in the health sector [26].

As per the official web site of CECB, the services provided by CECB include;

- Advise on construction proposals.
- Preparation of Survey Plans.
- Preparation of Master Plans.
- Rehabilitation of sewerage treatment plants.
- Design of building complexes.
- Renovation of Buildings.

There are offices of CECB with more often one or two work supervisors located within the hospital premises in most of the major Hospitals such as National Hospital, Teaching hospitals and General hospitals etc. Preparation of estimates for the minor renovation works for the daily requests of hospital administration, checking of measurements and construction supervision of such works are the routine duties being carried out by the work supervisors in CECB offices located within the hospital premises.

3.8.2. Current practice of structural design of GHBs

Structural design of GHBs are being carried out based on British standards and followings are the main documents frequently being used.

- Manual of Institute of Structural Engineers UK
- BS 6399 , BS 8110 -1985
- Standard Method of Detailing
- Reynolds Hand book

It was noticed that structural design of GHBs differs from designing of other buildings with regard to followings.

- Obtaining imposed load – As per the BS 6399
- Designing of structural members in the areas associated with radiation activities etc. as per the recommendation and specifications of Atomic Energy Authority.

It is a common incident that a large crowd of people enter and walk towards wards at the beginning of time allocated for visiting patients while the same crowd walking back through corridors at the end of such period. Effect of vibration due to such situation is ignored at the structural design of GHBs.

Toilet blocks of GHBs are frequently being used and observed wet throughout the day. Leakages, water dampness and deterioration etc. can be observed associated with all most all the toilet blocks. These kind of issues seems not being addressed specially at the initial design stage other than keeping required structural drops for laying pipes and water proofing work etc.

Balconies and Canopies of reinforced concrete are observed almost flat and no innovative approaches were observed in preventing accumulation of water.

3.8.3. Current practice of construction, renovation and maintenance of GHBs

3.8.3.1. New construction works

Project proposals and tentative cost estimates are prepared by the relevant hospital authorities in consultation with the Hospital works division of CECB for obtaining budgetary allocations and preliminary approvals.

CECB starts Preparation of Detailed architectural, structural and services drawings, detailed Engineers Estimate and the draft bid documents and forward to the relevant hospital Authorities or to the Ministry. Contract documentation and procurement actions based on the Government Procurement guidelines at pre construction stage are observed to be properly managed by both CECB and the Hospital Authorities/Health Ministry until the award of contract. However it is observed that same bidders are participating for bidding for construction contracts in the hospital sector and most of the procurement committee decisions have been made for award of contracts for the financially lowest bids.

After the contract award, contract administration and supervision is mainly carried out by the CECB. Most of the construction works are not continuously supervised by engineers or experienced technical officers except periodic or random supervisions. It is hardly completed a construction work as per the scheduled completion date, but no any contractor has been black listed so far due to their unacceptable performance. There are no recruited engineers in any discipline or technical officers in government hospitals except around ten numbers of government engineers working attached to the Building Engineering branch of Ministry of Health. They are mainly involving with the work of bid opening committees, preparation of Technical Evaluation committee reports with recommendations on draft bid documents, variations etc. and Contract award recommendations for the approval of relevant procurement committees. Also checking the engineers' estimates and payment certificates forwarded by CECB and random supervision of construction sites and preparation of estimates and bid documents for certain works entrusted by the ministry administration are being carried out by them.

Certain larger construction projects have directly been offered to CECB as Turnkey Contracts.

At the completion of work it seems insufficient attention on acquiring completed handing over synopsis such as mentioned below.

- As built drawings,
- Reports on Quality assurance and controlling.
- Inventory lists,
- Warranty certificates
- Maintenance manuals etc.

Further, A very poor attention and involvement was observed about getting rectified the defects during the defect liability period of a construction contract.

3.8.3.2. Renovation and maintenance works

A Building Schedule of Rates (BSR) has been prepared by CECB for ministry of Health for renovation of hospital buildings. Based on that detailed engineers estimates are being prepared for major and minor renovation works as per the requests made by the hospital authorities.

Conducting a detailed building audit by a systematic and a complete visit of the building according to a well-defined itinerary so that all the building components to be evaluated at sight is rarely practiced. Lack of attention has been given regarding the requirement of a degradation report/ condition assessment reports etc. prior to preparation of cost estimate of a renovation work. Also, it is not much concerned about the requirement of an appropriate specification and detailed drawings indicating existing arrangements, condition and the proposed modifications regarding a particular renovation work. Major concern is given only in preparing a cost estimate including a set of items extracted from the BSR mentioned above and the preparing of bid documents to comply with government procurement guidelines.

Attention of Technical Evaluation Committees and Procurement Committees is mainly focused on the compliance of the bidding documents to government procurement guidelines. Appropriateness and sufficiency of specifications and the required technical details for a proper execution of work seems given less attention.

Construction contractors are annually registered by the hospital authorities and the Ministry of Health for certain financial limits. Bids are invited for hospital building renovation works through National Competitive Bidding (NCB) or Limited Competitive Bidding (LCB) procedure based on the urgency of the renovation works. Most of the small value jobs through Maintenance Requests (MR) are getting done by obtaining quotations from a selected list of contractors.

3.9. Summary of review of field survey data

Critical and most frequent defects are observed to be associated with toilet areas, canopy slabs, open verandas, roof slabs and plumbing lines and A/C outdoor units etc. All most all the types of defects those can occur in RC members, brick/block masonry works and finishes could be observed during this particular study related to hospital buildings. Also the direct and indirect causes of defects were identified.

Most frequent defects observed in newly constructed buildings could be identified as;

- Cracks in RC structural members and masonry walls
- Cracks in floor and wall tiles
- Peeling off paints from slab soffits etc.

Poor workmanship, use of poor quality material and the inappropriate methodologies could be identified as the main reasons of defects associated with the newly constructed buildings in hospital premises.

Frequent defects observed in old buildings were identified as;

- Heavy formation of fungi
- Severe corrosion of reinforcement and spalling of concrete
- Cracks in brick masonry walls closer to larger trees etc.

Inadequate maintenance and improper repair works were observed regarding the deteriorated situation of the old buildings.

Both the new and old buildings were observed with the improper arrangements and lack of maintenance of other services such as plumbing and A/C outdoor units etc.

Further, no any maintenance plans being adopted in hospital buildings observed.

Despite the extent of deterioration as presented in photographic survey data in Appendix 01, most of the reinforced concrete framed structures are observed to be at an acceptable structural condition.

Local practice of structural design of GHBs is to design the buildings for ultimate limit state followed by specified checks for serviceability limit state in BS 8110 -1985. A special concern seems required regarding the design criteria for toilet blocks and operation theatres etc.

Pre-construction activities related to the construction of new buildings in hospital premises seems performing satisfactorily whereas the construction and post construction stages are given lesser attention.

With respect to the renovation of existing buildings in hospital premises, all activities throughout pre construction, construction and post construction stages are seems unsatisfactory, except the relevant procurement actions until the award of relevant work contract.

4. PREVENTION/REMEDIAL MEASURES FOR DEFECTS OF GOVERNMENT HOSPITAL BUILDINGS

Once identified the locations and the direct causes of defects it is convenient to address those issues in a well-organized rectification work. Suitable technical approaches are well documented in various references globally. Further the durability of buildings can be improved through appropriate use of presently available good quality water proofing materials, performance enhancing admixtures for concrete and specialists repair materials etc.

Table 4:1 Remedial measures for defects in GHB

Defect category	remedy by
Defects in RC structural members	- **Removal of damage concrete:** Regardless of the type of deterioration, all unsound and disintegrated concrete must be removed. The extent of concrete removal depends on the extent of damage. Concrete may be removed by power tools or by water blasting with or without entrained abrasives. Specified procedure as approved by a qualified engineer should be followed. - **Cleaning concrete substrate for patch repairs** To ensure good adhesion of mortar or new concrete to the parent material, the substrate should be clean and free of dust and loose material - **Cleaning reinforcement** If the deterioration of concrete has been caused by corrosion of reinforcement, the products of corrosion must be removed before placing the new concrete, otherwise the repair will not be effective. If the damage is due to chloride contamination, it is essential to remove

Table 4:1 Remedial measures for defects in GHBs- Cont.

	all rust from the steel, as any residual rust will be contaminated with chlorides that could restart the corrosion later. Water-abrasive blasting is the most effective method for cleaning the reinforcement. The abrasion removes the solid rust and water dissolves the chlorides away. Enough concrete must be cut away on the blind side of the reinforcement to allow room for water-abrasive blasting - the space will be needed for providing concrete cover to the steel. If the cause of damage is carbonation, rust removal is less critical and it will be sufficient to remove any loose rust that might prevent adhesion of the repair material to the steel. - **Adding reinforcement** If rusting has reduced the cross-sectional area of reinforcement considerably, extra reinforcement must be added before the repair as specified by the qualified engineer. - **Applying bonding coat to concrete** If the selected repair method requires application of a proprietary bonding coat to the concrete substrate, it is essential to read the manufacturer's instructions for preparation and application of the particular bonding material. These instructions must be strictly followed. Directions given here are for general guidance only. The working time of different types of bonding coats varies and is often limited. The bonding coat will prevent bonding if it is allowed to dry. It is therefore important to plan the timing for its application beforehand so that the repair can be completed within the allowed working period. The "wetness" of concrete substrate required prior to application of bonding coats is also different for different bonding materials. Generally, epoxy bonding coats are applied to dry surfaces, but

Table 4:1 Remedial measures for defects in GHBs- Cont.

	specially formulated resins are available for damp surfaces also. Cementitious bonding coats (whether modified with latex or unmodified) require the substrate to be "pre-wetted", but only just damp at the time of application. - **Coating reinforcement** Apart from cement slurry, other coatings are generally proprietary products and it is essential to read the manufacturer's instructions for their application. These must be strictly followed. - **Use an appropriate Formwork** - **Repair with an appropriate mortar as specified** Cement sand mortar, polymer modified cementitious mortar or with epoxy mortars. - **Adoption of proper curing** All types of cementitious repair need thorough and continuous curing to develop strength and impermeability, and to reduce drying shrinkage to a minimum while bond strength is developing. Water used for curing shall be free from ingredients harmful to concrete. Epoxy based materials are self-curing and do not require external curing - **Repairing cracks** It is important to recognize if cracking is of a size and type that is harmful, and act accordingly. For the purpose of repair identify whether the cracks are dead or live. Dead cracks can be repaired by any of the following methods: - Epoxy injection - Grouting

Table 4:1 Remedial measures for defects in GHBs- Cont.

	- Routing and sealing - Drilling and plugging - Stitching - Adding reinforcement - Overlays and surface treatments. Live cracks can be repaired by: - Flexible sealing. - **Apply protective coatings on concrete structure** - For increasing durability - To give extra protection against reoccurrence of deterioration and to conceal the repair work.
Defects in Masonry walls	- **Repairing cracks** Cracks that are subjected to permanent movement (e.g. due to temperature movements and live loads) should be treated as expansion joints. If they are not unsightly or if there is no danger of water penetration through them, they may be left as they are, otherwise they should be sealed with a flexible sealant of width and depth to suit the expected range of movement. Non-permanent seal If the expected movements are insignificant or if the crack is not to be sealed permanently implement the following procedure. This is the most common type of repair for movement cracks in masonry: - Clean the crack of loose dust and debris, oil, algae and other contaminants by using a high pressure water jet, compressed

Table 4:1 Remedial measures for defects in GHBs- Cont.

	air (oil free) or vacuum suction. Allow the surfaces of the crack to dry; - Prime the crack surfaces with a primer recommended by the sealant manufacturer; - If the width of crack is more than 5mm, insert a tight fitting closed-cell polyethylene foam backer rod into the crack. The backer rod must be pushed into a depth such that the sealant applied will have a width to depth ratio of 2:1, or minimum 5mm depth of sealant. For cracks less than 5 mm wide, do not insert a backer rod; - Seal the crack by caulking with a flexible sealant flush with the masonry face. Permanent seal - If the expected movements are significant or if the crack is to be sealed permanently, provide a recessed seal or a surface seal as described below. Recessed Seal - Cut a recess along the crack using a power chisel or crack cutter. The dimensions of the recess should comply with the requirements of the crack movement and sealant material Clean the recess of dust and debris by wire brushing followed by air-blasting with oil free compressed air; - Prime the surfaces of the recess with a primer specified by the sealant manufacturer; - Place a bond breaker strip at the bottom of recess; - Fill the recess with flexible sealant as per the manufacturer's instructions. Surface Seal

Table 4:1 Remedial measures for defects in GHBs- Cont.

	Narrow cracks subject to significant movement where aesthetics are not important may be sealed with a flexible surface seal - Clean the masonry surface adjacent to the crack of dirt, algae, and other contaminants. - Prime the masonry surface along the crack over a width of approximately 100mm with a primer specified by the sealant manufacturer; - Place a 20mm wide bond breaker strip over the crack; - Apply minimum 60mm wide and 3mm thick flexible joint sealant over the bond breaker with a trowel. **Repair procedure for dead cracks** Fine cracks are best repaired by epoxy resin injection. Wider cracks can be repaired as follows: - If cracks run through masonry units and mortar beds, cut out the units and remove the joint mortar. Wet the masonry. Allow to dry until it is just damp (no residual water). Install new units, bonding with mortar similar to that in the existing wall. Avoid strong mortar and use a well graded sand to minimize shrinkage. Where the wall is severely exposed, polymer additives may be used in the mortar to increase bond and durability, provided the sand used has a negligible clay content. - The above procedure for replacing cracked masonry units is also used for repairing spalled masonry. If cracks run through joints only (i.e. masonry units are not affected), rake the joints (on both sides of the walls if accessible) to a minimum depth of 15mm using a square edged

Table 4:1 Remedial measures for defects in GHBs- Cont.

	tool. Clean the joints of dust and debris with a wire brush or by oil-free air-blasting. Wet the masonry. Allow to dry until it is just damp. Fill and point with mortar not richer than a 1:2:9 mix of cement: lime: sand. **Fretting** To stop the fretting process permanently, it will be necessary to halt the flow of salt laden water through the wall. If this is not practical, the alternative is to repair or replace the masonry units or jointing mortar that have been damaged.
Defects in Finishes	- **Defects in finishes due to condensation associated with air conditioned areas;** Situation of condensation can be avoided by; - Providing appropriate ventilation means for non-air conditioned areas adjacent to air conditioned areas. - Appropriate provisions for providing heat insulation as necessary. - Minimizing the temperature differences in allocating the spaces for different functioning. - **Ceiling finishes** Replace damaged ceiling with good quality ceiling or keep exposed soffit with arranging exposed service lines in neat casings or in cable trays - **Wall finishes** - Removing all damaged plasters and plastering and painting with a good workmanship and approved quality paints. - Application of water proofing as appropriate - Applying wall papers with an acceptable surface preparation

Table 4:1 Remedial measures for defects in GHBs- Cont.

	- Replace damaged wall tiles with tiles of approved quality
	- **Floor finishes** - Replacing of floor finishes with tiles of approved quality and with a good workmanship as appropriate.

4.1. Discussion On Remedial Measures

Technical knowhow, specifications, methodologies and the specialist materials are being developed globally in remedying most of the defects associated with civil structures. Remedying defects in RC structural members, masonry walls and finishes are practically achievable once the direct and indirect causes of occurring those defects are well understood. Implementation of direct technical approaches in upgrading the existing condition of GHBs will be more effective under a circumstance that proper attention is given on followings;

- Prior assessment and situational analysis
- Sufficient detailing at initial design stages and use of appropriate specifications & methodologies
- Direct supervision by competent personnel during the execution of construction/Renovation activities.
- Enhancing the contract administration of construction contracts.
- Avoiding involvement by the inappropriate construction contractors.
- Attention on regular maintenance of GHBs.

5. CONCLUSION AND RECOMMENDATIONS

Conclusion

The main physical infrastructure of the Health sector is GHBs located Island wide. Assurance of safe and pleasant environment associated with these buildings are at an utmost importance as the government hospitals are the main service provider to the community in this sector. Long term war situation in the country has been a constraint in allocating adequate government funds in upgrading the built environment of the health sector. The requirement of adopting the concept of green building regarding the state sector has been enforced recently through new regulatory provisions under Urban Development Authority (UDA). However, the knowledge of safe building concept is hailed to be not wide spread in Sri Lanka.

Information illustrated in the report reflects the landscape of GHBs Island wide. based on the statistical data of LRH it can be predicted that buildings of age both more and less than 25 years are around 50% of total existing buildings under a circumstance having equal distribution of fund allocation for new construction of buildings in hospital premises island wide. Old buildings are of single and two-story buildings and consist mainly of load bearing wall structures and RC framed structures. Recently constructed buildings are ranging from three to ten-story buildings and common structural form is RC framed structures whereas the structural form of certain multi story buildings is a combination of RC frame and shear wall.

The requirement of appropriate technical personnel and the required extent of upgrading of built environment of health sector is seemed not well recognized in the National Health Strategic master plan 2016-2025.

Structural defects associated with GHBs were identified through this study including sufficient information on direct and indirect causes regarding the existing condition of GHBs. In renovation of GHBs, internationally available standard repair procedures are rarely practiced. Locally available standard specifications are mostly related to the new construction of structures. Most of the repair work to structural members of building/other structures are rely on the specifications of manufactures of certain products for structural repair works and adoption to even such specifications related to structural repair work of GHBs were observed to be insufficient due to lack of knowledge, awareness and supervision with respect to such works.

Preparation of a specific specification related to the GHBs seems very important. Further the preparation of existing layout drawings together with condition assessment prior to execution of any renovation activity must be made a mandatory initial requirement for achieving a better quality work through any renovation work. GHBs Island wide can be considered as a main source giving plenty of training opportunities for young crowd in the technical field such as civil engineers, draughtsman, quantity surveyors etc.

It is emerged important giving due consideration on following two additional concerns in initial structural /architectural design of GHBs.

- Zoning particular areas such as operation theatres and Intensive Care Units etc. considering required indoor environmental conditions as possible and appropriate.
- Following the design criteria for water retaining structures in designing reinforced concrete structural members of toilet blocks of GHBs.

This study confirms that initiation of structural failures are expedited due to the various non-structural related factors

Finally the facts reported by this study is supposed to attract adequate attention of the relevant officials in the health sector.

Recommendations

Other than the remedial measures illustrated in the Table 4.1 above regarding the defects of buildings, following general recommendations are made to be concerned in further upgrading the status of GHBs.

1) Restructure / establish a well organised Asset/Building Management Division including appropriate technical personnel and entrusted with clear responsibilities and an Action Plan regarding upgrading of GHBs Island wide.
2) Minimizing constraints regarding recruitment of adequate engineering executives for the health sector.
3) Strict adherence in not recommending/approving bidding documents without sufficient technical details certified by an appropriate and competent personnel.
4) Adopting pre specified mandatory requirement of submission of adequate documentary evidence related to the quality of the work before approving the payment certificates
5) Design of "Type Buildings" regarding GHBs. (constraints in available plots of lands should be addressed separately)
6) Developing a unique specification for GHBs and improving annually along with the BSR to incorporate productive market changes.
7) Incorporation of a unique theme for finishes applicable for all the GHBs.
8) Maintain a registry of building renovation and maintenance activities for each block of building giving due consideration on concise details of location, year and extent of deterioration admitted and cost etc. to be recorded
9) Planning a program to develop existing layout drawings in Auto CAD software for each building and incorporating such programs in an Action Plan.
10) Planning and Carrying out a comprehensive building Audit regarding the defects of GHBs on priority basis.
11) Specifying construction materials for toilet blocks of GHBs as per the standards for designing of water retaining structures

12) Designing balconies and concrete canopies with a considerable slope for avoiding accumulation of water as shown in figure 5.1

Figure 5:1 Example for angle canopy slabs

13) Avoiding haste execution of procurement activities related to construction and renovation of GHBs.

14) Making strict and stable decisions in black listing the construction contractors showing unacceptable performance in time and quality achievements.

15) Formation of a system attached with the Department of National Archives of Sri Lanka for collecting and conserving the "As Built Drawings" of Government Hospital Buildings.

16) Evaluation of the effect of vibration that can be generated by the quick walking of a large crowd along corridors to wards and incorporating such effect in designing structural members.

17) An optimum solution for condensation is recommended to be sought referring the matter as a specific area for carrying out a comprehensive analytical study.

REFERENCES

[1]. "Health in Sri Lanka", [Online] Available: https://en.wikipedia.org/wiki/Health_in_Sri_Lanka, [Accessed: June 2017].

[2]. De Silva T.G.R. "Hospital system in Sri Lanka, Shortcomings and remedies" Economic Review June 1997 [Online], Available: http://dl.nsf.ac.lk/bitstream/handle/1/14019/ER-23%283%297 .pdf?Sequence=2&isAllowed=y), [Accessed: June 2017].

[3]. Ministry of Health, Nutrition and Indigenous Medicine, "Annual Health Bulletin-2014" ISBN 978-955-577-998-2 Medical Statistics Unit, 385, Rev. Baddegama Wimalawansa Thero Mawatha, Colombo 10. 2016 [Online], Available: www.health.gov.lk/ [Accessed: June 2017].

[4]. A. Enshassi, E.I Farida, and S. Alkilani "Assessment of Operational Maintenance in Public Hospital Buildings in the Gaza strip" *International journal of sustainable construction engineering and Technology* (ISSN:2180-3240), - Department of Civil Engineering, IUG, Gaza strip, Palestine, University of Technology, Sydney, Australia.,2015.

[5]. M. Jaafara, and N.L Othmana, , "Categorization and Causes of Building Design Defect" A case study on Public Building- Hospital- Department of Quantity Surveying, School of Housing, Building and Planning, University Sains, Malaysia.

[6]. R.T.L. Allen and S.C.Edwards(1993), *The Repair of Concrete Structures*, (2nd Edition), Published by Blackie Academic & Professional, an imprint of Chapman & Hall, Wester Cleddens Road, Bishopbriggs, GlasgowG64 2NZ, UK

[7]. E. Beach, "Why does concrete crack", [Online] Available: http://www.ehow.com/about_5167320_concrete-crack.html. [Accessed: June 2017].

[8]. Portland Cement Association, "Types and Causes of Concrete Deterioration", [Online] Available: http://www.cement.org/...concrete.../is536-types-and-causes-of-concrete-deterioration.pdf

[9]. The concrete network ,"Preventing Concrete Cracks", [Online]Available: http://www.concretenetwork.com/concrete/preventing_concrete_cracks.htm

[10]. Suvo, "Why does concrete crack", Edited by Stonecypher L., [Online] Available: http://www.brighthub.com/engineering/civil/articles/47197.aspx

[11]. The Concrete Society, "Recognizing Defects and Probable Causes- Load Cracking and Structural Design Inadequacies", Chapter 3, Concrete Society Technical Report 54.

[12]. S.M.A. Nanayakkara, Lecture notes" M.Eng Degree in Structural Engineering Design" University of Moratuwa, 2013/2014"

[13]. H.J.Eldridge, *Common defects in Buildings*, Published by Her Majesty's Stationary Office, London (1976).

[14]. RailCorp, TMC 302-Engineering manual for structures repair, version 2.0, December 2009, [Online] Available: http://www.asa.transport.nsw.gov.au/sites/default/files/asa/railcorp-legacy/disciplines/civil/tmc-302.pdf. [Accessed: 2017].

[15]. E Brandt, and M.H. Rasmussen, "Assessment of Building Conditions", Danish Building and Urban Research, DK-2970 Horsholm, Denmark. COWI Consulting Engineers, DK-2800 Lyngby, Denmark.

[16]. G. Genre, F. Flourentzs, and T. Stockli -,"Building refurbishment: habitat upgrading" Ecole Polytechnique federal de Lausanne, Institute Technique du Batiment, LESO-PB, CH 1015 Lousanne, Switzerland, 1999.

[17]. S. Tennakoon "An assessment of health emergency preparedness and response capacity of Sri Lanka" Health Emergency and Disaster Management Training Centre (HEDMaTC) of Faculty of Medicine, University of Peradeniya.

[18]. "National Safe Hospital Training Assessment" - 2014 [Online] Available:https://docs.google.com/viewer?a=v&pid=sites&srcid=ZGVmYXVsdGRvbWFpbnxzcmlsYW5rYXNhZmVob3NwaXRhbGluaXRpYXRpdmV8Z3g6YjlkYTdlN2YwYWViYzEw. [Accessed: 2017].

[19]. www.Sundaytimes.lk. June 07. 2015.

[20]. W.P.S. Dias," Factors Influencing the Service Life of Buildings" *ENGINEER- Vol, XXXXVI, No.04,-7,2013* The Institution of Engineers, Sri Lanka,

[21]. M.T.R Jayasinghe., Lecture notes- "M.Eng Degree in Structural Engineering Design", University of Mortauwa. 2013/2014"

[22]. Ministry of Mahaweli Development and Environment "Guidelines of Green and Environment friendly building for the state institutions" April, 2016

[23]. P.H. Perkins, "Repair, Protection & Waterproofing of Concrete Structures", Published by Elsevier Applied Science, 1986.

[24]. Cement Concrete & Aggregates Australia, Concrete Basics, Sydney office: Level 6, 504, Pacific Highway St Leonards NSW Australia 2065 Postal address: Locked Bag 2010 St Leonards NSW 1590 [online], Available: http://www.ccaa.com.au/
www.concrete.net.au/publications/pdf/concretebasics.pdf. [Accessed: 2017].

[25]. Maciej Maksymowicz, Civil Engineering Department University of Minho 4800-058 Guimarães, Portugal, Doctoral thesis on "Evaluation of load capacity of concrete railway slab spans with defects" February 2008 [Online] Available:
https://repositorium.sdum.uminho.pt/bitstream/1822/8861/1/Thesis_Maciej.pdf

[26]. www.cecb.lk [Accessed: August 2017].

[27]. Manual for the design of concrete building structures to Euro code 2- September 2006, (ISBN 0 901297 42 9 978 / 0 901297 42 6) Published by the Institution of Structural Engineers, United Kingdom.

[28]. TR 54 Diagnosis of deterioration in concrete structures: identification of defects, evaluation and development of remedial action, ISBN 2008 [Online] Available:
https://www.thenbs.com/PublicationIndex/documents/details?Pub=CS&DocID, [Accessed: 2017].

[29]. www.timesrilanka.com. [Accessed: August 2017].

[30]. N. Ahzahar, N.A. Karim, S.H. Hassan, and J.Eman, "A Study of Contribution Factors to Building Failures and Defects in Construction Industry" Faculty of Civil Engineering, University Teknologi MARA Pulau Pinang

[31]. K.L. Garg, K. K. Jain, and A.K.Mishra, " Role of fungi in the deterioration of wall paintings"National Research Laboratory for Conservation (NRLC), E /3, Aliganj, Lucknow-226020, India

[32]. P. A. M.Basheer, S. E. Chidiact and A. E. Long "Predictive models for deterioration of concrete structures" Department of Civil Engineering, The Queen's University of Belfast, UK institute for Research in Construction, National Research Council, Canada