





Affordable housing does not mean lack of standards. Structural design and guidelines for building rammed earth walls have been described for one or two storey buildings based on limiting geometry and axial compressive stress [6]. CSRE load bearing walls have been designed according to Masonry code of practice BS 5628: Part 1-2005 [15] and constructed in two storey houses in Sri Lanka using steel-slip form moulds for the purpose of disseminating the technology as an affordable housing method [13]. Same technology has been used for building load bearing walls of two storey houses with timber moulds and CSRE wall junctions by designing the walls structurally using New Zealand code of practice NZS 4297:1998 [3].

## 2.2 Durability of CSRE

Durability is a parameter which is a concern when selecting any material or method of production. Governing factor of durability is the life span of the structure, the way of treating repairs and maintenance. This is a very critical issue for an earthen structure as it is liable to attack by the environment. Earthen buildings in Spain are usually in a terrible state of decay and owners prefer to demolish them instead of repairing [16]. Many historic examples from around the world are a clear demonstration of the durability of natural earth as a material in a wide variety of building types, techniques, climates and cultures. Key factors in this success are good design and detailing followed by regular maintenance and repair when necessary [7]. With attention to construction details and with a reasonable amount of routine maintenance, simple beachfront construction can last a very long time [17]. History of earth buildings around the world provides good evidence for durability. Even earthen homes in Sri Lanka have lasted more than 100 years and it is understood that sufficient external coats for walls and width of eaves are the main requirements of protecting walls from the effect of water. Due to being constructed using soil, the structures are particularly vulnerable to decay caused by environmental factors such as rain, wind and water flow [4]. Rammed earth possesses a generally high durability but all types of rammed earth walls are porous by nature and need protection from driving rain and long term exposure to moisture [10]. Defects in rammed earth that arise after construction include shrinkage and separation cracking at wall junctions. They may be due to the deficiencies of surface coatings, poor construction methods or structural defects.

Though there are some possible defects in earthen buildings and adverse effects on durability, earth has been identified as the alternative material for building walls of houses. Shrinkage cracks can be limited if drying out of the wall is carefully controlled, the clay content of the soil reduced and movement joints introduced [7]. Despite having a long and acceptable history in architecture, many associate earth use with poverty and under-development [18]. Rammed earth technology has developed through recent research and presently CSRE has been used in most parts of the world as a modern earthen building technology. Rammed earth popularity surged again during the 1970s when resources were once again limited and there was more of an emphasis on how humans impacted the environment. Rammed earth, as one of the oldest building methods, was seen as a good alternative to the usual building materials for its abundance and its low impact on nature [2].

## 3. Objectives

This study was based on a housing project at Madampagama, Hikkaduwa in order to;

- i. Examine existing conditions of CSRE walls in single storey houses after 13 years.
- ii. Identify possible defects of CSRE walls when using for a 13 years period.
- iii. Find the level of maintenance required for CSRE walls.
- iv. Assess the user's perceptions on CSRE walls.

## 4. Methodology

Data collection was done in this study under following two procedures.

- a) Visit and observe the CSRE walls in houses at Madampagama housing project to cover following information of CSRE walls of randomly selected housing units.
  - i. Wall cracks.
  - ii. Erosion of earth walls.
  - iii. Changes in wall finishes.
  - iv. Repairs.
  - v. Modifications.
- b) Questionnaire was filled by author to collect following information of CSRE walls through discussions with users of randomly selected houses.
  - i. Durability.
  - ii. Living conditions.
  - iii. Maintenance.
  - iv. Cooling effect.



The combination of the above two procedures will help to reveal a broader view of existence of CSRE walls after a 13 years period and to find users' perceptions on CSRE walls for housing.

## 5. Data Collection

Houses were randomly inspected (15 housing units) in August 2018 and discussed with users about their experience on living in earth buildings. Their views were recorded under the following areas.

- i. Durability of CSRE walls.
- ii. Maintenance.
- iii. Repairs.
- iv. Cooling effect.

The technical information on performance of CSRE walls during the 13 year period was recorded as follows.

- i. Wall cracks.
- ii. Separation of walls at CSEB wall junctions.
- iii. Application of lime wash.
- iv. Separation of wall plaster.
- v. Soil erosion.
- vi. Modifications.
- vii. Evidence of poor quality construction on inspection at the time of data collection.

## 6. Analysis of Data

### 6.1 Surface Coating

It was found that in all inspected housing units occupants had applied either lime wash or emulsion paint on the surface of the walls, especially inside the houses. Users said that when they touch walls, earth marks remained in their hands, sometimes on their body or cloth. Donor has taken action at initial stages to plaster walls in a few houses because of the requests from users.



Figure 2 - Surface Coating and Painting

### 6.2 Existing Condition of CSRE Walls

To evaluate the existing condition of CSRE walls, according to the identified defects on

CSRE walls, inspected houses are listed under three conditions as follows.

1. Good condition - No defects during past 13 years period
2. Moderate condition - Only cracks at junction of CSEB corners.
3. Poor condition - Soil erosion, cracks at wall junction of CSEB corners and separation of wall plaster.

Table 1 - Existing Condition of CSRE Walls

Conditions	Housing No.	No. of Houses
Good	03, 22, 29, 30, 31, 32, 33, 34, 35,	09 (60%)
Moderate	01, 02, 14, 28	04 (27%)
Poor	15, 16,	02 (13%)

### 6.3 Identified Defects

Wall deterioration is analyzed for CSRE walls in moderate and poor conditions (6 houses) under the defects identified (see Table 2) in house inspections. Summary of the information collected are presented against the defects identified.

Table 2 - Identified Defects on CSRE Walls

Defects	Housing unit No.	No. of Houses
Separation cracks (1 to 3 m length) at CSEB wall junctions	16, 15, 14, 28	04
Separation of wall plaster	01, 02,	02
Soil erosion at the base of the walls	01, 02, 16, 15	04
Water born soil erosion	15, 16	02



(a) Separation crack (b) Soil erosion

Figure 3 - Defects in CSRE Walls

### 6.4 Users' Comments on CSRE Walls

Data collected from the users were tabulated in Table 3 to evaluate their comments on CSRE walls.

**Table 3 - Occupants' Comments on CSRE Walls**

Discussed Areas	Housing unit No.	No. of Houses
1. Durability	Varied ideas	
2. Strength		
a) Satisfied	29, 31, 34, 35	04
b) Not Satisfied	15, 16	02
c) No idea	01, 02, 03, 14	07
3. Poor quality	28, 30, 33	
	15, 16, 01, 02	08
	14, 28, 30, 33	
4. Cooling effect	All users	13



**Figure 4 - Soil erosion in House 15 (Base of external wall)**

Since No. 15 and 16 houses have wall separation cracks they are not satisfied with CSRE walls. They think that these walls have low durability than other walling materials. They have experience in its deterioration and highly criticized quality of construction. They mentioned that these walls may have high strength but the failure is due to poor method of construction. Users in houses No. 33, 34 and 35 happily said that they received sample houses and there are no defects.



**Figure 5 - Sample Houses**

CSRE walls are new technology for these users; hence they are not in position to recommend durability or strength of CSRE walls. However 11 families (84%) are living in these houses without fear. Users have experience in living in cement block work houses and they believe cement blockwork is the best method for wall construction. According to their 13 years of experience all users said that there is a good cooling effect than cement block work.

## 6.5 Maintenance

CSRE wall existence or conditions are analyzed with respect to the method of maintaining these houses by the users during the past 13 year period. Housing units are categorized into four as follows. Cleaning is a constitute part of building maintenance activities [19].

Category A - Well maintained house where no deterioration of CSRE walls were observed.

Category B - Well maintained house where surface coating has been applied on CSRE walls and painted. Wall cracks have been repaired.

Category C - Poorly maintained house where surface coating has been applied on CSRE walls and painted. Wall cracks have not been repaired.

Category D - Modified house

House modified by the users by adding one or more compartments using cement block masonry walls, applying surface coatings, plastering walls, painting, fixing ceilings and laying floor tiles and wall tiles in kitchen and bath areas.

**Table 4 - Summary of Maintenance**

Category	Housing Unit No.	No. of Houses
A	03, 29, 30, 33, 34, 35	06 (46%)
B	14, 28	02 (15%)
C	16, 15, 01, 02	04 (31%)
D	31	01



**Figure 6 - Modified Houses**

It is found that about 61% of users have taken good attempts to maintain these houses satisfactorily but 31% of users have poorly maintained due to their economic condition. All elements of building deteriorate at a faster or slower rate depending on materials and methods of construction, environmental conditions and the use of the building [19]. These families occupied these houses as a donation due to tsunami disaster in December 2004. They are not rich enough to maintain these houses as required. It is noted that some have taken to repair walls but it has failed. At the discussions with these users, the author realized that they are afraid to make changes on



walls and attend modification or repairing walls as this technology is new to them.

## 7. Results and Discussion

Defects of earth buildings can assume two main forms: deficiencies of surface coatings; and, structural defects [7]. In this study it is found that most of the walls are protected by lime wash and in some walls decorated with coloured paint applied on lime wash. Therefore, CSRE walls require surface coating which should be based on soil or lime. After applying lime wash, colour painting can be applied on walls to keep a good appearance [3]. When observing the present condition of CSRE walls, cracks at CSEB wall junctions, peeling of plaster, water borne erosion and soil erosion at base of walls are the defects identified in this housing project. Same types of defects have been identified on CSRE walls in research conducted by Vasiliou & Walker [7]. This housing project was commenced as a result of finding cost effective walling methods in Sri Lanka in 2004 by CHPB. Author was a member of the team which developed CSRE technology from 2004. Since steel slip-form mould was used as support for casting CSRE walls, CSEB columns were cast at the junctions to get a good bonding between the wall and the corners. It was found that making corners need to be developed to avoid this separation cracks at wall junctions, hence pre cast CSRE wall junctions were introduced [20]. From the analysis based on defects of CSRE walls, it is found that 60% of houses are in good condition, 27% are in moderate condition and only 13% are in poor condition. When comparing the existing condition and the level of maintenance, good condition houses have been well maintained and moderate and poor condition houses have been poorly maintained during this 13 year of period. Maintaining a house, including cleaning, is necessary to fulfil its function and present a good appearance. It is highly desirable but hardly feasible to produce buildings that are maintenance free [19]. Soil erosion cases that have been noted at the base of gable side of external walls in most of the houses may be due to rain water gathered at the base of these walls. Water is a major agent of decay for earth buildings. Therefore, any routine maintenance work should primarily include measures to prevent deterioration from the effects of water [7].

It is highly recognized by the users that CSRE walls have good cooling effect in this housing project but most of the users did not make a good comment of the durability and the strength of the walls. This community needs a program on CSRE walling method and its maintenance to keep them aware on the acceptability of this technology. Since the author is continuingly carrying out development of CSRE walls in Sri Lanka, it is realized that cause of deterioration is not only due to the effect of water but also poor quality in construction in few of the houses at the later part of the this housing project. Though CSRE is one of the cost effective methods of wall construction it needs high supervision on quality control when constructing on site.

## 8. Conclusion

- i. It is revealed that CSRE wall needs surface coating based on lime or earth to protect wall erosion and maintain good living conditions in the house. Colour paint can be applied to make the wall to be of good appearance.
- ii. Wall cracks at CSEB wall junctions, peeling of plaster and soil erosion at base of walls are the defects identified in CSRE walls after a 13 year period. Majority of users (87%) maintained CSRE walls are in a satisfactory condition while living there without fear during the last 13 years. Economical wall repairing method is to be introduced to these users with an awareness program on CSRE wall construction as they are the people now living in these houses.
- iii. CSRE wall junctions can be included along with proper supervision for the construction of CSRE walls to avoid separation cracks at wall junctions in future constructions.
- iv. It is identified by the users of this housing project that CSRE walls have good cooling effect and most of CSRE walls are still in good condition with low level maintenance.
- v. Three sample houses constructed under proper supervision are in good condition without any defects for 13 year and the occupants are still satisfied about the construction. Therefore CSRE wall technology needs high supervision at construction stage to keep its durability, strength, and especially to be acceptable to the users.

## Further study

It is necessary to find suitable cost effective repairing methods of cracks for 13 year old CSRE walls and apply them in one house (No 15 or 16). An awareness program should be conducted for all users of this housing project regarding CSRE walling methods and demonstrate the repairing methods to enable them to attend to them when necessary.

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