REPORT ON THE EARTHQUAKE ASSESSMENT IN CHIPINGE

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1. Introduction

On the 23rd February the country was shaken by a major earthquake of magnitude 7.5 on the Richter scale with its epicentre on the northern banks of Save River near Espungabeira in Mozambique. The earthquake occurred at 0019 hours shaking much of Zimbabwe and Mozambique and parts of northern South Africa. The main shock was followed by numerous aftershocks of average magnitude 5, which were felt in most areas along the border. At the time of conducting the assessment, more aftershocks were being reported in areas close to the Mozambique borders with some villages asserting that they felt some shaking literally daily.

Although the earthquake was large and of shallow depth casualty figures were very low since its epicentre was in a sparsely populated settlement, in a National Park. In Zimbabwe, the earthquake was felt in most parts of the country although Chipinge and Chimanimani districts, which are nearer to the epicentre, were badly shaken.

Severely damaging earthquakes the world-over have repeatedly demonstrated the importance of improving the quality of both earthquake engineering design and construction. Records show that even some small earthquakes have caused deaths of many thousands of people in some areas of the world. This is primarily because of poorly designed and constructed buildings. Earthquake aftershocks can result in the complete collapse of buildings that were damaged during an earthquake.

It was against this background that the Department of Civil Protection dispatched a multisectoral team of experts to assess the nature and extend of damage caused by the Earthquake in Chipinge District. The team was sent almost a month after the event and some vital evidence of structural damage and ground cracks had been concealed by the incessant rains that pounded the area and by villagers who sought to reconstruct their shelter.

2.0 The Assessment Team

The team comprised of technical experts as follows

Mr R Munyira	- Seismologist (Met Office) Team Leader
Mr D Kamupandira	-Architect (PWD)
Mr P Chiriro	-Structural Engineer (PWD)
Mr T Gandi	-Architect (PWD)
Mr T Bondayi	-Physical Planner (Local Government)
Mr E Mabaso	-UN (OCHA)
Ms S Dube	-Local Government.
Mr S Chisedzi	- Civil Protection (Team Coordinator)

2.1. Funding and Transport

The assessment exercise was funded by **UNDP** under the Support for Strengthening National Capacity for Disaster Management in Zimbabwe Project. **OCHA** provided transport for the team.

3. Purpose

To conduct damage assessment of schools, hospitals, clinics, buildings and homesteads affected by the earthquake with the view to improve on existing building by-laws, designs and siting.

4. Methodology

The damage assessment was conducted through physical inspection, digital imaging and distribution of questionnaires to gather data on the earthquake. The team could not visit all the affected areas therefore a random sampling was made for the reported affected areas.

5. Areas /Institutions Visited

The assessment was conducted in Chipinge District and areas visited included Public Institutions and individual homesteads which were affected by the earthquake.

5.1 Health Institutions

Chiriga Clinic   Mahenye Clinic   Mt Selinda Hospital

5.2 Schools

Muzite Primary School, Mwacheta Primary School, Masimbe Primary School, Chikore Mission School, Chisavanye Primary School,Mahenye Primary School

5.3 Homesteads

Dimire Village   Manzvire ward 22

5.4 Other Institutions

Manzvire Business Centre   Chipinge Prison   Muzite Business Centre

6.0 Findings

The soils in northern Chipinge are generally reddish brown clay loams and are firm and suitable for construction purposes. In southern Chipinge the soils are predominantly sandy loam along the Save valley. The terrain in northern Chipinge is generally mountainous whilst in the south it is flat.

Most damaged buildings were located in remote rural areas, closest to the epicentre. Very little damage was recorded in urban settlements like Chipinge town itself or areas where local authorities were obliged to inspect the construction of structures. The most common type of damage were cracks on building walls, some vertical running longitudinal along an entire classrooms blocks and others.It was noted that most of the buildings affected by the earthquake had old minor cracks already, which were widened by the impact. Most of the structures affected are old buildings. Reports of ground cracks were received mostly on the Mozambique side, the small ones on the Zimbabwe side were already filled up by the time of the assessment.

A salient feature observed was the use of low cost construction methods and materials, which later failed under stress and age. The main patterns of earthquake damage included;

- Separation of walls at corners and T-junctions

- ❖ Separation of poorly constructed roofs from walls, which could lead to the eventual collapse of roof
- ❖ Disintegration of walls and eventual collapse or future possible collapse of the whole structure

For the collapsed dwellings visited the following was observed:

- The masonry walls consisted of irregularly placed home-made clay bricks that were laid in mud mortar.
- The firing of the bricks was of poor quality. These type masonry buildings were common in the rural villages visited.
- The quality of mortar and bricks used and the level of workmanship were very poor.
- No moisture barriers or reinforcement was provided. The most commonly used mortars consisted of very little cement (if any) to a very large proportion of sand.
- Cement was often substituted with clay in most mortar. The approximate crushing and shear strength of such mortar is very low

The use of weak materials and methods of construction subsequently meant the buildings were weak horizontally. Extreme weaknesses encountered included

- Failing to tie in at corners which compromised on performance of the masonry.
- The brick mould, in addition to the poor quality of mortar, rendered a very loose bond between the bricks, which made the structures extremely vulnerable to earthquake forces.
- There was strong evidence of lack of knowledge on why certain building procedures were necessary in the construction process.
- Lack of horizontal bond beams (ring beams) provided at the roof levels in many cases.
- Lintel beams were provided only above openings (doors and windows) and were not run continuously along the perimeter of the walls.
- In some cases, the bricks were laid dry (no mortar at all), leaving the walls extremely vulnerable to horizontal ground shaking.

In cases where Structures with Concrete block walls failed, the most probable reasons for failure were observed to be:

- Poor quality of concrete used for fabrication of blocks, rendering low strength blocks.
- Poor quality of the mortar used.
- Inadequate thickness of walls, which were the main shear resisting elements.
- No integrity of the wall in the transverse direction
- Weak connections at corners

Structures constructed without following the correct building principles such as the use of damp proof course, brick force, the correct cement- sand- mixture and correct bonding of bricks developed cracks. Some materials that were used for the construction of homesteads structures were sub-standard.

Manzvire Area- House built after 2000 Cyclone Eline Succumbed to the Earthquake

Dimire Village - House Built using Poor Building materials collapsed

6.1 Homesteads

All the visited homesteads in the district can be classified as Vernacular Architecture, which has been adapted to the western rectangular form of Architecture. Sun dried bricks (adobe) were used and this was done without proper reinforcement such that the houses were vulnerable to collapse when the earthquake struck. Three such structures succumbed to the shaking with east facing walls collapsing. A rare case was Mrs S Mhlanga’s round hut that collapsed trapping five occupants and injuring one.

Mrs Mhlanga's hut that caved in: now under reconstruction

Dimire Area- house collapsed

6.2 Health Institutions

Chiriga Clinic

It is believed that the clinic was built in the early fifties as a farmhouse and was later turned into a Clinic in 1980. Due to its advanced age, vertical cracks had developed on the walls and these were exacerbated by the earthquake. The cracks widened to widths of 10mm at some parts and these were observed in the reception area, treatment room and veranda.


Chiriga Clinic - Cracks at the Reception Area

Mt Selinda Hospital

The hospital was established in the 1890s. Though old and close to the epicentre, the firm structure are founded on bedrock and stood the effects of the quake but most windowpanes were shattered. The main Hospital building had minor faults apart from a few shattered windowpanes and a concrete chimney lid to one of the wards dislodged to the ground. Interior cracks on some staff houses were also observed.


Chimney lid weighing almost 100kgs was dislodged to the ground

6.3 Schools

The traditional form of school classroom block is the rectangle and all schools visited comprise of this basic architectural form which all display similar characteristics in terms of consequent to the effects of the quake. Irrespective of the materials used and method of construction, farm or cement blocks, sand cement or clay mortar, vertical cracks developed on the interior and exterior walls with internal junctions of walls being the most severely affected. Areas also affected in some classroom blocks include window and door lintels with the most severely affected being those made of unreinforced brickwork.

Mwacheta Primary School

Muzite Primary School

At Chikore High Mission the double story upper floors were most severely affected as some portions of plasterboard ceilings collapsed. This was mainly due to inappropriate fastening of the battens to the saw timber bearers resulting in non-structural integrity with the rest of the structure.

Chikore Mission: plastered ceiling collapsed

Signs of roof uplift and widening of cracks were also observed generally on all affected school blocks and residential facilities.

At Mahenye Primary School, the eastern wall of a block of classroom has cracks separating wall from the floor, wall from the slab (horizontal) and two vertical ones detaching the wall from the rest of the building.

A Class Room Block at Mahenye Primary School

6.4 Blair Toilets

The effects of the earthquake to Blair toilet are a cause of worry as these were the most severely affected with some of them totally collapsing. At Muzite Primary School and Mahenye clinic, the slabs and walls to Blair toilets had deep cracks splitting the slabs into two halves rendering them unsafe for use. Vertical cracks also developed on the walls. At Mwacheta School, the toilet completely collapsed. It was observed that the slab to some of these had no mesh reinforcement that would have prevented the slab unit from disintegrating.

6.5 The Modern Houses

Effects of the earth earthquake were also observed on modern structures/ houses built with sound construction principles though the cracks were minor as compared to those built earlier.

The Chipinge government complex was not spared

Muzite Primary School : Modern Teacher's House also Succumb to the Earthquake

7.0 Analysis

Many of the materials and building techniques had shortcomings that were quite evident. For instance in some cases timber trusses had never been treated against termite attack and hence were in a state of advanced deterioration. Apart from the fact that their reduced ability to withstand any forces be it wind or earthquake, the most imminent danger was that they would give in and fall.

There are three basic causes of defects to any structure that include dampness, movements (i.e.) physical change (under which earthquakes fall) and chemical or biological change. The sources of these causes are many and some interactive. In many cases encountered, it was difficult to blame the earth earthquake as the chief cause, because it was evident that other inherent weaknesses existed prior to the earthquakes. It can however not be dismissed that the shaking of the earth did play a part in the exacerbation of the defects.

The possible causes of dampness include rain, the ground itself, the construction process, the atmosphere (with condensation quite notable), water supply, faulty services, maintenance and general use of the building. The sources of movements include; externally applied loads (structural loading itself and movements in soils), changes in temperature, and changes in moisture, vibrations and other physical changes. Chemical changes manifest from dampness, temperature, solar radiation and presence of incompatible substances for example the setting of cement, adhesives and sealants.

It was observed that there was heavy reliance on the use of 'farm' bricks and other low-cost bricks. The danger with the use of such bricks is that they may differ greatly in strength from brick to brick, but any structure and part thereof is as strong as its weakest link. The use of this material in low cost construction is not being discouraged, but it should work hand in hand with good construction practice especially in workmanship. The mixing and placing of mortar would then be critical so as to create an adequate bond between brick and mortar.

Another form of bad practice employed was the absence of moisture barriers to prevent damp rising, a chief cause of cracks in walls, among others. As an example all public structures should include a damp proof membrane (dpm) usually under slabs and damp proof courses (dpc) for walls. Walls should also be reinforced by brickforce after a certain number of courses.

Cracks that appeared near openings in walls like doors and windows indicate the inability of the lintels above them to withstand any forces from above. It is possible that these were made from low strength materials like the questionable bricks themselves or weak timber. In a well-constructed structure, the loads find a quick and easy path to the foundation, however, when such weak links exist, they give in, manifesting in cracks and other defects like cracked and shattered windowpanes. Strong lintels ensure least interruption to force flow through walls.

7.1 Building Regulations and by-laws

In many areas visited there was a high possibility of non-compliance to the building codes and regulations due to factors such as lack of resources. Furthermore, in rural areas there was definite lack of inspection or any clearly defined structures to do this. It is apparent that structures in rural areas are built in any manner, using any materials without supervision or conformity with the requirements of any building regulations or by-laws.

7.2 Age

Age of any building also contributes to how it performs. Most of the buildings particularly in rural schools were old, and way past their design life with only the option of being demolished.

7.3 Building Response Characteristics

Different individual buildings shaken by the same earthquake respond differently. The effects of earthquake ground shaking depend on the specific response characteristics of the type of structural system used. In general, a large portion of the earthquake energy is contained in short-period waves. Therefore, short-period buildings with stiff structural systems experience larger forces than long-period, flexible, buildings. This concept is also applicable to the amount of force individual structural seismic elements and their components must resist. Stiff elements must be made stronger because they will attempt to resist larger earthquake forces than flexible elements in the same structural system.

Shape or configuration is another important characteristic that affects building response. Earthquake shaking of a simple rectangular building results in a fairly uniform distribution of the forces throughout the building. In a more complex T- or L shaped building, forces concentrate at the inside corners created by those shapes. Irregularly shaped buildings can suffer greater damage than regularly shaped buildings. Force when applied to any structure causes displacements. Inside a structure, the forces are associated with stresses and displacements with strains. A structure is pushed to that displacement. The actual distribution of seismic forces is non-uniform, complex and constantly changing. The horizontal earthquake forces cause large overturning effects, which result in edges of walls experiencing high compressive and tensile stresses.

7.4 Soils

Certain soil types inflict crippling effects on buildings such as those that contain heavy clay content. When exposed to moisture, clay expands, creating huge upward forces strong enough to crack a conventional foundation in half. Soil expansiveness, even of slight magnitude manifests itself in the form of cracked plaster, sticking doors, and sinking floors. When clay dries, it shrinks noticeably, creating cracks and valleys in the soil that wreak havoc with conventional foundation systems. Over time, this periodic heaving of the ground takes its toll on structures, causing premature deterioration, structural weakness, and a host of other chronic problems. This could explain the already existing weaknesses in some buildings visited. Structures built on soft soil are more severely damaged in earthquakes than those built on firm soil or bedrock. Soft clay soil shakes more violently than firmer sandy soil, which in turn shakes much more than hard rock.

For structures on flexible soil, the relative response is the largest at the first period of the soil-structure system. This period depends not only on the structure itself, but also on the properties of the foundation system, of the surrounding soil, and on the contact conditions between the foundation and the soil. Studies have shown that this period can vary significantly during earthquake shaking as function of the level of shaking, reflecting changes in stiffness of the structure and of the soil (permanent or temporary

8. Recommendations

- Generally the world over, designing and building large structures has always been a challenge, and that challenge is compounded when they are built in earthquake-prone areas. Efforts should be made to avoid the construction of large structures in these areas.

- Roofs should be made less flexible and therefore better able to withstand earthquakes.

- The rise of moisture can most effectively be stopped by the use of an impervious and continuous barrier using impervious materials like built-up felt or plastic. Rising damp commonly occurs in walls at or near the ground level and solid ground floor slabs, at junction with walls.

- Building codes provide the first line of defence against future earthquake damage and help to ensure public safety. Records of building response to earthquakes, especially those from structures that failed or were damaged, can lead to many revisions and improvements in building codes. Our current building by-laws and codes are not cognisant of such seismic effects. The codes for example, could specify the levels of earthquake forces that structures must be designed to withstand. These specifications will be based on current information from strong-motion instruments. As ground motions of greater intensity are recorded, the minimum earthquake requirements specified in building codes should be raised accordingly. In addition, provisions for different soil conditions should be added to the codes as scientists have already documented the significant influence of soil type on shaking intensity. In recent earthquakes, buildings built to modern codes have generally sustained relatively little damage.

- A network of instruments will provide even more extensive data in earthquakes to come. Using this information, scientists and engineers will be able to suggest further improvements to our building codes. These improvements will help protect citizens of Zimbabwe from loss of life and property in future earthquakes.

- Need for good, safe building practices even with the use of low cost materials.
- When such a disaster happens again in the future, engineers and other experts should inspect and investigate any damaged structure as soon as possible. This can enable them to learn more on what caused the collapse and improve designs.
- There must be an endeavour to eliminate bad construction methods currently employed .It appeared that well constructed buildings performed well under the level of shaking experienced during the earthquakes. We can however not ascertain how they would perform if the epicentre had been much closer.
- There should be careful consideration of the structural ramifications of architectural design decisions, and provide for ductile and continuous load paths from roof to foundation. A foundation must withstand heavy downward forces imposed by the weight of the structure above. It must also withstand strong upward pressure from moist swelling soils, plus the lateral forces imposed by heavy winds, and earthquakes.
- Regular maintenance should be done to structures, and this should include the treatment of termites
- Need to abide/adhere to correct building principles during the construction of public and private buildings.

- Standard building materials should be used in the construction of Public buildings.
- In built up areas the risk of fire immediately after an earthquake is often high thus devices should be installed in buildings that shut down electrical power supply automatically in the event of an earthquake striking.
- Need for an extensive and vigorous awareness campaign to inform the public on what measures to take in case of earthquakes.
- Implement earthquake-resistant building codes. Earthquake engineers attempt to design buildings that can absorb excess energy without falling. Steel beams are usually the best reinforcement because they provide the capacity to sway, stretch or vibrate, instead of breaking. This could however be difficult to apply due to the high cost of steelwork.
- The majority of deaths and injuries from earthquakes are caused by the damage or collapse of buildings and other structures. To design structures that can withstand earthquakes, engineers must understand the stresses caused by shaking. Gaining such knowledge requires a long-term commitment because large devastating earthquakes occur at irregular and often long intervals.
- Seismologists and other earth scientists should make known any movements of the earth and the areas and magnitudes affected so that structural engineers use this information to design stronger buildings so that loss of life and property can be reduced. Every time a strong earthquake occurs, the new information gathered enables engineers to refine and improve structural designs and building codes.

9. GUIDELINES

9.1 The Following are some Construction General Guidelines:

- Avoid irregularities in plan and section. Plan irregularities can result in twisting of the structure (leading to additional torsional stresses) and other stress amplifications
- Provide tie-downs and anchors for all structural elements, even those that seem secured by the force of gravity: the vertical component of seismic ground acceleration can "lift" buildings off their foundations, roofs off walls, and off of framing elements unless they are explicitly and continuously interconnected.
- Non-structural items such as suspended ceilings must also be adequately secured to the structural frame. Seismic forces are triggered by the inertial mass of all objects and elements within the building.
- Avoid unreinforced masonry or other stiff and brittle structural systems. Ductile framing systems can deform inelastically, absorbing large quantities of energy without fracturing.

9.2 Masonry

The ideal type of masonry is one with good workmanship, mortar and design, reinforced especially laterally and bound together using steel, concrete etc. It is designed to resist lateral forces. Some unreinforced masonry (URMs) risks can be reduced by generically bolting the masonry walls to the building’s roof and floors. More reliable risk reduction, however, requires engineering to technical standards developed specifically for URMs.

9.3 Better methods of low cost housing required especially in rural areas.

9.3.1 Use of Horizontal and Vertical Reinforcement in Masonry

The reinforcement can be made of any ductile material, including: rope, timber, chicken wire, barbed wire, or steel bars. The first few examples are for communities that might not be able to afford steel for instance. Vertical reinforcement helps to tie the wall to the foundation and to the ring beam and restrains out-of-plane bending and in-plane shear. Horizontal reinforcement helps to transmit the bending and inertia forces in transverse walls (out-of-plane) to the supporting shear walls (in-plane), as well as restraining the shear stresses between adjoining walls and minimizing vertical crack propagation. The horizontal and vertical reinforcement should be tied together and to the other structural elements (foundations, ring beam, roof). This attachment provides a stable matrix, which is inherently stronger than the individual components.

Use of buttresses in the critical parts of a structure increases stability and stress resistance. Buttresses act as counter supports that may prevent inward or outward overturning of the wall. They may also enhance the interlocking of the corner bricks. These could be of particularly good use in the construction of classroom blocks. The critical sections include: corners and intermediate locations in long walls, where buttresses take the form of perpendicular bracing walls, which are integrated into the wall structure.

A ring beam (also known as a crown, collar, bond or tie beam or seismic band) that ties the walls in a box-like structure is one of the most essential components of earthquake resistance for load-bearing masonry construction. To ensure good seismic performance of building, a ring beam needs to be provided continuously like a loop or a belt. The ring beam must be strong, continuous and well tied to the walls and it must receive and support the roof. The ring beam can either be made of concrete or timber.

10. Conclusion

It is important to note that, in areas where the ground cracks were visible, a fault line has developed and it becomes a question of time when it will be stressed and break again, resulting in another earthquake, a case in point is the Muzite Primary School Muzite Primary where the earthquake caused some cracks on the ground.

It is normal that a series of aftershocks occur after such a large earthquake and the events witnessed in the Chipinge area are very normal. However, the more they occur, the more susceptible the occupants of the cracked structures.

While to some extend the team advised occupants to stop using the damaged structures, swift action is required by the local authorities to move in and assist the affected. The possibility of the damaged structures giving in to high winds, aftershocks and or any other disturbance is substantially high.