INTRODUCTION OF SEISMIC RESISTANCE FEATURES IN THE CONSTRUCTION OF BUILDINGS IN TANZANIA

I. A. Rubaratuka
Department of Structural Engineering, University of Dar Es Salaam
P. O. Box 35131, Dar es Salaam

Available data indicates that a greater part of Tanzania lies within a seismic region. However, to date most of the buildings in the country have been designed and constructed without considering seismic loads. In addition no design codes have been developed to guide the seismic design for buildings and other related structures in Tanzania. This paper outlines the basic design concepts, which are useful during the design of seismic resistant buildings before the seismic design code is developed and adopted in Tanzania.

Keywords: *Seismic resistant, seismic joints, earthquakes, redundancy, failure mode.*

INTRODUCTION

Earthquake engineering technology which is being practiced in some countries has not been disseminated or applied in other parts of the world including Tanzania, which the greater part of it falls within the active earthquake zone. Studies carried out in East Africa [Hiroshi,1970], indicate that East Africa lies right within the active seismic zone of the world. According to the Earthquake Hazard Centre, about 90% of the area of Tanzania and Uganda, and 50% of Kenya may be affected by strong earthquake(Charleson, 1997).

Seismic history of Tanzania dates back to 1909 when major earthquakes were registered for twenty six days mainly in the Livingstone mountains near lake Nyasa in the south – west (Sayers, 1930). On 13th December, 1910 a strong shock compared to those of San Francisco in 1906 and Messina in 1908 hit the eastern in Congo (Democratic Republic of Congo) (Gutenberg, et al, 1949). Since then earthquakes were felt in Usambara mountains, in the vicinity of lake Natron, Njombe, Rungwe, Songea, Mpanda and Lindi at different times. On 13th and 14th February, 1954, minor cracks were caused in walls and ceilings in Nkinga mission, Nzega District and at least one building cracked in Shinyanga (Gutenberg, et al, 1949). On 7th May, 1964 Mbulu was hit by one of the strongest recent earthquakes in Tanzania which caused damage to about twenty houses and resulted in four deaths. The maximum assessed intensity on the Modified Mercalli scale was VII (Rodrigues, 1970). In May 1999, Mbeya Municipal experienced two tremors in two days consecutively. A similar tremor had hit the same place in 1997 (Nyenyembe, 1999). On the first day of September, 1999 earthquake tremors hit villages around Lake Nyasa. The seismic risk map of Tanzania (Figure 1) indicating seismic zones in accordance to seismic intensity is a clear justification of the existence of earthquakes.

In 1994 Fort Portal in Western Uganda experienced earthquake measuring six on Richter scale which destroyed life and property. In February, 1999 alone, Uganda experienced two tremors measuring between three and four on Richter scale. Places prone to earthquakes include Rift Valleys among others (Ochieng, 1999).

Despite all these facts about the existence of earthquake in Tanzania and other East African countries, there is no earthquake code which has been developed and approved to guide design and construction of earthquake resistant structures in Tanzania. A survey carried out indicate that most of the structures are designed and constructed without taking into account seismic loads.

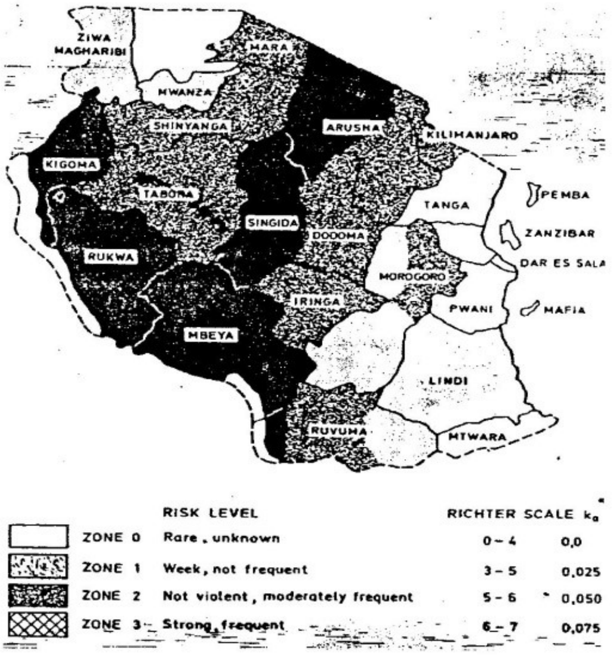


Figure 1: Seismic risk map of Tanzania

We are frequently reminded of earthquake danger. Buildings and other structures that are safe for gravity and wind loads can be extremely dangerous in lateral loads such as earthquake shaking. In the early 80's, The Tanzania Bureau of standards prepared a draft Tanzania standard code of practice for design of structures in earthquake areas, which to-date is yet to be put into practice.

Uganda has set up an earthquake preparedness unit called the National Seismological Network Project to develop a code of practice for design and construction of buildings as an input in the national building code (Ochieng, 1999).

Absence of notable earthquake effects in Tanzania over the past few decades led many designers to think that Tanzania is almost free of strong earthquakes which is misleading. Taking into account that the return periods for the largest seismic shocks is over 40 years and noting the recent intensive construction taking place in Tanzania, it is not ruled out that the near future may hold devastating events for us.

The conviction and experience of designers trying to minimize loses from earthquake damaged structures, is that risk of damage and collapse can be reduced significantly by applying basic earthquake design principles which are cost effective.

Therefore, this paper tries to outline the basic principles of designing and constructing seismic resistant structures, which in the absence of earthquake design code in Tanzania may serve as guidelines during the design of different structures.

BASIC CONCEPTS FOR SEISMIC RESISTANT DESIGN AND CONSTRUCTION

At the very early stage of building design, the configuration, basic materials, structure and framing of the building have to be selected. These factors greatly affect the seismic design as follows:

Form of superstructure

Building configuration

For seismic resistant design, the plan should be simple, compact, symmetric and regular in plan and elevation

Simplicity

From the point of view of earthquake resistance, a simple configuration such as a square or a circular shape is desirable. For buildings with winged shapes such as L, T, H and others, the wing portion often collapses under severe earthquake. In such cases, seismic joints which structurally separate the wings as shown in Figure 2 (a, b, c) should be provided.

Compactness

In buildings with long extended shape, complicated forces act because of the difference in the phases of seismic motion. Therefore, seismic joints are required in such buildings as shown in Figure 2d.

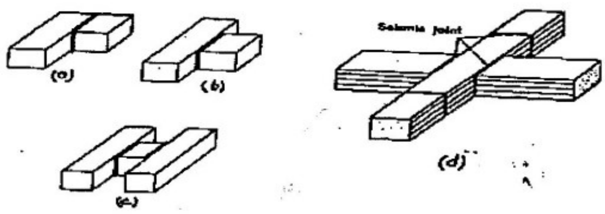


Figure 2: Seismic joints

Symmetry

To minimize or avoid torsional forces and deformation, the centre of stiffness of a building should coincide with the centre of mass. To attain this condition, it is desirable to have symmetry both in the building configuration and in the structure. If eccentricity exists between the centres of mass and stiffness, the horizontal forces due to earthquake will result in bending and torsional deformation. Torsional deformation is greater in a building with a greater eccentricity between centre of mass and centre of stiffness (see Figure 3).

Figure 3: High eccentricity and low torsional rigidity

Vertical configuration

The vertical configuration comprises uniformity, continuity and proportion. It is recommended to avoid drastic changes in the vertical configuration of a building.

When a vertical configuration is discontinuous as shown in Figure 4, a large vibrational motion takes place in some portion and a large diaphragm action is required at the border to transmit forces from the tower to the base. In such cases, dynamic response analysis has to be undertaken to ensure earthquake resistance. A building with a large height to width ratio exhibits large lateral displacement under lateral force. The overturning moment due to axial column force in such a building tends to become unmanageably large.

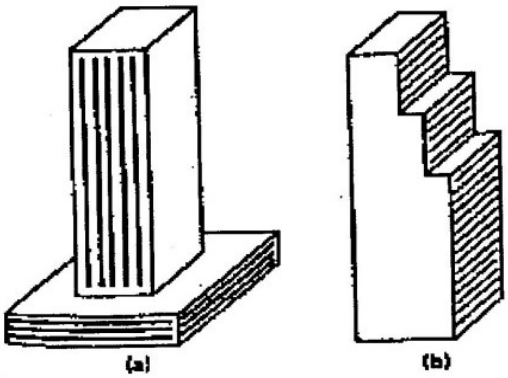


Figure 4: Discontinuous configuration

The same applies to the compressive and pullout forces which act on the foundation. Therefore, appropriate measures such as increasing the static earthquake load have to be taken. For example, in Japan, the static earthquake load is increased in the design of the buildings with height to width ratios greater than 4.

Strength and Stiffness

Strength and stiffness are two of the most important characteristics of any structure However, although these two concepts are present in structural design and analysis, the distinction between strength and stiffness is critical as discussed below.

Vertical direction

It is recommended to avoid sudden changes in the vertical distribution of strength and stiffness. The relevant parameter is the ratio of story weight between adjacent stories. If there is a soft story in a building as shown in Figure 5, plastic deformation tends to concentrate in the soft story, and this may cause the entire building to collapse. Such a condition is often found in buildings with pilots in the first floor and shear walls above. Stiffness and strength can be adjusted by increasing columns or bracing in the soft stories.

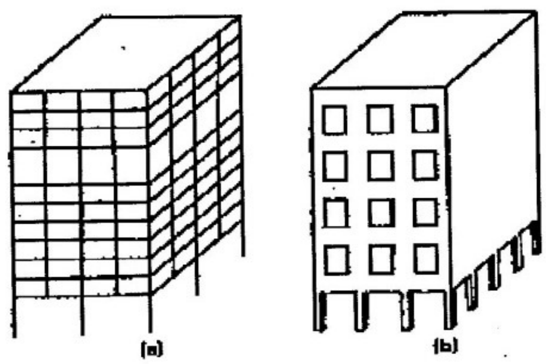


Figure 5: Buildings with soft stories

Horizontal direction

If both slender and short columns exist in the same story, shear force is concentrated in the relatively stiff short columns, which thus fail before the slender columns. In a structural frame, slender columns can be turned into short columns by introducing spandrels. In this case, nonstructural walls should be separated from structural members to avoid their influence on structural behaviour under earthquakes (Wakabayashi, 1986). Forces concentrate also in short beams. This situation can be alleviated by adjusting beam depths, hence avoiding stress concentrations. Reinforced concrete members likely to suffer from stress concentrations can be endowed with ductility by diagonal reinforcement.

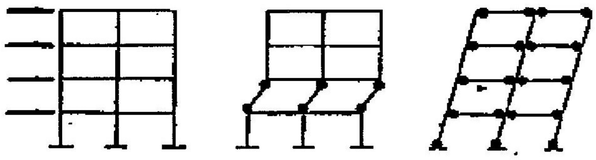


Figure 6: Selection of failure mode

Other considerations

Redundancy

Redundancy in the structural system permits redistribution of internal forces in the event of failure of key elements. Despite the need to keep redundancy low in structural systems in view of thermal stress and uneven settlement of the ground, but under the action of earthquake forces, on the other hand, high redundancy is desirable because local failure does not then induce collapse of an entire building if the capacity for plastic deformation is large. Redundancy combined with adequate strength, stiffness, and continuity, can alleviate the need for excess in ductile detailing. Redundancy can be provided by several means such as: a dual system, a system of interconnected frames that enable redistribution between frames after yield has initiated in individual frames, and multiple shear walls (Moehle, 1981).

Failure mode

For earthquake resistant buildings it is recommended to provide strong columns and to allow prior yielding of the beams in flexure due to the following reasons:

a) Column failure means the collapse of the entire building.

b) In a weak column structure, plastic deformation is concentrated in a certain story, as shown in Figure 6(b), and a relatively large ductility factor is consequently required.

c) In both shear failure and flexural failure of columns, degradation is greater than in beam yield because of the axial forces in the columns.

Even when a frame is designed with strong columns and weak beams, plastic hinges form at the base of the lowest story columns in a statical failure mode as shown in Figure 6 (c). Plastic hinges also form in many column ends during inelastic vibration. Columns should therefore always be provided with adequate ductility.

Stiff or flexible structures

A flexible structure such as a moment - resisting steel frame is advantageous for a site where expected ground motion is of short period, since it takes up a relatively small motion. However, a flexible structure tends to exhibit large lateral deflections which induce damage in nonstructural members. In tall buildings, oscillations due to wind gusts can cause discomfort in the occupants, in which case a stiff structure is desirable.

Framed systems

Framing systems

Moment resisting frame

Moment resisting frames are used to provide seismic resistance in which lateral forces are resisted by bending and shearing of columns and beams, which are connected by moment connections. To assure ductile failure under repeated loading, it is recommended to design joints to be stronger than adjoining members.

(a) (b) (c) (d)

Figure 7: Lateral load resisting systems. (a) lateral load bearing shear wall(b) shear walls with columns. (c) In filled shear walls. (d) braced frames.

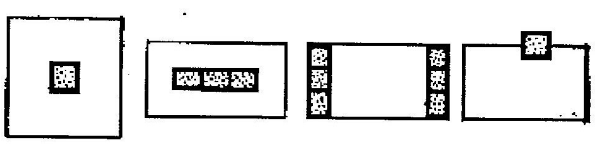
Frames with vertical diaphragms

If the strength and stiffness of a frame are not adequate, load bearing walls and/or bracing are often used to complement the frame's strength and stiffness as illustrated in Figure 7.

Shear walls and bracing are useful also for protecting nonstructural components from failure by reducing story drift. From an aseismic point of view, frames shown in Figure 7 (b) and (c) are superior to (a). However the frame shown in Figure 7(d) is advantageous for flexibility of the enclosed space and thus is often used. Vertical diaphragms and bracing are usually placed in internal walls, external walls, or core walls which encase elevator shafts, staircases and other such spaces. Cores are usually located as shown in Figure 8. Structural cores should be located so as to minimize eccentricity between the centre of mass and the centre of stiffness.

Behaviour of frames under horizontal forces

In a high rise building frame with load bearing walls or bracing, the two different structural elements (that is, the frame plus the walls or the bracing) work together to resist horizontal forces. Shear deformation is predominant in the pure frame as shown in Figure 9 (b), while flexural deformation is predominant in the shear - wall system shown in Figure 9(c). A structural frame with load bearing walls exhibits an intermediate form of behaviour.



(a) (b) (c) (d)

Figure 8:. Location of cores. (a) Centre. (b) Middle portion. (c) Ends (d) Eccentric.

In the lower part of the building, the walls resist the greater part of the shear force, but the share gradually decreases in higher stories as shown in Figure 9 (d).

In the upper portion of the building, the share may become negative. This is the case when rotation of the wall is prevented. If rotation of the wall anchors is allowed, this trend of the negative shear is likely to occur. If flexural deformation occurs in a load bearing wall, the adjacent boundary beam undergoes large deformation and should have adequate ductility.

Also, adjacent columns are subject to large axial force, so that difficulties arise both in designing the column cross-section and in dealing with the pullout force on the deformation. To avoid this disadvantageous situation, it is advisable to distribute the structural elements which carry horizontal forces as shown in Figure 10 (a) and (b).

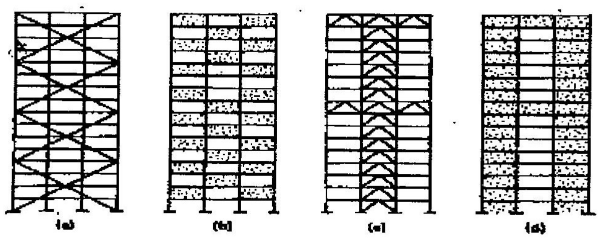


Figure 10: Arrangement of vertical diaphragms

It is recommended to use a large, rigid frame as indicated in Figure 10 (c) and (d), by making the walls or bracing deep in some regions. If the problem of handling large axial forces in the columns and large pull out forces on the foundations exists, then the number of frame planes with horizontal load bearing elements should be increased.

Selection of materials and types of construction

To ensure seismic resistant design, the following major characteristics should be provided:

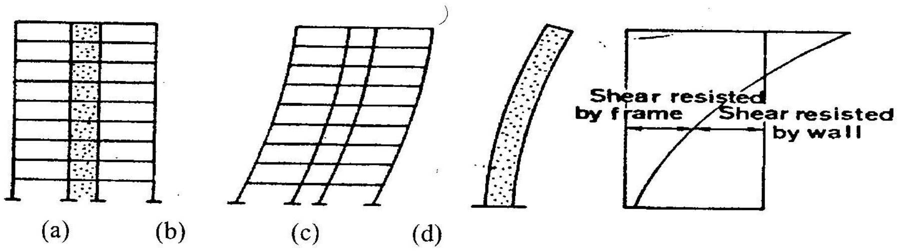


Figure 9: Contribution of frames and shear walls to story shear

a) High strength to weight ratio.

Since seismic force acts on a building as an inertial force, it is recommended to use a light and strong material and/or structural system.

b) High deformability

High plastic - deformation capacity can compensate for any deficiency in strength.

c) High uniformity

Separation of structural elements when subjected to earthquake should be prevented.

d) Low degradation

It is recommended to use a structural system which has low degradation in strength and stiffness under repeated loading.

e) Cost effectiveness

The above listed major characteristics are used to determine the superiority of one structural material over another. However, since both ductile and brittle members can result from a combination of brittle concrete and ductile steel, performance of structural components cannot be evaluated by materials alone. Further factors, such as structural continuity at connections, must be taken into account in the evaluation of an entire structural system composed of such structural components for earthquake resistance. The following priority ordering for earthquake resistance is recommended for building structures:

i) Steel structures

These are especially suitable for high - rise buildings because the following major characteristics are satisfied: high strength to weight ratio, high deformability, low degradation and high uniformity.

ii) Steel and reinforced concrete composite structures.

These have characteristics intermediate between those of pure - steel structures and reinforced concrete structures.

iii) Cast - in - situ reinforced concrete structures.

These are inferior to steel structures with respect to high strength to weight ratio, high deformability and low degradation. This form of construction is mostly used in low, middle rise buildings but limited to high rise buildings except in areas where steel structures are too expensive.

iv) Pre - cast concrete structures

Although not widely used in Tanzania, concrete structures with pre-cast elements are used for low to middle rise buildings. This type of structure lacks uniformity in comparison with the cast in - situ integral concrete structure.

Mixed structures which combine two or more of these structural systems can also perform well with regard to earthquake resistance when the proper member is used in the proper position. In mixed structures it is important to ensure load - bearing capacity and ductility in the interfaces of various components.

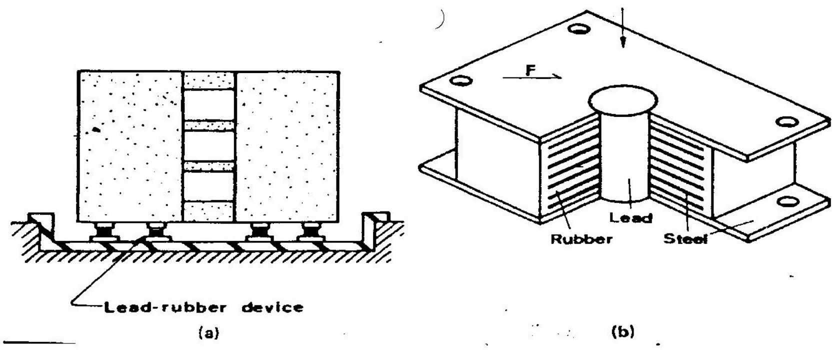


Figure 12: Base isolated structures. (a) Idealized elevation of a base isolated building. (b) Lead - rubber device.

Devices for reducing seismic effect

Devices have been worked out which either prevent earthquake forces from acting on a structure or absorb part of the earthquake energy that is introduced into the structure.

Dampers

Dampers are artificial energy - dissipation devices which consume a portion of the ground motion energy that is introduced into a building structure. Plastic flexural or torsional deformation of steel are inserted in the middle of bracing, at wall - to - wall joints, or at the borders of a wall and a surrounding frame.
Sometimes, steel plates with slits are placed between the wall and the surrounding frame as shown in Figure 11. In this case, it is important to avoid excessive degradation and brittle fracture of the element under large repeated deformation.

Base - isolated structures

For this case, the structural base is isolated by introducing rollers which prevent ground motion from being transmitted from the building foundation into the superstructure. The concept of base isolation is best suited for low rise, rigid structures located on hard ground. It is not suitable for use in a high rise building since the overturning moment is significant.

More practical devices have been proposed and used. One of these devices is a horizontal flexible mounting which supports the building while allowing it to move freely in the horizontal direction. A load limiter resists movement due to small horizontal loads (see Figure 12). The horizontal flexible mounting is normally a sandwiched rubber and steel plate. Up to a certain yield load, the load limiter works elastically, and at higher loads it exhibits plastic deformation, which allows horizontal building movement. The load limiter is a flexural or

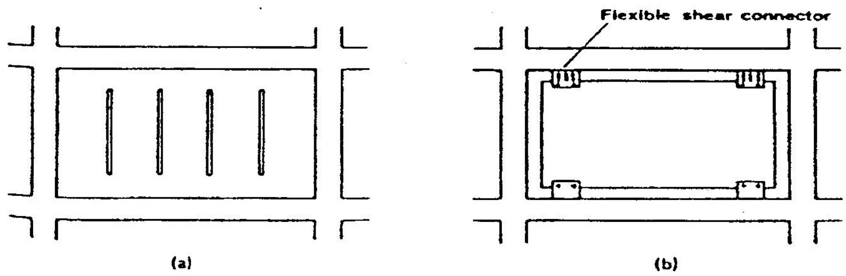


Figure 11: Ductile shear walls (a) slit shear wall (b) shear wall withflexible shear connectors.

torsional member with various possible configurations and is made of steel, lead, or other materials.

When deformed plastically, it works as a damper to minimize the response and limit the amount of horizontal movement. In Figure 12, the horizontal mounting and the load limiter are built as one piece, with the limiter being the central lead cylinder which resists flexural.

SEISMIC DESIGN PRACTICE IN TANZANIA

In Tanzania there is no earthquake code of practice which has been approved to guide the design and construction of earthquake resistant structures. To-date, in Tanzania, design and construction of earthquake resistant structures can be based on the building Research Unit Guideline No. 2 and the draft no. 1 of code of practice for design in seismic areas by the Ministry of Works.

These documents provide a proposal for seismic zones in Tanzania and recommendations for design of earthquake resistant buildings. The question of safeguards against earthquakes is first judged in relation to the type and importance of the proposed building. For smaller buildings exempted from control, it is assumed that no earthquake precautions need to be taken in the structural design.

For buildings where safety in earthquakes is considered important, judgment is made in relation to earthquake hazard in the particular area of Tanzania in which the new building is to be erected. The seismic map for seismic zones and magnitudes of earthquakes which may occur in different parts of Tanzania based on all available information of major earthquakes up to 1969 is shown in figure 1.

The draft code of practice and Building Research Unit (BRU) technical guidelines outline how to determine earthquake loads, state the basic principles of seismic design, and give specific recommendations for the design of masonry and reinforced concrete structures.

CONCLUSIONS AND RECOMMENDATIONS

In Tanzania, most of the buildings have been designed and constructed in areas which are prone to seismic activity without taking into account seismic loads and even the basic earthquake design principles. The fact that part of Tanzania lies within a seismic region signifies the importance of strengthening the existing buildings so that they can withstand earthquakes loads in future, and the need to develop the seismic design code.

However, for the buildings to be constructed before a seismic design code is developed and adopted, the above outlined basic principles may serve as guidelines towards designing and constructing seismic resistant buildings in Tanzania.

There is a need to develop the already prepared draft Tanzania standard code of practice for design of structures in earthquake areas so that it can guide the design of seismic resistant structures in Tanzania.

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