MINE-INDUCED SEISMIC EVENTS AND ITS EFFECT ON NEARBY SETTLEMENTS IN SOUTH AFRICA

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ABSTRACT:

Recent seismic activities have revealed certain flaws in building designs in South Africa. Seismic activities in Southern Africa are predominantly mine-induced. The characteristics of these activities are distinctly different from tectonic activities and its effects on buildings and structures are different. Structural failures in the seismic event of 9 March 2005 at Stilfontein near Klerksdorp have been investigated as a case study. This paper describes the characteristics of seismic events in Southern Africa based on recorded seismic events. A field study of the Stilfontein 2005 event in South Africa has shown that the general orientation of buildings as north facing is a major factor in failures during medium seismic events. Typical failure modes and causes of failure are discussed. Design and detailing recommendations are proposed to avoid failures of similar nature in buildings and other infrastructure.

KEYWORDS: Seismic activities, mine-induced activities, building orientation, in-plane, out-of-plane.

1. INTRODUCTION

Most architects, engineers and builders do not consider seismic resistance as a design requirement in the Southern African region. This is mainly because the region has not experienced any serious destructive earthquake in recent years. The most destructive earthquake in South Africa in recent years appears to be the Ceres earthquake of 1969. The earthquake with a magnitude of 6.3 on the Richter scale occurred at 8 pm on September 29 1969 in the Ceres-Tulbagh region of the Western Cape Province about 100 km from Cape Town. The shocks and aftershocks were felt as far as Durban (1 175 km from epicenter) and it claimed nine lives and caused damages to property worth millions of Rands. Several cases of reported minor earthquakes are also known to have caused considerable damages and casualties particularly to the mining industry.

The most recent significant seismic event in the region is the earthquake that hit Mozambique on the 23rd of February 2006. The U.S. Geological Survey reported that it had an epicenter 140 miles southwest of Mozambique's main port of Beira and struck just after midnight. It was also felt in Zimbabwe's capital, Harare, and as far away as Durban. At least five aftershocks were immediately recorded and more were expected in the coming days because of the quake's size. The tremor occurred near the southern end of the East Africa rift system, a seismically active zone which has produced quakes measuring magnitude 7.6. Some buildings were damaged in Beira and the walls of some buildings had collapsed in Chimoyo, north of the epicenter.

Although the boundaries of the African tectonic plates lie outside the African continent, intra-plate activities do occur particularly in the rift valley of East Africa. The most common activities in South Africa are mine induced tremor. In any case it is necessary to take seismic action into account in the design of infrastructure. A case study of the Stilfontein earthquake is reported with further recommendations.

2. SEISMICITY OF SOUTHERN AFRICA

The study of the seismicity of Southern Africa started as early as 1910. Over the past two decades, researchers and scientist have put in a lot of work in the earthquake hazard mapping of the region (South Africa, Mozambique, Zimbabwe, Botswana, Namibia, Lesotho and Swaziland). This includes recent work published by Fernandez [1,2], Fairhead and Kijko [3,4] among others.

The seismicity of areas located in the interiors of the major tectonic plates is low but it is difficult to correlate with known tectonic characteristics. The Southern African (SA) region is located in an intra-plate area but it is associated with a rather complex seismic characteristics. Most destructive earthquakes are of a tectonic origin and the epicenters of over 90% of global natural earthquakes occur at the boundaries of the major plates. The seismicity of Southern Africa with its sporadic, scattered shallow earthquakes belongs to the type of intra-plate activity which may occasionally reach critical values such as the earthquake of 8 December 1976, in Welkom, Orange Free State which measured 5.5 on Richter scale and the recent event in Klerksdorp on March 9 2005 which measured 5.3 on the Richter scale. The map depicts the EQ magnitude mapping of Southern Africa. Certain zones in the region have EQ magnitudes of over 7, which gives a corresponding value of over 0.3g ground acceleration. However, most seismic events in the region measure below 5M and originate in the mining areas. However, earthquakes of magnitudes as low as 2M can be disastrous to the mines. The epicenters of mine tremors are shallow, usually lower than 2 km and are hazardous only in the immediate vicinity of the mines. Natural earthquakes have a much lower frequency of occurrence but are much more hazardous to the region.

3. EARTH TREMORS RELATING TO MINING ACTIVITIES

It is known that up to 40 or more tremors are recorded monthly in Southern Africa. The recordings are predominantly in the places surrounding the gold mining areas like the Transvaal and the Orange Free State. Many events are also recorded around the Carleton and Klerksdorp areas annually. Mine induced tremors have distinct characteristics compared with natural (tectonic) earthquakes. Ockleston [5] and Milford [6] reported that tremors in the region have a characteristic high peak horizontal accelerations and velocities measuring up to 0.45 g and 67 mm/s respectively. In Carletonville (1986) a peak acceleration of 0.45 g was measured. This is even higher than the peak acceleration of 0.36 g obtained from the well-known El Centro (Mexico) earthquake of 1940. The difference between the two seismic events is that while the El Centro earthquake caused massive damages to structures, the Carletonville tremor only caused minor damages and cracking to structures located in the vicinity of the epicenter. Looking at other characteristics of mine tremors, one can see the reason for the differences in the destructive capacities of the two types of seismic activities: The frequencies of mine-induced tremors are usually high and range between 10 Hz and 50 Hz. This implies that mine tremors are not likely to produce structural response from structures with low natural frequencies. Generally structures with natural frequencies less than 2 Hz will not generate structural responses to this type of events. High-rise buildings do not respond to this type seismic excitation because they have natural frequencies of much less than 2 Hz. Figure 1 shows the estimated natural frequencies for different categories of structures. It can be seen that the single storey residential buildings are expected to respond to this type of excitation as they fall in the high frequency range. Mine tremors occur at relatively shallow epicenters, typically at depths of 2 - 4 km. This means that the spread is over a small area. Moreover the attenuation of mine tremors is rapid. For example an acceleration of 0.39 g measured at 2.5 km reduces to 0.13 g at a 10 km distance (Milford).

4. EARTHQUAKE ACTIONS ON LOW-RISE STRUCTURES

Earthquake motions are directional and walls of low-rise structures may generally be subject to either in-plane or out-of-plane action. If the motion is in-plane, walls tend to crack diagonally in shear shown in the sketch in Figure 2. The situation may become critical if the cracks propagate to corners to form kinematic mechanism and failure. If the motion is out-of-plane, the effect of intense wind loading is simulated. Tension cracks occur at wall intersections, walls fall out at ultimate stage as shown in Figures 2.

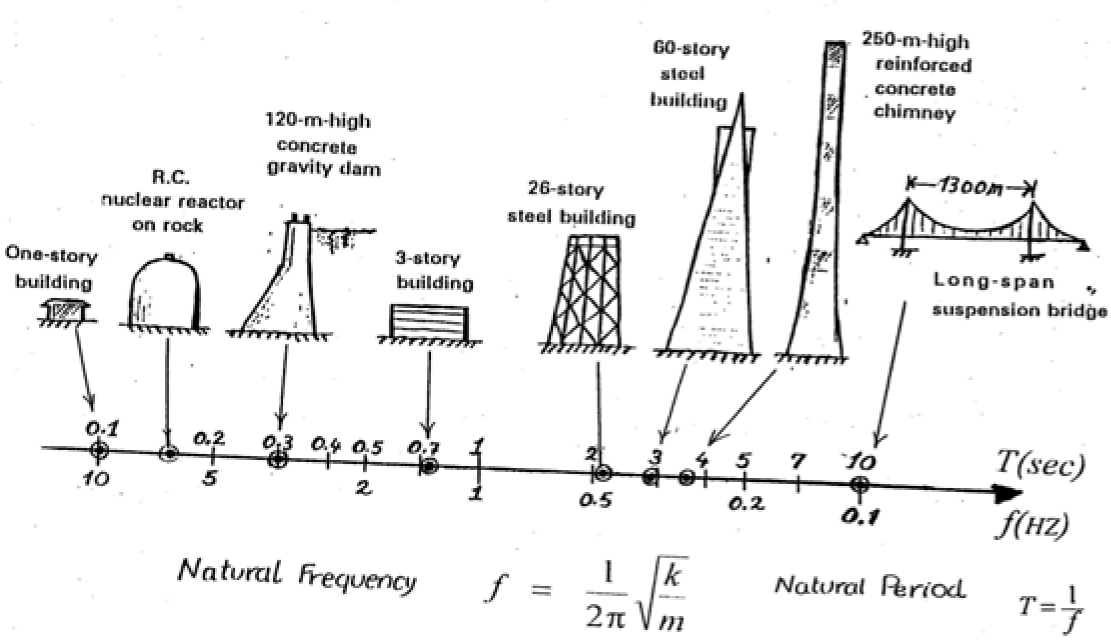


Figure 3: Typical natural frequencies and natural periods of structures

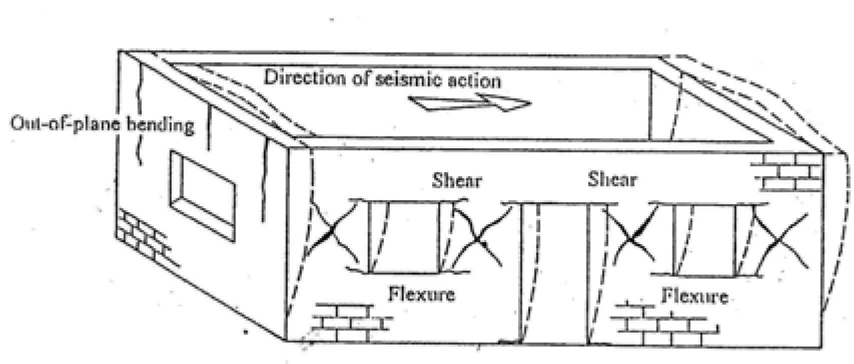


Figure 4: Typical deformation of building walls due to seismic action

5. CASE STUDY OF THE STILFONTEIN EVENT

The event has the following details:
Date: 2005/03/09, Time: 12:15:31.7, Latitude: -26.903, Longitude: 26.752, Magnitude: 5.3 ML and Region: Klerksdorp Area. The research group visited the area on 10 to 11 March 2005.
Most of the damage was centered on the city centre area in as Stilfontein. Two blocks of flats known as the Bal Eaton court were very extensively damaged (see Figure 3). Two schools, the Stilfontein High and the Driefonteine Primary school were also extensively damaged, especially the second/third floors. The main causes of the damages and possible design detailing to prevent such damages were investigated.

Some of the failures at the Stilfontein (klerksdorp) event are summarized below in Figure 3 – 9. The structural responses are further explained in the following paragraphs.

(a) **(b)**

Figure 3: (a) In-plane and (b) out of Plane Response of the Bal Eaton Court building.

- Figure 4 shows failure of a cantilevered wall and the need to tie to columns or intersecting wall
- Figure 5 shows typical failure observed in gable walls. The walls need to be strengthened by reinforced columns and by tying to roof structure.
- Fixed window glasses were broken while the movable windows remained intact (Figure 6).
- Collapses at wall intersections underlines the need to tie masonry to intersecting walls or columns as shown in Figures 7 and 8.
- The flexibility of Hydraform walling system was demonstrated by the absorption of the load without cracking through the masonry units as shown in Figure 9.

Figure 4: Failure of a cantilevered wall

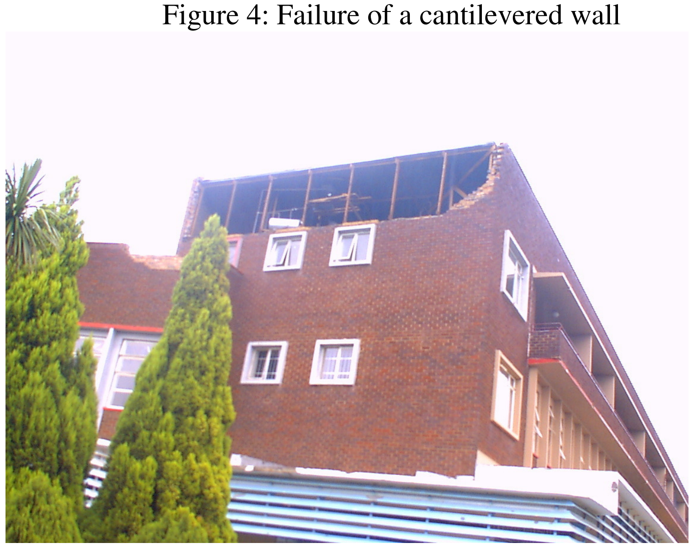


Figure 5: Out-of-plane failure of a gable.

Figure 6: Responses of fixed and moveable windows.

Figure 7: Failure at wall intersections without ties.

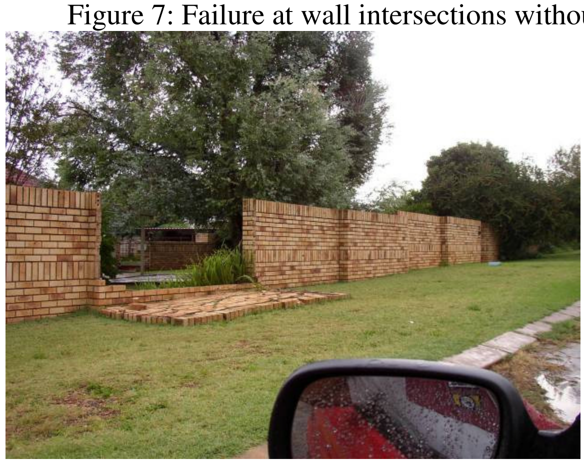
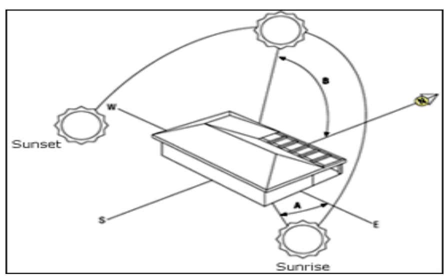


Figure 8: Collapse of an irregularly shaped wall section

Figure 9: Behaviour of dry-stack walling system

6. EFFECT OF ORIENTATION OF BUILDINGS

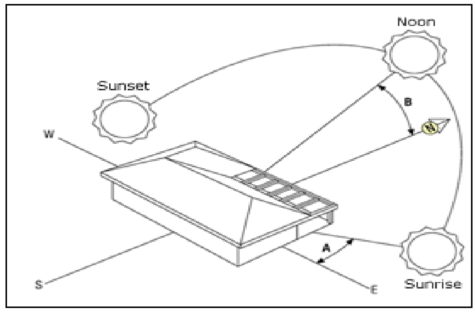
The relative positioning of a building to the sun is seasonal and depends on the location on the planet. The sun's movement and positions at any period can be described using the solar chart. In the Southern African region, in summer the sun rises earlier, south of due east and climbs high in the sky before setting south of due west (see Figure 10). Major summer heat gain in a building occurs through the roof and through the east and west windows and walls of the home.



HorizontalRise/Set Angle (A)	Noon Altitude (B)
28° south	80°

Figure 10. The sun's movement during summer (December)

In winter the sun rises later, north of due east and stays low in the northern sky before setting north of due west. North facing windows and walls receive maximum winter sun and warmth as shown in Figure 11. By placing living areas and windows to the north it allows rooms to be heated during the day thereby reducing the need for artificial heating at night. It's best to locate your. A building's orientation with relation to the sun will impact its ability to optimize passive heating and cooling, natural ventilation, and day lighting. Generally, it is best to elongate the building along the east-west axis, thus increasing the area of the building that faces north. By doing this, the building's exposure to the sun will be maximized. By optimizing exposure to the north direction, schools and public buildings have access to a more diffuse light that is suitable for day lighting. Light comes from the east and west only when the sun is low in the sky, therefore using windows for lighting on those sides is likely to cause glare. Living and outdoor areas are generally on the north side of buildings as they will be warm and sunny in winter. Living areas to the west are minimized as they receive the full summer sun and will require artificial cooling.



Horizontal Rise/Set Angle (A)	Noon Altitude (B)
25° south	36°

Figure 11: The sun's movement during winter (June)

The design of most buildings for optimum climatic control has the net effect that the main walls or shear walls in buildings are aligned in the North-South direction as shown in Figure 12. The openings for windows and doors are mainly in line with the East-West direction to maximize winter heating.

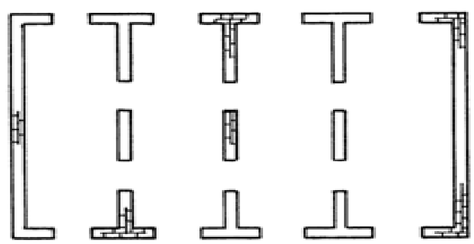


Figure 12: Inadequate positioning of shear walls

This results in loss of stiffness in buildings in the E-W direction. The stiffness of the building in the N-S direction is much higher than in the E-W direction. In the Stilfontein earthquake of 9 March 2005, the earthquake forces were predominantly in the E-W direction, the weaker direction. Although 5.3 M is considered mild earthquake, it caused maximum damage as the shear walls were in N-S direction and were therefore hit in the out-of-plane (weaker) direction. A typical failure in a public building is shown in Figure 5.

7. DISCUSSION AND CONCLUSIONS

The characteristics of seismic action of Southern Africa has been presented and discussed. Low-rise structures are most at risk from mine-induced tremors. For structures located in the mining areas additional provisions should be made for the design and detailing of low rise residential buildings to minimize damages during tremors. A field case study was carried out and revealed major causes of failure in buildings. All buildings, which are more than five storeys, should be designed to resist a moderate earthquake. This should be in line with zone 1 of the UBC code in the USA.
Full-scale dynamic tests should be conducted to obtain qualitative and quantitative information concerning the resistance of low-rise structures to typical seismic actions of the region. Design, fabrication and performance of a shake table for dynamic investigation have been presented. The table is designed for the simulation of the specific seismic characteristics of Southern Africa. Shaking table can adequately simulate most aspects of the behaviour of real houses during real earthquakes.

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