Structural engineering observations from the 26 November 2019 M_w 6.4 Albanian earthquake

A.W. Charleson
Victoria University of Wellington, Wellington.

N. Vesho & A. Marku
Polis University, Tirana, Albania.

ABSTRACT

The M_w 6.4 earthquake that occurred near the city of Durres, located on the west coast of Albania, may be considered small in comparison to the design earthquake, yet it caused an enormous amount of damage to buildings. Fifty-one people died, approximately 3,000 were injured and between 5,000 and 14,000 people needed shelter.

The paper presents observations of damaged buildings. Although there are many examples of building collapse and damage due to well-understood critical structural weaknesses, most damage appears to be caused by the incompatible combination of flexible frame structures then infilled with brittle clay hollow-brick and plastered walls. These walls suffered in-plane damage from lateral deformation and were mostly unrestrained from face-load collapse. These non-structural elements, as well as many interior partitions of the same material, dominated structural behaviour.

In order to achieve more resilient buildings in the future, local engineers will need to re-evaluate especially two aspects of their current design approaches that cause excessive lateral flexibility; namely, moment frames without beams other than those within the depth of floor slabs, and the irregular orientation of rectangular columns that leads to many columns bending about their weak axis. Engineers will also need to work closely with architects to avoid future damage to infills and partitions.

1 INTRODUCTION

The M_w 6.4 Albanian earthquake occurred at 4:00 am on 26 November 2019 causing 51 fatalities, injuring 3000 people, rendering up to 14,000 people homeless and seriously damaging over two thousand buildings in the cities of Durres and Tirana. The epicentre, with a focal depth of about 20 km was located close to the Adriatic coastline, about 7 km north of the city of Durres, and 30 km west of Tirana, the capital city of Albania (Figures 1 and 2).

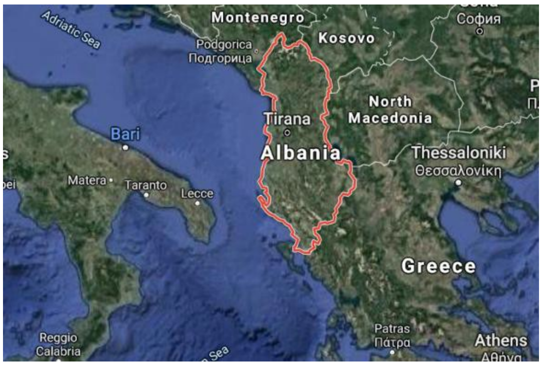

Figure 1: Location of Albania

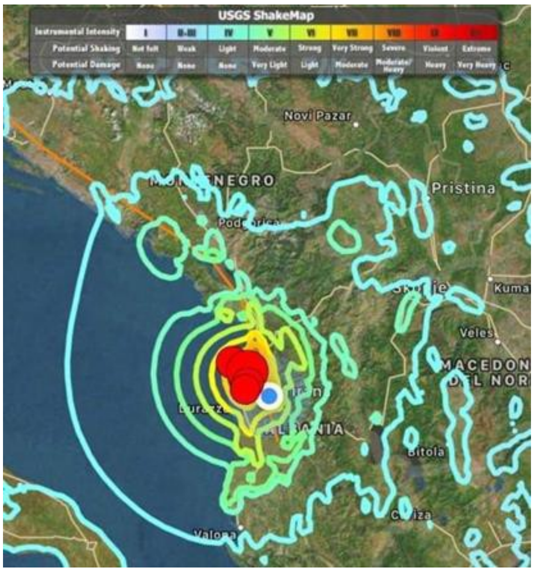

Figure 2: Earthquake affected area with intensity contours shown (from USGS).

Detailed information is available about the earthquake intensities, the geology and effects of soft-soil amplification in the affected region, building types and extent of liquefaction (Lekkas 2019). Those authors also note that Durres is located in a seismically active area and has been almost totally destroyed by earthquakes at least seven times previously; in 177 BC, 334 or 345 AC, 506, 1273, 1279, 1869 and 1870.

Also, a M_w5.6 earthquake in the same vicinity on 21 September 2019 damaged 500 buildings in the city.

Although this paper is written just one month after the earthquake, another report also of a preliminary nature contains information about the history of local building codes and construction approaches, aftershock occurrence and the performance of building types including schools, hospitals and housing (Alam 2019).

Regarding the characteristics of the earthquake shaking, so far only two response spectra are available (Figure 3), (IGEWE 2020). They are obtained from two accelerograms recorded in Tirana, 30 km from Durres. Unfortunately, an accelerometer in Durres stopped recording after 15 seconds of shaking but ‘reconstituted’ spectra may be available in the future. Due its lesser epicentral distance and greater amplification from soft soils, the Durres spectra are likely to exhibit higher spectral accelerations and over a longer period range. The duration of strong shaking in Tirana was approximately 40 seconds, about four times longer than the smaller M_w5.6 September earthquake.

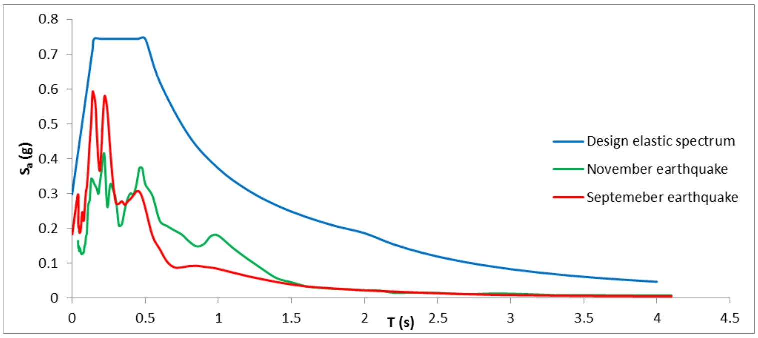

Figure 3: Two response spectra from Tirana are compared to the current design code elastic spectrum

This paper is based on the observations during two reconnaissance visits to Durres, seven and 11 days after the earthquake, and to the town of Vore, mid-way between Durres and Tirana, one week later. By the time these visits were made the most severely damaged and partially-collapsed buildings had already been demolished. Some information about them can be found in the references noted above. The visits reported here mainly focused upon badly damaged buildings and consisted of observing from behind hazard tapes preventing entry. In some cases, though, with police and building owners’ permission we were able to enter and inspect in detail.

2 BUILDING CONSTRUCTION

In the earthquake-affected area three types of construction predominate; unreinforced masonry, precast panel construction and reinforced concrete frame and infill. There may be a small percentage of reinforced concrete shear wall buildings. Steel framed buildings are uncommon and found only in industrial complexes. No timber buildings were observed. Unreinforced masonry was very common in single and multi-storey buildings prior to 1980. It is seen in apartment, factory and institutional buildings up to five storeys high.

These buildings rely on thick solid clay brick load-bearing walls to resist gravity and lateral loads. The floors, and often the roofs, consist of cast-in-place reinforced concrete slabs. As such, the floors can be considered effective diaphragms, transferring out-of-plane wall loads to walls acting in-plane.

Precast panel construction was popular after the 1960s and during the communist regime. Mainly used for apartment buildings, these were also up to five storeys in height. Although it is likely, especially in the marine environment of Durres and due to a lack of maintenance, that steel corrosion is present, these buildings performed well. Our colleagues who escorted us to examples of the worst damage did not include any buildings of this construction type. Rapid observations from streets also confirmed these buildings performed well. A later study of typical floor plans will indicate if dense and regular interior cellular wall configurations, that are to be expected in high-density housing, can take the credit for this good performance.

The most common method of construction, at least around Durres, is reinforced concrete frames and infill walls. Popular since the 1980s to the present time, this construction typology is used for single- and double-storey detached houses through to apartments 12 storeys high. In these frame and infill buildings the frames and the entire concrete skeletons are constructed first and then infilled with hollow clay bricks which are then plastered (Figure 4). Interior walls are of the same material and construction type.

Figure 4: A reinforced concrete frame is completed and then walls are infilled

According to local code requirements, a mid-height horizontal reinforced concrete band is required in each infill to resist face-loads, but this member was not seen in any damaged building. Since the infills and partitions are constructed after the completion of the concrete frame the only connection between infill and frame members is mortar. Walls are therefore very vulnerable to out-of-plane collapse and this was a very frequent occurrence. This lack of reliable connection between infill and frame contrasts distinctly with Confined Masonry construction. In this technique, masonry walls are constructed first, and only then are reinforced concrete tie-columns and beams cast. This construction sequence ensures the masonry is confined and therefore can resist lateral loads more reliably than infilled frames (Meli and Brzev 2011).

The floors of reinforced concrete infill frame buildings consist of both precast and cast-in-place concrete. Although no precast floors were observed in the buildings visited, Lekkas et al (2019) report that some multi-storey buildings with these floors collapsed. The hollow-core slabs were not tied together at all and so floor diaphragm action was completely absent. Cast-in-place floors typically take the form of concrete ribs and topping between and over hollow clay brick or polystyrene infills.

Although we have described the most prevalent structural system as a reinforced concrete frame and infill, the description is inaccurate for two reasons. And both reasons explain why the medium- to high-rise buildings observed were so flexible under lateral load. First, one of the prerequisites of a structural frame is that it possesses beams. In the majority of frame buildings observed there were no beams other than those within the depth of floor slabs (Figures 5 and 6). Generally, these slab-beams were 300 mm deep and although adequate to carry gravity loads for spans around six metres, the "frame" is very flexible. It is surprising that such a frame could meet code lateral deformation requirements? Beams at least 600 mm deep would normally be expected. At least one structural benefit of using such shallow beams is that columns are stronger than the beams, in accordance with the principle of Capacity Design.

Figure 5: Fallen infill panels reveal beams no deeper than slabs

Figure 6: Slab-beams in the first floor of a 12-storey frame building. Note polystyrene rather than hollow clay brick infills.

The second inaccuracy in describing most of these buildings as frame buildings is the absence of regular frames. As illustrated in Figure 7, the problem is the irregular orientation of columns in plan. In each orthogonal direction there is only one significant frame with multiple bays where columns bend about their strong axis. All other frames have only one or two bays where column depths are orientated parallel to the frame direction. Yet again, the frames are very flexible, and this plan irregularity also introduces torsional eccentricity. Finally, with reference to Figure 7, we note a single reinforced concrete elevator shaft in plan. However, this element cannot be considered a shear wall suitable for resisting lateral load. Its large height-to-depth ratio render it extremely flexible (and weak). At least its placement near the centre of plan avoids torsional eccentricity.

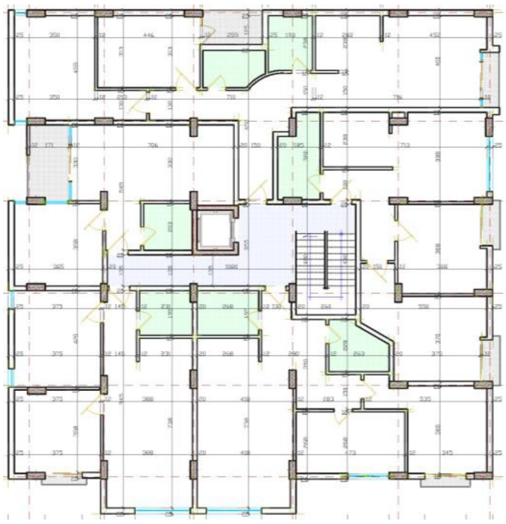

Figure 7: Typical floor plan of a 10-storey building with irregular column orientation

3 TYPICAL BUILDING DAMAGE

3.1 Structural damage

As mentioned above, before our reconnaissance, those relatively few buildings with severe structural damage had been demolished. Many images of such damage are included in other reports, such as those by Lekkas (2019) and Alam (2019), and in future reports likely to be published as part of EERI's Learning from Earthquakes program (EERI 1973), and elsewhere. Needless to say, there are examples of structural damage and collapse due to almost every type of vertical and horizontal configurational irregularity. The common causes of collapse were soft storeys and floor diaphragm inadequacy. Shear damage in short columns, and in normal columns due to torsional irregularity, was also prevalent. Much, if not most, of this and all other structural damage appeared to be caused by the presence of stiff infill and partition walls.

3.2 Non-structural damage

What is most striking about the damaged buildings still standing, and often uninhabited, is the extent of non-structural damage. The building shown in Figure 8 is typical of tens if not hundreds of others. Extensive damage has occurred to infills and partition walls *at the lower half of the building only*. It was confirmed by one building owner that while non-structural walls on lower floors had suffered extreme damage due to in-plane deformations and out-of-plane failure, upper floors were virtually undamaged. These buildings exhibit *soft-storeys* rather than a single soft-storey. All elastic and inelastic deformation has concentrated in up to five or fewer lower levels. There was very limited evidence of inelastic behaviour in structural members.

This observed damage in the lower floors of buildings is not entirely expected in earthquake engineering practice. According to theory, lateral interstorey deflections of frame buildings are greater near the base, but certainly present at the top of buildings, especially when higher modes are induced. Also, maximum horizontal accelerations increase with height. From a simplified perspective then, one expects greater in-plane damage due to interstorey deflections at lower floors of a building, but greater out-of-plane damage at higher levels. It appears therefore that in-plane deflection and damage has made infills and partitions more vulnerable to out-of-plane failure, and that the softening of the lower infills has created several soft-storeys that have effectively isolated the upper floors. Stiffened by their undamaged walls, these upper storeys have then acted as a rigid body above very flexible and long-period frames beneath. We hope that researchers using push-over and dynamic analyses, and by modelling all brick walls can confirm what is now only a theory.

Figure 8: Multi-storey building with extensive wall damage to lower storeys

It was also noticeable how most low-rise buildings suffered no or minor damage (Figure 9). Although the primary structures have been designed as open or bare reinforced concrete frames, the infills and partition walls which are far stiffer (and stronger?) than the frames have acted as bracing walls. Given the low intensity of ground shaking, the walls have remained elastic. No diagonal tension failure was observed nor diagonal compression forces great enough to damage the tops or bottoms of columns. This latter failure mode was observed in just one building in which the infills were of solid bricks. Neither have walls fallen from their frames to which they are so unreliably attached. For this low-intensity shaking, walls have unintentionally functioned like the bracing walls of Confined Masonry houses.

Figure 9: An undamaged house adjacent to a badly damaged building

Another type of non-structural damage observed was to seismically-unseparated reinforced concrete stairs. Figure 10 illustrates a typical example. The lowest stair landing and its supporting beam was cracked. This damage may have prevented more serious damage that could have occurred due to torsional eccentricity caused by the unseparated stairs. Otherwise the structure and infills appear undamaged. Possibly the flexibility of the infill due to no mortar in vertical joints between bricks and before plastering reduced the demand on the soft-storey ground floor columns.

Figure 10: The lower stair landing on the left-hand side is damaged by unseparated stair flights acting as inclined struts in one direction and as elements in bending and shear in the other

4 OVERCOMING THE PROBLEMS OF BRICK INFILLS AND PARTITIONS

Avoidance is the most common strategy to overcome the problems identified above. Light-weight and relatively flexible infills are one option, followed by precast panels whose flexible connections to frames are detailed to accommodate calculated interstorey drifts. Another solution involves designing the primary structural system stiff enough to protect unseparated infills. Otherwise, if masonry infills are to be used the best strategy is to separate. A recommended detail is shown in Figure 11 (Hollings 1981).

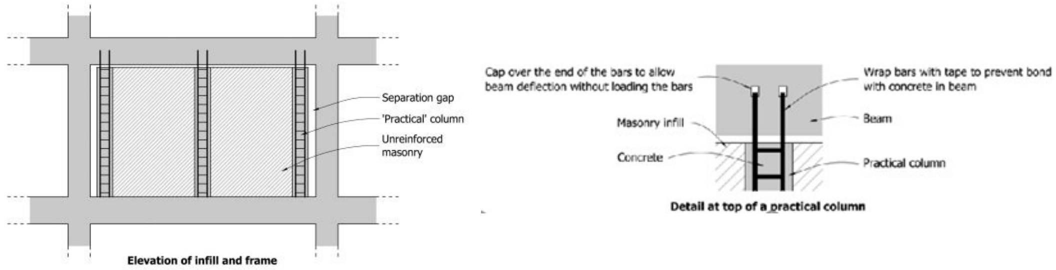

Figure 11: Suggested masonry infill separation detail

This detail prevents the infill forming a diagonal compression strut and experiencing diagonal tension. The vertical 'practical' columns, essentially vertical beams, support the infill against face loads. For more information refer to Charleson (2008) who devotes an entire chapter to this topic. However, the solution of Figure 11 is not ideal. The presence of the infill stiffens and strengthens the beam, and prevents normal length plastic hinges forming at beam ends during an earthquake. Instead of distributed cracking along beams up to twice their depths, one wide crack will form at column faces, greatly limiting the ductility capacity of the hinges. Debonding beam longitudinal steel in the potential plastic hinge region may be worth investigating to improve inelastic performance.

Recent recommendations for improving the seismic performance of infills (and brick partitions) begin with suggestions for improving out-of-plane performance. These include:

- providing supplementary vertical mullions
- strengthening the infill wall using reinforced concrete overlays
- strengthening the infill wall using fibre reinforced polymer (FRP) overlays or near surface mounted FRP strips (note that FRP strips will be required on both sides)
- strengthening the infill wall using engineered cementitious composite (ECC) shotcrete overlays
- removing the infill wall." (Technical project team 2017).

In the same document suggestions are also made to improve in-plane performance that involve strengthening the infill and include those already mentioned above. These suggestions which are intended to transform previously non-structural elements into structural elements should be done very carefully to avoid damage to the primary reinforced concrete frame members.

Separation is the recommended strategy for preventing concrete stairs both becoming damaged or damaging the primary structure. Provision of separation, which in practice is very simple, must be made to prevent stairs trying to resist interstorey drift in any horizontal direction. For details, refer to Charleson (2008).

5 CONCLUSIONS

Most of the damage to the buildings observed was either to non-structural elements or caused by non-structural elements, namely infill and partition walls of plastered hollow brick masonry. The degree of damage was intensified by the flexibility of medium-to-high rise frame buildings caused by a lack of conventional beams and irregular plan orientation of reinforced concrete frame columns. These deficiencies need to be remedied in new Albanian construction.

Brick walls represent a hazard to life, and when damaged the hazard they pose forces inhabitants out of their buildings until repairs are made. As repairs are made to the damaged buildings, care is required to ensure that the same damage will not reoccur during the next significant earthquake.

There is an urgent need for further research and development to provide culturally appropriate solutions to overcome the reported problems with brick walls in frame buildings. A concerted effort is required by both engineers and architects.

REFERENCES

Alam, M., Alberto, Y., Aranha, C. et al. 2019. *Virtual earthquake reconnaissance team (VERT): Phase 1 Response to M6.4 Albanian earthquake November 26, 2019.* http://learningfromearthquakes.org/images/earthquakes/2019_Albania_Earthquake/VERT_Phase_1_-_Albania_EQ_2019.pdf (Accessed December 2019).

Charleson, A. W. 2008. *Seismic design for architects: outwitting the quake*. Oxford: Elsevier. Chapter 10.

EERI 1973. Learning from earthquakes program. https://www.eeri.org/projects/learning-from-earthquakes- lfe/ (Accessed December 2019).

IGEWE - Institute of GeoSciences, Energy, Water and Environment

2020. http://www.geo.edu.al/newweb/?fq=november (Accessed January 2020).

Hollings, J. P. et al 1981. *Indonesian Earthquake Study: Vol. 6 Manual for the design of normal reinforced concrete and reinforced masonry structures*. Wellington: Beca Carter Hollings and Ferner Ltd., (unpublished).

Lekkas, E., Mavroulis, S., Papa, D., Carydis, P. 2019. The November 26, 2019 M_w6.4 Durrës (Albania) earthquake. *Newsletter of Environmental, Disaster and Crises Management Strategies*, No. 15, ISSN 2653- 9454.

Meli, R. and Brzev, S. 2011. *Seismic design guide for low-rise confined masonry buildings*. Confined Masonry Network and The World Housing Encyclopedia. http://www.world-housing.net/wp- content/uploads/2011/06/Confined-Masonry-design-guide-thumbnail1.jpg (Accessed May 2020).

Project technical team 2017. *The seismic assessment of existing buildings: technical guidelines for engineering assessments,* Section C7.9. https://www.building.govt.nz/building-code-compliance/b- stability/b1-structure/seismic-assessment-existing-buildings/ (Accessed December 2019).